Is the Great Moderation Over? An Empirical Analysis

By Todd E. Clark

The economy of the United States was markedly less volatile in the past two to three decades than in prior periods. The nation enjoyed long economic expansions in each of the last three decades, interrupted by recessions in 1990-91 and 2001 that were mild by historical standards. While it has proven difficult to conclusively pinpoint the causes of the reduced volatility, candidates include structural changes in the economy, better monetary policy, and smaller shocks (good luck). Many economists and policymakers came to view lower volatility—the Great Moderation—as likely to be permanent.

More recently, the severity of the recession that started in late 2007 has led some observers to conclude the Great Moderation is over. The recession produced declines in economic activity steeper than in the sharp recessions of the 1950s, 1970s, and early 1980s.

However, the occurrence of a sharp recession does not necessarily mean variability has returned to pre-Great Moderation levels or that the Great Moderation is over. For example, the recession may have produced a more modest rise in volatility that could be temporary. Whether any rise in volatility is more likely temporary than permanent will

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depend on the cause of the rise in volatility. An increase in volatility due to structural changes in the economy or monetary policy might be permanent. But an increase in volatility driven by larger shocks might prove temporary. This article conducts a detailed statistical analysis of the putative rise in volatility and its sources to assess whether the Great Moderation is over. The article concludes that, over time, macroeconomic volatility will likely undergo occasional shifts between high and low levels, with low volatility the norm.

The first section of the article shows that macroeconomic volatility has risen significantly in recent quarters, reversing much of the Great Moderation. However, compared to the Great Moderation, the recent rise in volatility was not as widespread across sectors of the economy. The second section examines potential causes of the rise in the volatility of the U.S. economy, focusing on shocks to oil prices, the housing sector, and financial markets. Based on estimates from a small macroeconomic model, most of the rise in macroeconomic variability can be attributed to larger shocks to oil prices and financial markets. Together, the narrower breadth of the rise in volatility and the evident role of larger shocks to oil prices and financial markets point to bad luck as the general explanation for the recent rise in volatility. The third section considers the implications for the permanence of the Great Moderation and the future volatility of the economy.

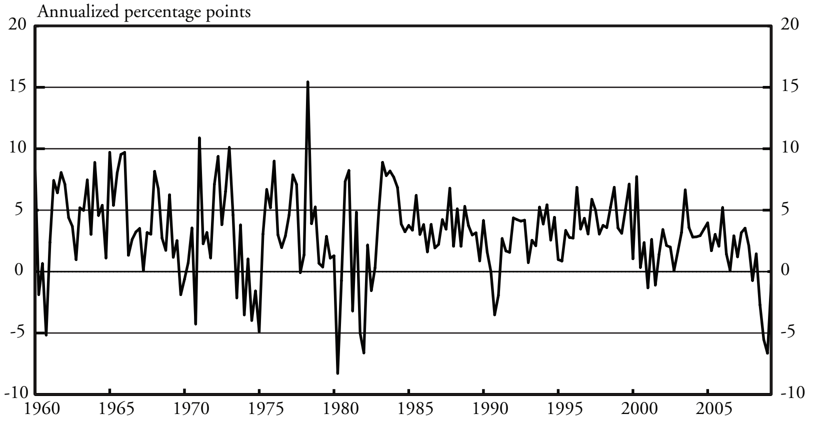
I. EVIDENCE OF INCREASED VOLATILITY

Many studies have now documented the Great Moderation (e.g., Blanchard and Simon, Kim and Nelson, McConnell and Perez-Quiros, and Stock and Watson 2002, 2003). During the Great Moderation, growth rates of real GDP were sharply less variable than in the 1960s and 1970s (Chart 1).[1] From 1960 through the early 1980s, the United States experienced quarterly GDP growth rates as high as 15 percent and as low as -8 percent. Starting in 1984, the variability of GDP growth was much lower, as swings in growth became much more muted (Kim and Nelson, McConnell and Perez-Quiros, and Stock and Watson 2002, 2003).

More recently, though, the recession has produced sharp declines in GDP growth reminiscent of the 1960s and 1970s (Chart 1). Growth plummeted to roughly -6 percent in each of 2008:Q4 and 2009:Q1.

Chart 1

REAL GDP GROWTH



These changes in GDP growth suggest a rise in volatility back toward the level that prevailed prior to the Great Moderation.

While Chart 1 suggests an increase in volatility, it does not quantify the magnitude of the change, or the precise timing. For a more formal assessment, this section follows Stock and Watson (2002, 2003) in estimating statistical models that allow volatility to vary over time.[2] The analysis covers GDP growth and a wide range of other macroeconomic indicators for the United States. These estimates reveal a partial or complete reversal of the Great Moderation in many sectors of the U.S. economy. Appendix 1 provides similar evidence for GDP growth in the other Group of Seven (G7) economies: Recent events have caused estimates of volatility to move significantly higher in all of the nations, reversing much of the Great Moderation.

The statistical model

For each variable of interest (generically denoted y_t), the statistical model used to assess changes in volatility relates the current value of the variable to past values and a shock that captures unexplained, sudden movements in the variable:

$$y_t = \beta_{0,t} + \beta_{1,t} y_{t-1} + \beta_{2,t} y_{t-2} + \beta_{3,t} y_{t-3} + \beta_{4,t} y_{t-4} + e_t .$$

The model captures the dependence of the volatility (standard deviation) of each variable y_t on the coefficients on past values of y_t and the standard deviation of the error term.

More specifically, the model recognizes that shifts in either coefficients or the standard deviation of the error term could change the standard deviation of the variable. A rise in the variability of shocks would lead directly to increased volatility of the variable. For example, an increase in the variability of GDP growth could be due to bigger shocks to GDP. An increase in the (non-intercept) coefficient values will also generally lead to greater volatility. An upward shift in the coefficients would increase the influence of past values on the current value of the variable, making the variable more sluggish. As a result, following a shock, the variable would more slowly return to baseline. The longer-lived departure from baseline would result in a higher standard deviation of the variable. For instance, an increase in the variability of GDP growth could be due to more drawn-out responses of GDP to shocks, reflected in larger model coefficients.

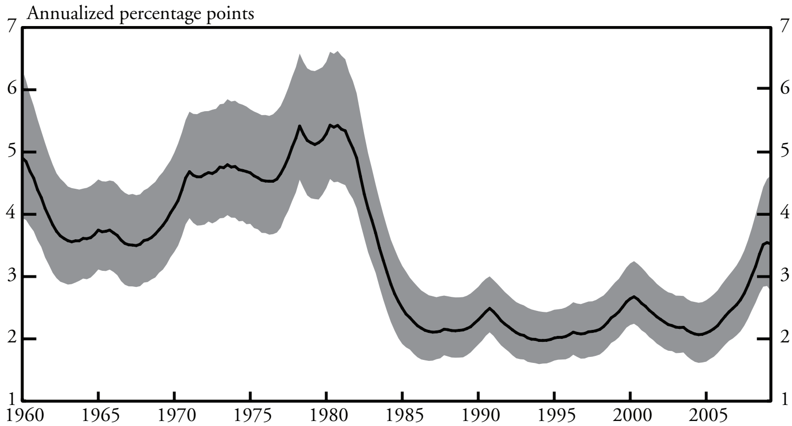
To capture periodic changes in volatility, the model treats the coefficients on past values of the variable and the variance of the error term as evolving smoothly over time (from quarter to quarter). In turn, the model-implied volatility of the variable can vary from quarter to quarter. In this section, the model-implied volatility is an instantaneous standard deviation. In any quarter, the instantaneous standard deviation of a variable is what the standard deviation would be for all time in the future if the variance of shocks and the coefficients on lagged values of the variable stayed at their current levels.[3]

This section reports estimates of volatility (instantaneous standard deviations) obtained by fitting the model to GDP growth and a range of other economic indicators. All estimates are based on data from 1960:Q1 through 2009:Q2. The list of indicators is broadly the same as in Stock and Watson (2003). Appendix 2 provides more detail on the statistical model and estimation methodology.

Volatility estimates

The statistical estimates show that the volatility of GDP growth has reversed much of the Great Moderation (Chart 2). The Great Moderation produced a significant, fairly sudden reduction in volatility. The

Chart 2
ESTIMATED STANDARD DEVIATION OF GDP GROWTH



Notes: Black line: point estimate of fitted standard deviation. Shading: 70 percent confidence interval.

instantaneous standard deviation of GDP growth fell from a peak of 5.4 percent in 1980 to 2.1 percent in 1986. However, recent events have caused the estimates of volatility to move considerably higher.[4] The estimate of GDP growth volatility for 2009:Q2 (3.5 percent) is roughly equal to its level as of 1983. To confirm the statistical significance of the increase in variability, Table 1 reports the statistically estimated probability that the instantaneous standard deviation of GDP growth is higher in 2009:Q2 than in 2003:Q4.[5] For GDP growth, the probability is 95.9 percent.

Consistent with the findings of such studies as Stock and Watson (2003), the estimated changes over time in the model-implied standard deviations of GDP growth are driven primarily by movements in the volatility of the error term of the model. The estimated coefficients of the models have changed gradually over time, but not by nearly enough to account for the Great Moderation or the more recent rise of volatility. Instead, the swings in volatility shown in Chart 2 are driven by movements in the standard deviation of the shock term of the model.

Further analysis of sectors of the U.S. economy may prove helpful to determining the sources of the rise in volatility and implications. Model-based statistical estimates reported in Chart 3 show the Great

Table 1

ESTIMATED PROBABILITIES OF AN INCREASE IN VOLATILITY FROM 2003:Q4 TO 2009:Q2 (PERCENT)

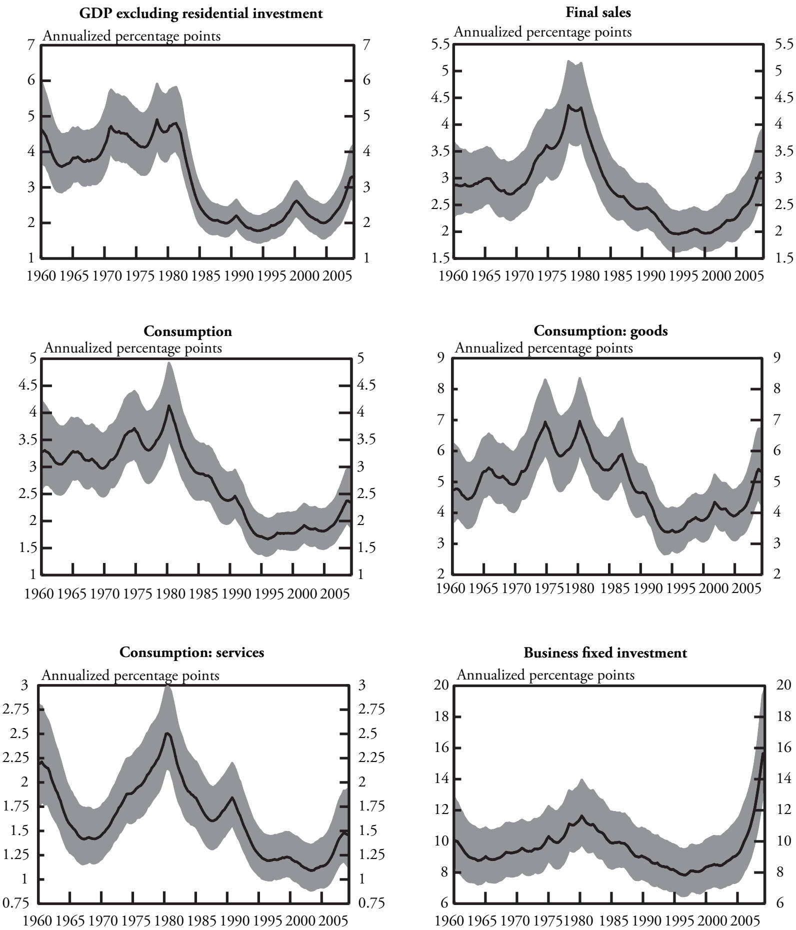
Indicator	Probability
GDP	95.9
GDP excluding residential investment	95.3
Final sales	92.8
Consumption	83.6
Consumption: goods	85.4
Consumption: services	84.9
Business fixed investment	99.6
Residential investment	99.2
Inventory contribution to GDP growth	63.0
Net exports contribution to GDP growth	94.9
Government spending	48.4
GDP: goods	92.6
GDP: services	63.3
Payroll employment	97.7
Unemployment	98.1
Inflation: GDP	96.0
Inflation: core PCE	75.1
Federal funds rate	97.5
10-year Treasury bond	62.3

Moderation yielded a very broad-based reduction in volatility, touching all variables considered (see also Stock and Watson 2002, 2003).[6] Variability fell for final sales and inventories; all broad categories of consumer spending and business investment; residential investment; net exports; government spending; the goods and services components of GDP; inflation; and interest rates.

The statistical estimates also show that the volatilities of many major macroeconomic indicators have recently reversed much of the Great Moderation (Chart 3). However, the rise in volatility is not quite as widespread as the Great Moderation. Volatility has risen sharply for goods sectors (for example, the goods components of consumption and GDP), measures of investment (business fixed and residential investment), and measures of inflation that include food and energy (inflation in the GDP price index).[7] The increase in volatility has been smaller for

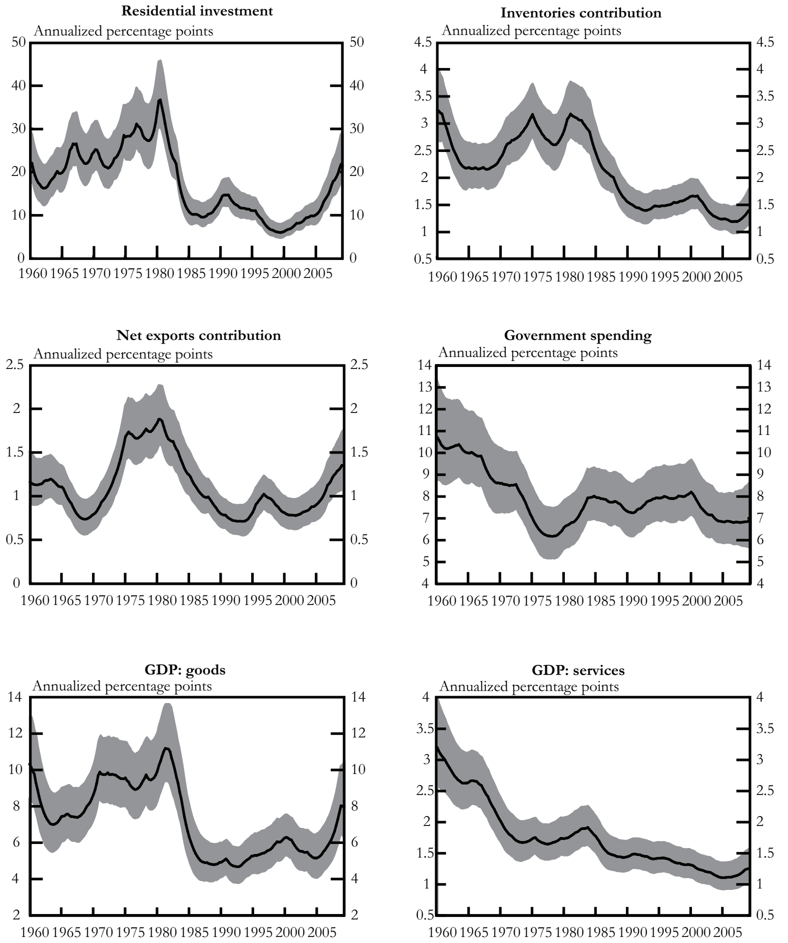
Chart 3

ESTIMATED STANDARD DEVIATIONS OF U.S. INDICATORS



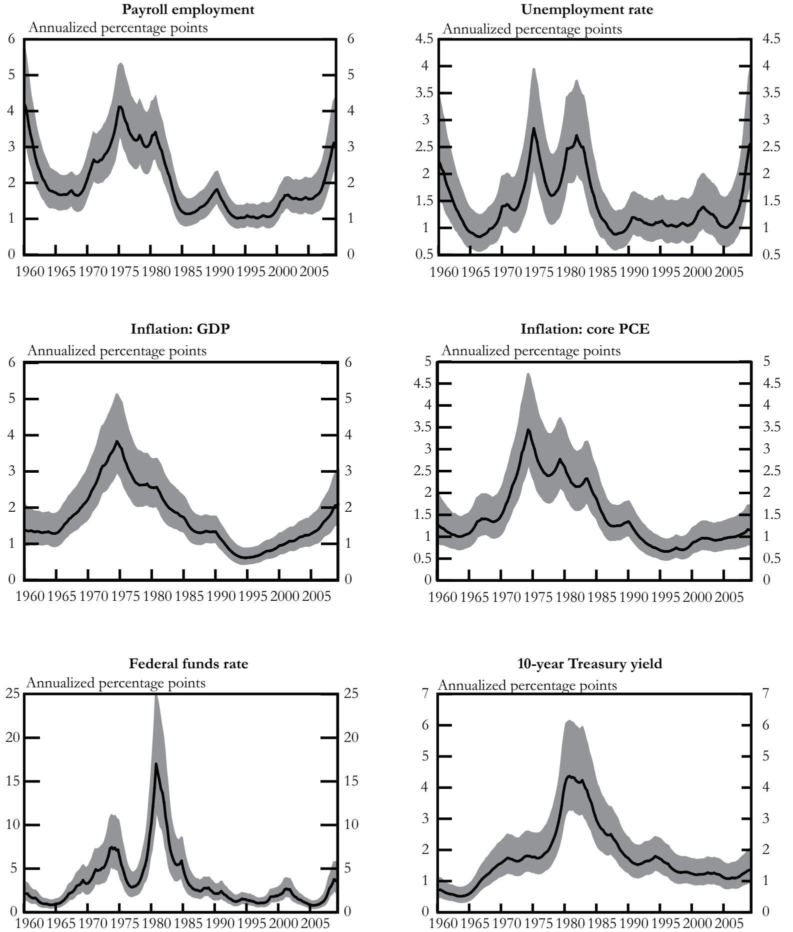
Notes: Black line: point estimate of fitted standard deviation of each variable. Shading: 70 percent confidence interval.

Chart 3, continued



Notes: Black line: point estimate of fitted standard deviation of each variable. Shading: 70 percent confidence interval.

Chart 3 continued



Notes: Black line: point estimate of fitted standard deviation of each variable. Shading: 70 percent confidence interval.

services sectors (services consumption and the services component of GDP), the inventories contribution to GDP growth, core inflation, and 10-year Treasury yields. The stability in the volatility of inventories is especially noteworthy in light of the importance some research has placed on inventory management as an explanation for the Great Moderation (for example, McConnell and Perez-Quiros). Estimated probabilities of an increase in volatility confirm that increases in volatility are highly likely and therefore significant for goods sectors, measures of investment, and measures of inflation that include food and energy (Table 1).[8]

As in the case of GDP growth, the estimated changes over time in the model-implied standard deviations of U.S. macroeconomic indicators are driven by movements in the volatility of the error term of the model. Although many of the estimated coefficients of the models have changed modestly over time, the swings in volatility shown in Chart 3 are due to movements in the standard deviation of the shock term of the model.

II. CAUSES OF THE RISE IN VOLATILITY

Determining whether the rise in macroeconomic volatility documented in the last section signals the end of the Great Moderation requires an assessment of the root causes of the increase in variability. The simple statistical model of the last section indicates the increased variability is due to more volatile shocks to each variable. For example, the volatility of GDP growth has risen because the volatility of the error term in the GDP equation has moved higher. This error term, though, reflects an array of unmodeled, fundamental forces, including shocks to oil prices and financial conditions. The challenge is to determine what fundamental factors have driven up the volatility of the error term in the simple GDP equation and, in turn, the volatility of GDP growth.

If the Great Moderation has ended, it is most likely because one or more of the factors responsible for the Moderation is no longer at work. Thus, to determine why volatility has increased, the natural starting point is to consider the causes of the Great Moderation. This section begins with a brief review of the causes of the Great Moderation and their potential for explaining the increase in volatility. The section then focuses on the most direct explanation for greater variability: bigger shocks to oil prices, the housing sector, and financial markets. After describing the macroeconomic model used in the analysis, the section presents the results. Estimates of the model indicate most of the rise in the volatility of the U.S. economy can be attributed to larger shocks to oil prices and financial markets.

Potential causes of the Great Moderation

Most research on the causes of the Great Moderation has considered three broad explanations: structural changes in the economy, improved monetary policy, and good luck (Stock and Watson 2002, 2003; Cecchetti, Flores-Lagunes, and Krause). Potentially important structural changes include improved inventory management (McConnell and Perez-Quiros) and financial innovations (Dynan, Elmendorf, and Sichel). For example, market-driven financial innovations such as securitization made credit available to more households and firms. Increased availability of credit may have allowed households and firms to better smooth out changes in spending over the course of ups and downs in the business cycle. In addition, the elimination of ceilings on interest rates on bank deposits (Regulation Q) helped to stabilize the supplies of funds available to lenders and, in turn, borrowers.

Some economists believe volatility in the economy fell after monetary policy began to respond more systematically to deviations of inflation and GDP growth from desired levels, following the experience of high inflation in the 1970s (Clarida, Gali, and Gertler present evidence of a change in policy). According to Bernanke (2004), in the late 1960s and early 1970s, policymakers eased monetary policy to stimulate the economy and achieve a higher level of economic activity, which boosted inflation. Policymakers responded by tightening policy to lower inflation, which led to a sharp contraction in economic activity. In response, policy was eased to stimulate the economy, beginning the cycle again. This instability in policy added to the volatility of the economy. Starting in 1979, policymakers began to respond more systematically and consistently to inflation and GDP growth. By the early 1980s, monetary policy's responsiveness to inflation had increased to a more appropriate level and helped to stabilize the economy (Bernanke (2004); Clarida, Gali, and Gertler).

Yet another explanation for the Great Moderation is known as the "good luck" hypothesis (Stock and Watson 2002, 2003; Ahmed, Levin, and Wilson). According to this line of reasoning, the economy was highly volatile from the 1960s through the early 1980s because it was subject to unusually large shocks, such as dramatic increases in oil prices.[9] From the early 1980s until perhaps recently, the economy has been lucky in the sense that shocks have been much smaller. As a result, the economy was much less variable than during the period of large shocks.

Despite considerable research, broad agreement on the causes of the Great Moderation remains elusive. At least some research supports each of the explanations. But the evidence is far from clear-cut. For example, a number of studies have found that the Great Moderation is better explained by reductions in the sizes of shocks (good luck) than by changes in the conduct of monetary policy (Stock and Watson 2002, 2003). Yet some other studies have shown a significant portion of the Great Moderation to be the result of changes in the conduct of monetary policy (Canova; Benati and Surico).

The ambiguity of the evidence on the causes of the Great Moderation could in part be due to the difficulty of distinguishing what are truly shocks from structural aspects of the economy and policy. As Greenspan and others emphasized in the general discussion of Stock and Watson (2003) at the Jackson Hole Symposium, the small models commonly used to assess the Great Moderation may ascribe to unexplained shocks changes that in fact represent systematic responses to events in the economy. Greenspan argued that what changed with the Great Moderation was the flexibility of the economy, with better inventory management, gradual deregulation, and greater flexibility of labor and financial markets. Several commentators suggested the conduct of monetary policy had also improved and lowered economic volatility (for example, DeLong). Small macroeconomic models, such as the one used later in this article, may not be rich enough to capture some changes in the flexibility of the economy, such as better inventory management, or the behavior of monetary policy. Some of the Jackson Hole commentators on Stock and Watson (2003) argued simple models attributed too much of the Great Moderation to smaller shocks and not enough to improvements in structural aspects of the economy and policy.[10]

Potential causes of rising volatility

Despite the absence of agreement on the causes of the Great Moderation, the natural starting point for explaining the recent rise in volatility is to consider whether the forces that may have caused the Great Moderation could have more recently reversed course. First, could past structural changes in inventory management or financial markets have reversed themselves? Probably not. It seems unlikely that there has been a sudden change in inventory management that could account for increased volatility. In fact, the evidence in the previous section indicates the volatility of inventories has remained at about the Great Moderation level. An unwinding of structural changes in financial markets that contributed to the Great Moderation is also unlikely. For example, regulations such as ceilings on deposit interest rates (Regulation Q) have not been reinstated. While securitization has fallen sharply during the crisis, it has not been eliminated. So, at least prime borrowers continue to be able to use credit to smooth their spending through the business cycle.

Similarly, changes in the response of monetary policy to economic activity and inflation seem unlikely to account for the recent rise in macroeconomic volatility. The behavior of monetary policy is widely viewed as having been consistent and stable from the early 1980s into this decade (Lubik and Schorfheide). Policy has taken unusual steps to respond to the sharp recession and financial crisis, but these policy changes occurred after the beginning of the event—not in time to have caused the rise in volatility. However, some observers have argued the decision to keep the federal funds rate target very low for too long in 2003-2004 represented a departure from the normal behavior of policy that helped to sow the seeds for the housing bust and subsequent economic crisis (Taylor). While this view could have some merit, other research on the conduct of policy in the early part of this decade indicates that policy acted appropriately and consistently with historical norms (Elmendorf). In addition, Gertler observes that the United Kingdom experienced a similar housing boom and bust despite having maintained a significantly tighter monetary policy in 2003-2004.

Larger shocks seem to be the most promising explanation for the recent rise in volatility.[11] There is reason to think the sharp recession and associated rise in volatility could be the result of some specific shocks. Oil prices posted record increases over the course of 2007-2008, rising from $54 per barrel in January 2007 to nearly $134 in June 2008. In some models of the relationship of GDP growth to oil prices, the jump in oil prices fully accounts for the recession (Hamilton 2009a,b). The collapse of the housing market also sharply slowed the economy through the direct contributions of residential investment to GDP and spillovers associated with consequences such as job losses in construction (Bernanke 2008, 2009). Residential investment fell more than 50 percent from 2005:Q4 to 2009:Q2, and total employment in construction fell 16 percent over the same period.

Finally, the crisis in financial markets that erupted in August 2007 made financing more costly and difficult to obtain, likely reducing consumer and business spending. The crisis originated with increased delinquencies on subprime residential mortgage loans but spread to other financial assets and markets, such as commercial mortgage-backed securities. Starting in August 2007, most spreads between interest rates on risky loans and safer loans soared. One such measure, the TED spread, is the difference between the 3-month London Interbank Offered Rate (an interbank lending rate that is risky because the loans are unsecured) and the 3-month Treasury yield (the safe rate). The TED spread rose from 0.26 percentage point at the end of January 2007 to 1.5 percentage point at the end of August 2007 and more than 4 percentage points in mid-October 2008. In the face of a high degree of aversion to risk and a strong desire for liquidity, credit has only been available to the highest-quality (lowest risk) borrowers for much of the crisis.

The crisis in financial markets is widely viewed as a shock that contributed importantly to the severity of the recession. Admittedly, though, to some extent the financial shock could have been made possible by some of the same past financial innovations that contributed to the Great Moderation. For example, while the increase in mortgage securitization may have enabled more consumers to use credit to smooth their spending over the course of business cycle, the mortgage securitization market suffered from various incentive problems (Ashcraft and Schuermann; Dugan; Keys and others). For one, mortgage originators had no obligation to hold any interest in a loan and therefore had insufficient incentive to ensure the quality of the borrower.[12] Many observers have blamed the financial crisis on these incentive problems. In addition, the Great Moderation could have helped to foster the shock to financial markets by causing borrowers, lenders, and investors to underestimate risk (Carney). Although the deeper causes of the financial crisis are beyond the scope of this article, the crisis likely constituted a shock that could have contributed to the rise in macroeconomic volatility.

Empirical evidence on the causes of increased volatility

Based on such reasoning, this section uses a small macroeconomic model of the U.S. economy to assess the roles of shocks to oil prices, housing, and credit conditions in the rise of volatility. With structural changes in the economy or monetary policy unlikely sources of a rise in volatility, the regression coefficients of the model—which capture the structural relationships in the model—are held constant over time. But the variances of the shocks to the model are allowed to change from period to period. Accordingly, the model provides a decomposition of the recent rise in macroeconomic volatility into contributions from various shocks, including shocks to oil prices, housing, and financial market conditions. To the extent that shocks have become larger, the resulting increase in the volatility of the macroeconomy can be viewed as a result of bad luck. In light of the Great Moderation debate over difficulties in correctly disentangling shocks and structural aspects of the economy, a bad luck explanation will be more credible if shocks to oil prices, housing, or financial market conditions—shocks widely thought to have occurred—drive the rise in macroeconomic volatility.

Model description. The variables in the macroeconomic model include the real price of oil (the log of the spot price/GDP price index), inflation in the GDP price index, the growth rate of GDP excluding residential investment, growth of residential investment, a measure of financial market conditions, and the federal funds rate. In this model, GDP excluding residential investment is used in lieu of overall GDP to make it easier to disentangle shocks specific to the housing sector and shocks to the overall economy.[13] Although housing is measured with just residential investment to limit the size of the model and volume of results to be presented, the broad findings are unchanged by the addition of housing prices to the model.[14] Financial market conditions are measured with an index of financial stress in the United States from the International Monetary Fund (IMF), developed in Balakrishnan and others.[15] The IMF's stress index is based on seven financial market indicators, including an interbank interest rate spread, a corporate bond spread, stock returns, and a measure of volatility in stock returns.

The model relates the current value of each variable to the values of all variables over the past four quarters. For example, growth in residential investment is a function of the past four quarters' values of oil prices, inflation, GDP excluding residential investment, residential investment, the financial stress index, and the federal funds rate. Each equation includes an error term that captures shocks. For instance, the error in the oil price equation will capture as shocks sudden movements in oil prices.[16] Models of this form are commonly used in macroeconomic research (for example, Jarocinski and Smets).[17]

To assess the roles of various shocks in accounting for the recent rise in volatility, the macroeconomic model simplifies some aspects of the single-variable model of the last section (see Appendix 2 for details). To capture changes in the volatility of the economy, the standard deviations of the shocks to the model are allowed to vary smoothly over time, taking different values each quarter. However, in contrast to the specification of the single-variable model, the regression coefficients are assumed to be constant over the estimation sample of 1985:Q1 through 2009:Q2. Holding the regression coefficients constant is a practical (to make the estimation statistically tractable) requirement with a model having more than a few variables. Using an estimation sample that starts in the mid-1980s should help to ensure the regression coefficients are truly stable over time.[18] For example, many economists believe the conduct of monetary policy changed in the late 1970s or early 1980s but has been stable since then (for example, Clarida, Gali, and Gertler).[19] Therefore, a number of other studies have used the same approach of treating model coefficients as constant over a sample from the mid-1980s through the present (for example, Jarocinski and Smets).

The model implies the volatility of each included variable to depend on all the coefficients on past values of the variables and the variances of the shocks. In this section, the model-implied volatility is reported as an instantaneous variance.[20] In any quarter, the instantaneous variance of a variable is what the variance would be for all time in the future if the variances of shocks and the coefficients on lagged values of the variables stayed at their current levels. Because the coefficients are held constant over time, increases in instantaneous variances of the variables must result from increases in the variances of the shocks, which are allowed to vary over time. However, not all of the shock variances need to increase to drive a shift in macroeconomic volatility. The rise in macroeconomic volatility could be due to just a single shock variance.

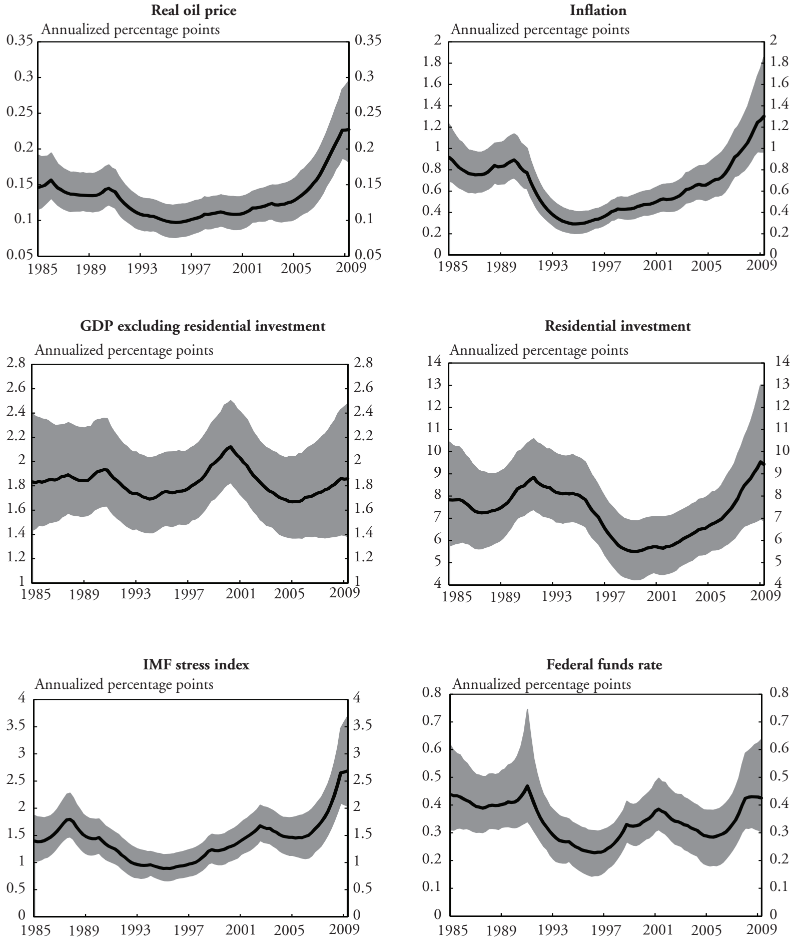
Results. To determine which shocks may have driven the rise in macroeconomic volatility, the natural starting point is the volatilities of the shocks in the model. Chart 4 reports estimates of the standard deviations of the shocks in the model.[21] The volatilities of some of the model's shocks have risen significantly in recent years. For example, the standard deviation of oil price shocks has doubled since 2001. The standard deviation of shocks to financial stress has increased by more than 80 percent since 2005. The variability of shocks to inflation and residential investment has also moved significantly higher since the early part of this decade. In contrast, the variability of shocks to GDP excluding residential investment has remained essentially flat. Similarly, the estimated volatility of shocks to the federal funds rate has remained within the relatively narrow range in which it has fluctuated since 1985. For these two variables, the rise in volatility evident from the single-variable model considered in the first section must be due to other shocks. The macroeconomic model used in this section is designed to capture such propagation over time of shocks in one variable to other variables—for example, the delayed influence of oil prices on GDP growth.

Chart 5 and Table 2 report estimates of the instantaneous variance of each variable implied by the estimated macroeconomic model, broken down into the estimated contributions of each source of shocks.[22] The chart provides the complete time series of variances and contributions. The height of the shaded contours gives the total variance; each separate contour gives the contribution from a particular shock. Wider contours imply larger contributions. Table 2 reports point estimates of the total change in variance from 2003:Q4 to 2009:Q2, along with shares of the change in total variance attributable to each of the model's shocks.[23]

The estimates of instantaneous variances from the macroeconomic model indicate the recent rise in macroeconomic volatility is primarily due to increases in the variances of shocks to financial markets and oil

Chart 4

ESTIMATED STANDARD DEVIATIONS OF SHOCKS IN MACROECONOMIC MODEL



Note: Black line: point estimate of fitted standard deviation of each variable.
Shading: 70 percent confidence interval.

Chart 5

ESTIMATED VARIANCES AND VARIANCE CONTRIBUTIONS FROM MACROECONOMIC MODEL

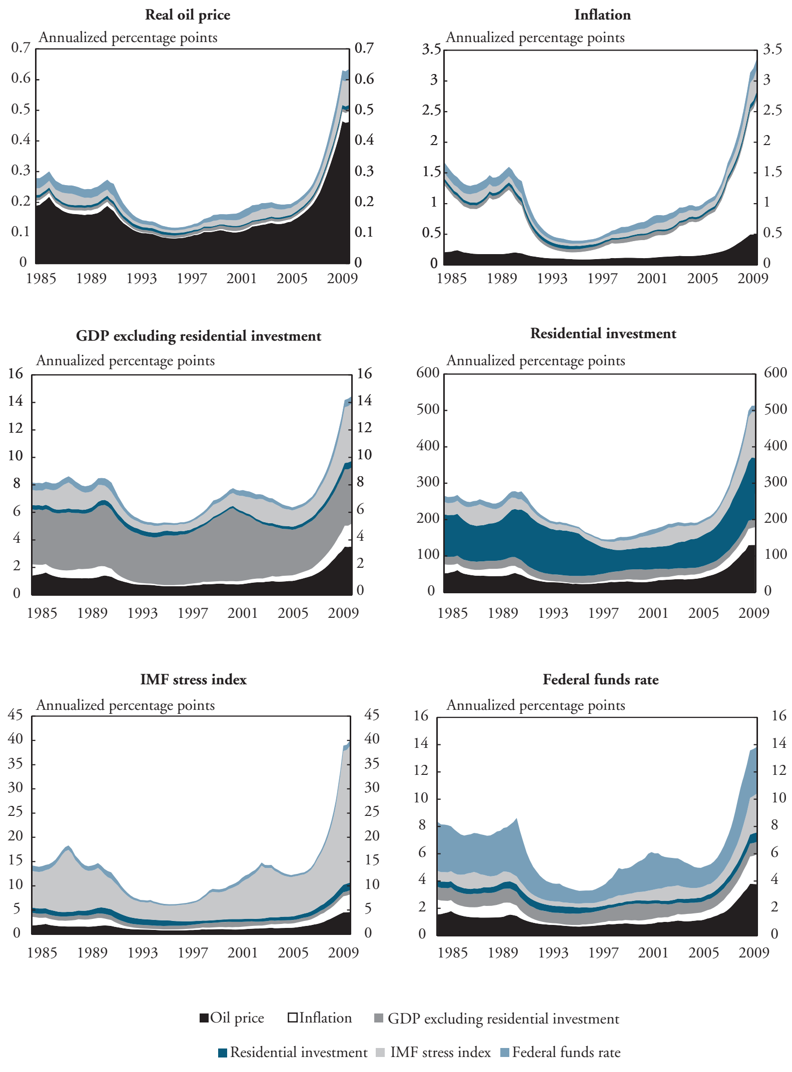


Table 2

CHANGES IN ESTIMATED VARIANCE CONTRIBUTIONS FROM 2003:Q4 TO 2009:Q2

Variable	**Change in fitted variance, total**	**Percent of change in total variance due to change in variance of each type of shock**					
		Oil price	Inflation	GDP ex res. inv.	Res. inv.	IMF stress index	Fed funds rate
Oil price	0.44	75.5[a]	5.8[a]	0.3	1.5	13.2[a]	3.6
Inflation	2.41	14.8[a]	69.5[a]	0.4	1.7	10.1[a]	3.4
GDP ex res. inv.	7.71	33.1[a]	16.6[a]	7.2	3.5	36.5[a]	3.2
Res. inv.	323.31	29.4[a]	11.5[a]	1.0	29.2	26.3[a]	2.6
IMF stress index	26.72	12.5[a]	10.4[a]	0.5	3.3	71.3[a]	2.0
Fed funds rate	8.45	32.2[a]	19.7[a]	1.3	4.6	23.2[a]	19.1

Notes: The first column reports the change from 2003:Q4 to 2009:Q2 (positive numbers indicate rising variances) in the total variance of each variable obtained from the macroeconomic model estimates. These figures are sums of the posterior medians of the contributions reported in Chart 5. The remaining columns report the shares of the change in variance accounted for by each shock in the model. These shares are computed from the posterior medians of the contributions reported in Chart 5 and the total change in variance reported in the first column. A superscript [a] denotes a change in contribution that is significant in the sense that the (posterior) probability of an increase in the variance contribution exceeds 95 percent (note that none of the probabilities exceed 90 percent but not 95 percent).

prices (Chart 5, Table 2). The contributions of financial stress to the variabilities of growth in GDP excluding residential investment and growth in residential investment have risen sharply in recent quarters. The point estimate of the contribution of financial shocks to growth of GDP excluding residential investment rose by 2.81 percentage points from 2003:Q4 to 2009:Q2, accounting for 36.5 percent of the total increase in GDP variability. The estimated contribution of financial shocks to residential investment shot up 85.11 percentage points from 2003:Q4 to 2009:Q2, which is 26.3 percent of the total change in variance for residential investment. The contributions of financial stress to the variances of inflation and the federal funds rate have also risen significantly, accounting for 10.1 and 23.2 percent, respectively, of the increase in volatility for these variables. The estimated probabilities of increases in variance due to financial market shocks exceed 95 percent, indicating the increases are statistically important.

The large increase in the volatility of oil prices has also significantly boosted the variability of GDP, residential investment, inflation, and the federal funds rate. The point estimate of the contribution of oil price shocks to GDP excluding residential investment increased 2.55 percentage points from 2003:Q4 to 2009:Q2 (33.1 percent of the total change in variance for GDP). The estimated contribution of oil price shocks to inflation rose 0.36 percentage point (14.8 percent of the total) for inflation. The contribution of oil shocks to the federal funds rate jumped 2.72 percentage points from 2003:Q4 to 2009:Q2, accounting for 32.2 percent of the overall rise in funds rate variability. With the estimated probabilities of increases in variance exceeding 95 percent, the changes due to oil prices are statistically significant.

Perhaps surprisingly, the increased variability of shocks to residential investment has yielded only small changes in the volatility of the other model variables. For example, the estimated contribution of housing shocks to the increased volatility of GDP excluding residential investment is 0.27 percentage point, or 3.5 percent of the total increase. But larger shocks to housing do play a role in the rising volatility of residential investment, pushing the estimated contribution of housing shocks up 94.39 percentage points from 2003:Q4 to 2009:Q2 for 29.2 percent of the change in the overall volatility of residential investment.

Finally, the model ascribes much of the rise in the volatility of inflation, and some of the increase in the variability of GDP and the federal funds rate, to shocks to inflation. The point estimate of the contribution of inflation shocks to the overall variability of inflation rose 1.67 percentage points from 2003:Q4 to 2009:Q2, accounting for 69.5 percent of the total change in inflation volatility. But these measured shocks to inflation could represent other fundamentals not included in the model, such as food prices or non-oil energy prices. Estimates of an alternative version of the model including core consumer price inflation instead of GDP inflation yield a much smaller role for inflation shocks.

III. IMPLICATIONS

The evidence in the previous two sections indicates macroeconomic volatility has risen significantly in recent quarters, and that the increase in U.S. volatility can be primarily attributed to larger shocks to oil prices and financial conditions. However, the increase in volatility is not as widespread across sectors as the Great Moderation. This section discusses the implications of these findings for the permanence of the Great Moderation and the future volatility of the economy. The section first discusses the implications of existing evidence on the sources of the Great Moderation for its permanence. In that context, the section then turns to the implications of the recent increase in volatility.

The inconclusive evidence on the causes of the Great Moderation could be seen as suggesting that the Moderation was partly due to each of structural change, improved policy, and good luck. Any contributions from changes in economic structure and policy seem likely to be permanent—that is, to contribute to a permanently lower level of macroeconomic volatility. For example, the improvements in inventory management techniques introduced some years ago should be permanent and have lasting benefits on the variability of production. Similarly, financial innovations such as securitization will remain in place, making credit available to more consumers and firms (allowing them to smooth spending) than was the case before securitization became common. To be sure, the crisis may have permanently reduced the level of securitization, but securitization will continue to occur because it offers considerable benefits to financial market participants. Policymakers may also enact reforms that help to preserve securitization in its most important forms. As a result, most observers expect securitization to increase after the crisis (Calomiris; Knowledge@Wharton; Penner; Schwarcz). Finally, the late 1970s or early 1980s shift of monetary policy toward more systematic behavior in responding to economic activity and inflation should be permanent and contribute to permanently lower volatility of the economy.

On the other hand, as Pescatori observes, there is no reason to think any portion of the Great Moderation due to good luck should be permanent. Good luck can turn into bad luck and cause volatility to rise. For example, to the extent the Great Moderation was partly due to fortuitously smaller shocks to energy prices, at some point in the future the economy could be subject to larger shocks to energy and, in turn, an increase in macroeconomic volatility.

Based on this reasoning, up until the recent crisis it might have been reasonable to believe the Moderation had permanently lowered macroeconomic volatility, but perhaps not (permanently) to levels as low as was experienced during a period in which luck was primarily good. Structural change and improved policy contributed to permanent reductions in volatility, while good luck's contribution should prove temporary. As a result, volatility was permanently lower, although not necessarily as low as indicated by the data for the Great Moderation period.

In such a context, what does this article's evidence on rising volatility and its sources imply for the durability of the Great Moderation? The first section's finding that the recent increase in volatility is concentrated in certain sectors of the economy (for example, goods production and investment but not services components, and total inflation but not core) suggests the Great Moderation, which affected all sectors, has not come to an end. The narrower breadth of the rise in volatility is suggestive of specific shocks affecting parts of the economy—bad luck—rather than broad changes in structure or policy that would tend to affect the entire economy. The second section of this article provides more direct evidence that bad luck has driven the recent rise in volatility. Specifically, the second section shows that larger shocks to oil prices and financial conditions account for most of the increase in macroeconomic volatility.[24]

Accordingly, once the crisis subsides and the period of very bad luck passes, macroeconomic volatility will likely decline. In the future, the permanence of structural change and improved monetary policy that occurred in years past should ensure that low volatility is the norm. That level of volatility may not be quite as low as during the Great Moderation, when good luck consistently prevailed. However, as recent events have shown, the volatility of shocks hitting the economy will likely vary over time. During occasional periods of bad luck, macroeconomic volatility could rise significantly. Therefore, over time, macroeconomic volatility seems likely to undergo occasional shifts between high and low levels, with low volatility the norm.

Such changes in volatility have implications for assessments of risk by all decision makers. For example, risk premia incorporated in lending rates should take account of the potential for occasional periods of higher-than-normal economic volatility that could produce steeper-than-normal recessions. Were a relatively steep recession to occur, loan delinquency rates could rise significantly. The interest rates charged on the loans should reflect the small probabilities of such outcomes. On a more positive note, the recognition by financial market participants that volatility can turn up from time to time could make the financial system less prone to booms and busts associated with periods of extreme optimism and pessimism (Carney).

As another, related example, shifts over time in volatility imply the uncertainty surrounding macroeconomic forecasts also changes over time. Such changes in uncertainty will need to be reflected in the measures of forecast uncertainty reported by many central banks. Some central banks publish fan charts showing probabilities of outcomes. The Federal Reserve publishes discussions of uncertainty in the periodic Summary of Economic Projections included in the minutes of meetings of the Federal Open Market Committee. All such central bank reports on forecast uncertainty will need to take account of variation over time in macroeconomic volatility.

As a final example, household decisions on savings should take account of the potential effects of an occasional steeper-than-normal recession on their income, job situations, and wealth. As recent events have highlighted, severe downturns can eliminate jobs normally thought safe and cause asset values and wealth to plummet. Some consumers will want to consider saving more in the event of such rainy days.

IV. CONCLUSIONS

The severity of the recession that started in late 2007 has led some observers to conclude the Great Moderation—a period of low macroeconomic volatility that began in the United States in the mid-1980s—is over. The recession was the worst in the post-war period, producing an unprecedented decline in economic activity.

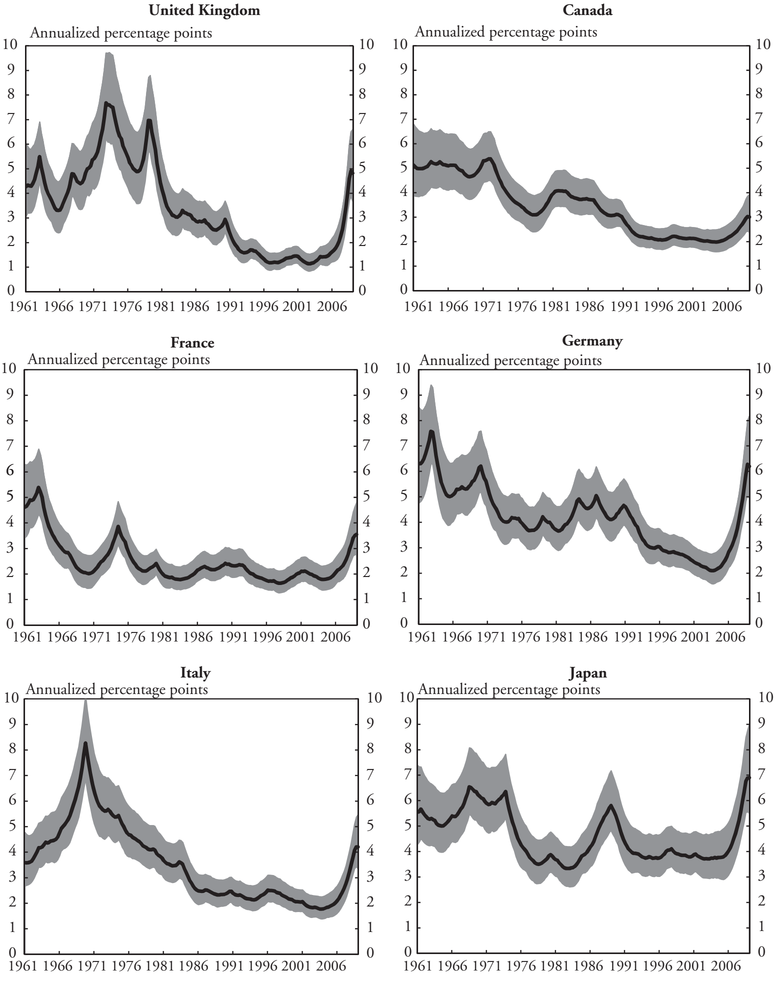
This article examines whether the Great Moderation is over. Estimates in the article show the volatilities of GDP growth and many (not all) sectors of the U.S. economy have reversed much of the Great Moderation. A statistical examination of potential causes of the rise in the volatility of the economy points to larger shocks to oil prices and financial markets. The article concludes that, over time, macroeconomic volatility will likely undergo occasional shifts between high and low levels, with low volatility the norm. In this sense, the Great Moderation is not over.

APPENDIX 1

This appendix provides estimates of changes in GDP growth volatility for other G7 economies, based on data through 2009:Q2 and the statistical model used in the first section of the article.[25] These statistical estimates show that the volatilities of many G7 economies have reversed much of the Great Moderation (Chart A1). The Great Moderation produced significant reductions in volatilities in all economies, sometimes fairly suddenly (as in the United Kingdom and Japan) and sometimes more gradually (as in the other countries). However, recent events have caused the estimates of volatility to move higher in all countries, some much more than others. The rise in volatility has been especially sharp for Germany and Japan. The United Kingdom and Italy have also experienced dramatic increases in variability. The rise in volatility has been more muted for Canada and France. Statistically estimated probabilities that the instantaneous standard deviation of GDP growth is higher in 2009:Q2 than in 2003:Q4 confirm the significance of the increase in volatility. For all countries, the probability of a rise in volatility is 95 percent or more.

Chart A1

ESTIMATED STANDARD DEVIATIONS OF GDP GROWTH IN G7 ECONOMIES



Note: Black line: point estimate of fitted standard deviation in each country. Shading: 70 percent confidence interval.

APPENDIX 2

This appendix details, in technical terms, the statistical models and estimation methodology used in the article.

Single-variable model specification

The univariate model is an autoregression (AR) with time-varying coefficients and stochastic volatility. Letting y_t denote the variable of interest measured in quarter *t*, the model takes the form:

$$y_t = \beta_{0,t} + \beta_{1,t} y_{t-1} + \beta_{2,t} y_{t-2} + \beta_{3,t} y_{t-3} + \beta_{4,t} y_{t-4} + h_t^{.5} \varepsilon_t, \operatorname{var}(\varepsilon_t) = 1.$$

The errors ε_t are independent shocks; h_t is the instantaneous error variance. With the β_t coefficients stacked in a vector B_t, the model can be rewritten as:

$$y_t = X_t^{'} B_t + h_t^{.5} \varepsilon_t,$$

where X_t is a stacked vector containing all of the right-hand-side variables (the constant and the lags of y_t).

The time variation in coefficients and variances is modeled with random walk processes, which relate current values to last period's values plus a shock. The time variation of the model parameters is governed by the following equations:

$$B_t = B_{t-1} + u_t$$

$$\log h_t = \log h_{t-1} + n_{t.}$$

All of the innovations in the model are assumed to follow joint normal distributions, with independence among ε_t, u_t, and n_t.

The instantaneous standard deviations reported in the article are functions of the time-varying coefficients and error variances. For each period *t*, these instantaneous variance estimates are obtained by (1) rewriting the estimated AR(4) model as a first-order vector autoregressive (VAR(1)) process with coefficient matrix C_t (where the first row of C_t contains the AR coefficients β_t and the other elements are ones or zeros) and error variance matrix Σ_t (the first element is h_t and the other elements are zeros), and (2) solving the equation $V_t = C_t V_t C_t' + \Sigma_t$ for V_t, where the first element of V_t contains the instantaneous variance of y_t (see Hamilton (1994), pp. 259-66).[26]

Single-variable model estimation

The univariate model is estimated with the Bayesian methodology detailed in such sources as Cogley and Sargent and Primiceri. The sample period is 1961:Q2 to 2009:Q2 in the G7 analysis and 1960:Q1 to 2009:Q2 in the U.S. analysis. Bayesian estimation combines prior distributions for all coefficients with the likelihood to obtain posterior distributions. Markov chain Monte Carlo methods are used to simulate the posterior distributions from prior distributions that are normal or inverted Wishart. The reported estimates are based on 10,000 draws obtained by first generating 10,000 burn-in draws and then saving every fifth draw from another 50,000 draws.

The priors use estimates from 10 years of data preceding the estimation sample (a training sample). In the analysis of U.S. variables, the training sample is 1950:Q1 through 1959:Q4. In the analysis of G7 data, only for the United States and France is GDP data available for 10 years preceding the estimation starting point of 1961:Q2. Accordingly, in all other G7 estimates, the training sample estimates are taken from estimates for GDP growth in the United States from 1951:Q2 through 1961:Q1. The prior mean and variance of the initial value of the AR coefficients (B_0) are set to the training sample's least squares estimates of the coefficients and four times their variance, respectively. The prior mean of the log of the initial value of the instantaneous error variance, h_0, is set to the log of the residual variance from the pre-sample estimate; the prior variance is set to 4.0.

The priors on the amount of time variation in the coefficients and the error variance reflect an expectation that some time variation is likely. The (inverted Wishart) prior for the variance of u_t, the shocks to the AR coefficients, uses a mean of 0.001 times the variance of the least squares estimates from the training sample, with 10 degrees of freedom. The (inverted Wishart) prior for the variance of n_t, the shock to the log variance, uses a mean of .002 and 5 degrees of freedom (so the Wishart scale matrix is $.002 \times 5$).

Modifications of the priors described above did not change the qualitative results presented in the article. These modifications included the following, implemented separately: (1) tightening the variance on the initial value of volatility to 0.5 (from 4.0); (2) raising the scaling factor controlling the time variation in coefficients to 0.005 (from 0.001); (3)

lowering the scaling factor controlling the time variation in coefficients to 0.0005 (from 0.001) and raising the degrees of freedom to 20; (4) lowering the prior mean on time variation in volatility to 0.005 (from 0.02); and (5) raising the prior mean on time variation in volatility to 0.05 (from 0.02).

Multi-variable macroeconomic model specification

The macroeconomic model is a VAR with constant regression coefficients and stochastic volatility.[27] In light of the evidence in such studies as Levin and Piger of shifts in trend inflation, the model incorporates the steady state specification developed by Villani. Let y_t denote the vector of variables measured in quarter *t*: the log of the real price of oil, inflation, growth in real GDP excluding residential investment, etc. Let d_t denote the vector of deterministic variables used to capture the long-run means of each variable: a constant and a dummy variable with value 1 from 1991 onward (per the dating of Levin and Piger) and 0 in previous periods. Let $\beta(L) = I - \beta_1 L - \beta_2 L^2 - \beta_3 L^3 - \beta_4 L^4$ and ψ = a 6 × 2 matrix of coefficients on the deterministic variables. The model takes the form:

$$\beta(L)(y_t - \psi d_t) = A^{-1} H_t^{.5} \varepsilon_t, \, \mathrm{var}(\varepsilon_t) = I$$

$$A = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 \end{pmatrix}$$

$$H_t = \begin{pmatrix} h_{1,t} & 0 & 0 & 0 & 0 & 0 \\ 0 & h_{2,t} & 0 & 0 & 0 & 0 \\ 0 & 0 & h_{3,t} & 0 & 0 & 0 \\ 0 & 0 & 0 & h_{4,t} & 0 & 0 \\ 0 & 0 & 0 & 0 & h_{5,t} & 0 \\ 0 & 0 & 0 & 0 & 0 & h_{6,t} \end{pmatrix}.$$

The errors ε_t are independent structural shocks, identified from a recursive, or Choleski, ordering. The reduced-form residuals are $A^{-1}H_t^{.5}\varepsilon_t$. The components of H_t are instantaneous error variances. Under the ordering of variables in y_t, a shock to oil prices, for example, can have an immediate impact on GDP growth, but a shock to GDP growth can only affect oil prices with a one-period delay.

The time variation in the variances of H_t is modeled with random walk processes, which relate current values to last period's values plus a shock. For notational convenience, let h_t denote a vector containing all of the instantaneous error variances $h_{i,t}$ of H_t. The time variation of the log variances is governed by the following equations:

$$\log h_t = \log h_{t-1} + n_{t.}$$

All of the innovations in the model are assumed to follow joint normal distributions, with independence among ε_t and n_t.

The instantaneous variances and variance contributions reported in the article are functions of the VAR coefficients (the coefficients of both $\beta(L)$ and A) and error variances (H_t). For each period *t*, these instantaneous variance estimates are obtained from a 100-step ahead variance decomposition (see, for example, Hamilton (1994), pp. 323-24).

Multi-variable macroeconomic model estimation

The multi-variable model is estimated with Bayesian methodology, combining portions of the Markov chain Monte Carlo algorithms of Villani and Cogley and Sargent. The sample period is 1985:Q1 to 2009:Q2. The reported estimates are based on 5,000 draws, obtained by first generating 20,000 burn-in draws and then saving every fifth draw from another 25,000 draws. As detailed below, the priors required in the estimation use some estimates taken from 15 years of data preceding the estimation sample (a training sample of 1970:Q1 through 1984:Q4).[28]

As suggested by Del Negro, an informative prior is applied to the VAR coefficients in order to reduce problems with explosive autoregressive roots. The prior takes a Minneapolis form, with prior means of 0 on all coefficients and prior standard deviations controlled by the usual hyperparameters, with overall tightness of 0.5, cross-equation tightness of 0.5, and linear decay in the lags. The variable standard deviations that enter the Minneapolis prior are taken from AR(4) models fit to each variable over the training sample. In the case of the priors on the deterministic variables, for simplicity the priors are based on simple means and standard deviations of the series over the estimation sample. For all variables except inflation and the federal funds rate, the prior on the coefficients of the dummy variable has a mean of zero with a very, very tight standard deviation to effectively rule out mean shifts. The prior for the coefficients of the Choleski matrix A is normal and uninformative, with a mean of zero for each element and a variance of 1000^2 (and covariances of zero across coefficients).

The priors on the amount of time variation of H_t reflect an expectation that some time variation is likely. The prior mean of the initial value of the log variances, h_0, is set to the log of OLS estimates of AR(4) residual variances from the training sample; the prior variance is set to 4 times an identity matrix. The (inverted Wishart) prior for the variance of $n_{i,t}$, the vector of shocks to the log variances for equation *i*, uses a mean of .002 and 5 degrees of freedom (so the Wishart scale matrix is .010 for each variance).

Modifications of the priors described above did not change the qualitative results reported in the article. These modifications included the following, implemented separately: (1) tightening the variance on the initial value of volatility to 0.5 × I (from 4.0 × I); (2) lowering the prior mean on time variation in volatility to 0.005 (from 0.02); and (3) raising the prior mean on time variation in volatility to 0.05 (from 0.02).

ENDNOTES

[1]The quarterly growth rates used in Chart 1 and all subsequent analysis are annualized log growth rates.

[2]Another statistical formulation that allows volatility to vary over time is a generalized autoregressive conditional heteroskedasticity (GARCH) model. Canarella and others estimate GARCH models for GDP growth in the United States and United Kingdom with data through 2007 and conclude that the Great Moderation is over. However, based on just data through 2007, the models used in this article do not yield a material rise in volatility.

[3]For illustrative purposes, suppose the coefficients $\beta_{0,t}=\beta_{2,t}=\beta_{3,t}=\beta_{4,t}=0$, such that the model simplifies to an (time-varying) AR(1) process. In this case, the instantaneous standard deviation is $\frac{\sigma_t}{\sqrt{1-\beta_{1,t}^2}}$, where σ_t denotes the standard deviation of the model error e_t in quarter t.

[4]Consistent with the timing suggested by the raw data plotted in Chart 1, model estimates obtained for data samples ending at different dates indicate the rise in volatility is driven primarily—although not entirely–by data for 2008:Q4 and 2009:Q1. GDP growth volatility begins to turn up with model estimates obtained for data through 2007:Q4. The sharpest increase in volatility occurs when the model is estimated with data through 2008:Q4 or 2009:Q1. Nonetheless, these model estimates indicate volatility began to rise in 2006. This earlier timing may be due to the smoothing of volatility changes by the model, which is designed to capture gradual changes.

[5]The Bayesian statistical methodology used to estimate the models makes such probabilities natural and easy to compute. In each case, the reported probability is the percentage of posterior draws in which volatility is higher in 2009:Q2 than in 2003:Q4.

[6]All measures of spending are expressed in real (not nominal) terms, based on data released after the July 31, 2009, benchmark revision of the GDP accounts (obtained from the FAME database of the Board of Governors in early September 2009).

[7]While not reported in the interest of brevity, the rise in volatility is evident for investment split into the equipment-software and structures components and for total PCE inflation.

[8]The probability of an increase in volatility is lower for consumption and its components than for GDP or investment.

[9]While it is widely believed that large oil price movements reflect supply shocks with significant effects on the U.S. macroeconomy, some research, summarized in Kilian, has shown that the movements in oil prices are at least partly the result of demand forces and responses to macroeconomic developments.

[10]Giannone, Lenza, and Reichlin make the same point and show that, in large models, shocks play a smaller role in accounting for the Great Moderation. Benati and Surico find that empirical models commonly used to assess the roles of shocks versus policy in the Great Moderation will routinely attribute to shocks changes that in truth are due to policy.

[11]Canarella and others argue that a rise in volatility is unlikely to be the result of changes (from good to bad) in policy or inventory management.

[12]However, Schwarcz argues the originate-to-distribute problem likely played little role in the crisis.

[13]The simple treatment of housing represents an important source of uncertainty in the conclusions. Shocks to housing supply and demand may have played different roles in the recent rise in volatility. However, the model used in this section does not distinguish supply and demand shocks, because it would be very difficult to do so in a model that allows variation over time in the variances of the shocks. Jarocinski and Smets use sign restrictions to identify shocks to housing supply and demand. For computational tractability, the model of time-varying volatilities used in this article requires that shocks be identified from a Choleski decomposition.

[14]In light of the need for data back to at least 1985, the house price series used in the robustness analysis was the repeat sales index from the Federal Housing Finance Agency. Alternatives such as the Case-Shiller index from Standard and Poor's are not available that far back in time.

[15]The stress index of Hakkio and Keeton has some advantages over the IMF index, but the available data series starts too late (1990) to permit usage in this section, which requires data back to 1985. Measuring financial market conditions with a spread between medium-risk, long-maturity corporate bond yields and 10-year Treasury yields developed by Gilchrist, Ortiz, and Zakrajsek yields results qualitatively similar to the reported results based on the IMF stress index. This spread is intended as a measure of the premium firms must pay to finance projects with credit instead of internal funds. Gilchrist, Ortiz, and Zakrajsek argue this spread better captures credit supply shocks than do alternatives such as the spread between Baa and Aaa bond yields. Historically, the spread has a very strong association with changes in GDP, business investment, and other measures of economic activity. Using this interest rate spread in lieu of the financial stress index gives a modestly larger role to financial market shocks in the recent rise in macroeconomic volatility.

[16]Shocks to oil prices, residential investment, and the other variables are identified on the basis of a Choleski ordering, with the variables ordered as listed in the description of the model. In the case of oil prices, Kilian argues for identifying energy shocks by ordering oil prices first in the model. Monetary policy shocks are commonly measured by placing the federal funds rate after indicators of inflation and economic activity (see, for example, Christiano, Eichenbaum,

and Evans). GDP excluding residential investment appears before residential investment because there is likely to be some lag between the onset of a housing-specific shock and its spillover to the rest of the economy. In contrast, an overall shock to the economy should, by definition, immediately affect both residential investment and GDP excluding residential investment. Therefore, a shock that contemporaneously affects both residential investment and GDP excluding residential investment is treated as an aggregate shock and captured by the Choleski-orthogonalized shock to GDP excluding residential investment. For the other variables, the appropriate ordering is less clear. However, the results presented are robust to alternative orderings of the variables.

[17]This article's model both generalizes (by allowing time-varying volatility) and simplifies (by including fewer variables and a less sophisticated identification scheme) the model Jarocinski and Smets use to analyze the role of housing in the macroeconomy.

[18]For example, Clark and Terry show the impact of energy prices on the economy fell by the mid-1980s but remained largely constant thereafter.

[19]Not all economists agree. For example, Sims and Zha present evidence that the conduct of monetary policy has been largely constant over time, while the sizes of shocks have changed significantly.

[20]In this section, the fitted volatilities are variances instead of standard deviations to simplify breakdowns into contributions. The fitted variance is the sum of the contributions. But the fitted standard deviation is not the sum of the standard deviations of the contributions (it is the square root of the sum of variances of the contributions).

[21]The chart reports the standard deviations of the structural shocks obtained from the Choleski decomposition, rather than the reduced-form shocks.

[22]The estimates are obtained from 100-step ahead forecast error variance decompositions. The 100-step horizon is long enough that the estimated variances effectively correspond to the fitted variances. The reported figures are posterior medians.

[23]The total variances and shares in the table are based on the posterior median contributions. Medians of shares computed from the posterior distribution of shares are quite similar.

[24]Admittedly, what is less clear is the extent to which these larger estimated shocks are truly just shocks or partly reflect structural changes in the global economy. Some might argue the measured shocks to oil prices and financial market conditions that largely account for the rise in the volatility of the U.S. economy are truly just shocks. Others might view the measured shocks as partly stemming from structural changes in, for example, global energy markets or past innovations in financial markets. But it seems likely that the measured increase in the sizes of the shocks reflects true changes in the size of shocks, and in turn, the return of some bad luck.

[25]Data on G7 GDP are taken from the FAME database of the Federal Reserve Board of Governors (all the FAME-source data are chain-weighted). For all countries except the United States, United Kingdom, and France, the sample of GDP growth rates was extended back to 1960 with GDP data from the OECD.

[26]Common econometric software packages have built-in commands for solving the equation. An alternative, equivalent approach is to use the solution given in equation (11) of Cogley, Primiceri, and Sargent.

[27]Clark and Clark and Davig use similar models.

[28]The available data on the IMF stress index do not go all the way back to 1970. For the training sample estimation, the stress index is filled in – for the period 1970 to 1979—with a series that sums a prediction of the stress index based on related financial market variables available during the period with a simulated error.

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