Rules versus Discretion:

Inference Gleaned from Greenbook Forecasts and FOMC Decisions

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Abstract: From 1987 through 2013, the Federal Open Market Committee appears to have set its federal funds rate target with reference to Greenbook forecasts of the output gap and inflation and, at times, also to have made further adjustments to the funds rate as those forecasts were revised. If viewed in the context of the Taylor (1993) Rule, discretionary departures from the settings prescribed by Greenbook forecasts consistently presage business cycle turning points. Similarly, estimates from an interest rate rule with time-varying parameters imply that, around such turning points, the FOMC responds less vigorously to information contained in Greenbook forecasts about the changing state of the economy. These results suggest possible gains from closer adherence to a rule with constant parameters.

Keywords: Greenbook forecasts, Taylor Rule, Time-varying parameters.

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1. Introduction

More than thirty years ago, Allan Meltzer (1987, p.1) noted that the "tradition in which many of us were raised is that policymakers should adjust policy actions based on forecasts of the future path of the economy and their best judgments." Meltzer went on to show, however, that Federal Reserve staff forecasts of economic performance were so imprecise that predictions just one quarter into the future could not distinguish statistically between the likelihood of strong economic performance or a recession. Joutz and Stekler (2000) affirmed these earlier results, observing that before and during the four recessions experienced over the period from 1965 through 1982, the Greenbook forecasts generally failed to call the cyclical peak in advance and also displayed a tendency to predict the cyclical trough too early. Similarly, Sinclair, Joutz, and Stekler (2010) found that the Fed appears to have accurate impressions of economic performance in the current quarter but cannot predict the state of the economy one quarter ahead.

Results in Romer and Romer (2000) and Gamber and Smith (2009) showed somewhat better relative performance, with the Fed's Greenbook forecasts being superior to private sector forecasts, especially with respect to inflation; Romer and Romer (2000), based on their finding, recommended that the Fed share its forecasts with the public in an effort to enhance private sector decisionmaking. Most recently, however, Sinclair, Stekler, and Carnow (2015) found Greenbook forecasts of real GDP growth, inflation, and the unemployment rate to be similar to those reported by the Survey of Professional Forecasters. Perhaps because this evidence is so mixed, or perhaps because as Meltzer also noted, "traditions die slowly," the Fed's policymaking Federal Open Market Committee (FOMC) continues to use some, not fully specified, mix of forecasts and judgments to set its target for the federal funds rate.

This paper takes another look at the Fed's Greenbook forecasts, but not in terms of their accuracy relative to alternatives generated by the private sector or by specific econometric models. Instead, the aim here is to characterize more sharply the role that forecasts play in the Fed's policymaking process and thereby identify potential improvements that could be made within the existing strategic framework.

The analysis begins by incorporating Greenbook forecasts of the output gap and inflation into a forward-looking version of the Taylor (1993) Rule. Sinclair, Gamber, Stekler, and Reid (2012) and Tien, Sinclair, and Gamber (2018) point out that if FOMC decisions are shaped by such a rule, errors in Greenbook forecasts will translate into errors in setting the federal funds rate target that may, in turn, have implications for the realized values of output and inflation. If the FOMC uses information in the Greenbook forecasts to inform its policy decisions, it also is interesting to examine whether and how the FOMC responds to these forecast errors when setting future values for the federal funds rate target. The statistical tests performed here indicate that, indeed, over a twenty-six-year period spanning 1987 and 2013, the FOMC appears to have set its target for the federal funds rate with consistent reference to Greenbook forecasts for the output gap and inflation and, at times, also to have made further adjustments to the funds rate target in response to forecast revisions made as incoming data revealed errors in the initial economic projections.

Regarding the FOMC's use of judgment in the policymaking process, additional results show that deviations of the actual federal funds rate from the values prescribed by a forecast-based Taylor rule display consistent patterns over the business cycle. Throughout the 1987-2013 sample period, the FOMC appears to have held the funds rate "too low for too long" during cyclical expansions, generalizing the pattern that Taylor (2009) associates with the episode between the recession of 2001 and the financial crisis of 2007-2008.[1] On the other hand, periods during which the FOMC held the funds rate above the target prescribed by the forecast-based Taylor rule presage all three of the cyclical peaks in 1990, 2001, and 2007.

Estimates of a Greenbook forecast-based interest rate rule with time-varying parameters, obtained by adapting the Bayesian methods of Cogley and Sargent (2005), Primiceri (2005), and Belongia and Ireland (2016) to a single-equation context, provide additional insights into the nature and sources of deviations from the standard Taylor Rule.

[1] See Branch (2014), however, for an alternative interpretation of these events that attributes the FOMC's preference for setting the funds rate below levels prescribed by the Taylor Rule to an asymmetric loss function that reflects its members' caution against overpredicting inflation and the output gap.

These estimates show that the federal funds rate became less responsive to changing Greenbook forecasts around business cycle turning points, implying that the FOMC has been hesitant to react both to signs of economic weakness that appear before cyclical peaks and signs of improvement that emerge as the economy starts to recover.

These results highlight a surprising feature of the FOMC's policymaking strategy not anticipated in previous work, cited above, that looks solely at the accuracy of Greenbook forecasts without considering how those forecasts interact with the Committee's federal funds rate targeting decisions. Here, consistent with results from previous research, the pattern of Greenbook forecast errors indicates that the Fed fails to anticipate the severity and duration of cyclical downturns. Yet, the new results obtained here also reveal that by failing to respond decisively to signs of weakness that do appear in Greenbook forecasts around cyclical turning points, the FOMC tends to amplify instead of ameliorate the recession that follows. These observations suggest that if the Fed conducts policy according to something like a Taylor Rule and continues to do so in the future, gains would accrue from placing more consistent weight on evolving Greenbook forecasts and correspondingly less weight on judgmental deviations from or adjustments to the parameters of the Rule.

This could be a great hook for the intro. If sentiment helps Taylor rules, FOMC, trust yourselves!

2. Greenbook Forecasts and the Taylor Rule

The original Taylor (1993) Rule depicts the FOMC as setting its target for the federal funds rate in response to changes in the output gap as a measure of real economic activity and year-over-year changes in the aggregate nominal price level as a measure of inflation. Taken together, the output gap and inflation encapsulate both sides of the Federal Reserve's statutory dual mandate to achieve maximum sustainable employment and price stability. Recognizing that lags in the effects that monetary policy actions have on the economy makes the FOMC's federal funds rate targeting strategy a forward-looking exercise, the Taylor Rule is modified here to prescribe a response of policy to changes in the Fed's own "Greenbook" forecasts for the output gap and year-over-year inflation.

These Greenbook forecasts are recorded in the Greenbook data set maintained by the Federal Reserve Bank of Philadelphia. The forecasts are produced by the research staff at the Board of Governors and presented to the FOMC for consideration when decisions are made about setting a target for the federal funds rate. Here, the data begin in 1987:3, the first date for which forecasts of the output gap are available. This allows the analysis to sidestep issues, discussed first by Orphanides (2001, 2004) and more recently by Nikolsko-Rzhevskyy and Papell (2012) concerning the sources of the Fed's estimates of potential output during earlier periods. Also, because the Greenbook only began to report forecasts for inflation based on the price index for personal consumption expenditures in 2000, the series for inflation is based on the Consumer Price Index (CPI), which the Greenbook reports from 1987 forward.[2] Each series terminates 2013:4, because of the five-year embargo on the release of Greenbook forecasts.

Quarterly time series for both the output gap and CPI inflation are based on observations drawn from the first Greenbook produced in each quarter. Table 1 lists in detail the notational conventions used throughout the paper. In general, $y_{t+k|t}$ denotes the Greenbook output gap forecast for time $t + k$ made at the beginning of time t. Meanwhile, the inflation forecast $\pi_{t+k|t}$ is constructed by averaging the forecasts of quarter-to-quarter inflation made at the beginning of time t for the four quarters ending with $t + k$; hence, it is a forecast of year-over-year inflation at $t + k$ made at the beginning of t.

Benchmark results are obtained with $k = 4$, implying a four-quarter-ahead forecast horizon. This choice is motivated by Alan Greenspan's observation, quoted in Orphanides (2001, p.978) that "because monetary policy works with a lag, it is not the conditions prevailing today that are critical but rather those likely to prevail six to twelve months, or even longer, from now." Thus, in particular, the output gap forecast, $y_{t+4|t}$, is the one made at the beginning of quarter t for the same quarter of the following year and the inflation forecast, $\pi_{t+4|t}$, is a

[2] Tables and figures in the appendix show that results derived using CPI inflation resemble quite closely those obtained using PCE price inflation when the sample is abbreviated to run from 2000:1 through 2013:4, the period for which forecasts of both inflation measures are available.

forecast made at the beginning of quarter t of year-over-year inflation four quarters ahead. Additional results are also reported when $k = 2$, implying a two-quarter forecast horizon instead. Then, $y_{t+2|t}$ denotes the forecast made at the beginning of quarter t for the output gap two quarters ahead, and $\pi_{t+2|t}$ is the forecast made at the beginning of quarter t for year-over-year inflation between quarters $t - 2$ and $t + 2$.

Each series of k-quarter-ahead forecasts are compared to updated series for the same variables constructed k quarters later on the basis of updated information. For the output gap, $y_{t|t}$ corresponds to the Board's estimate of the output gap for quarter t made at the beginning of quarter t. For inflation, $\pi_{t|t}$ is constructed as the average of the Greenbook's projection of CPI inflation for the current quarter t and the Greenbook's "historical value" of inflation from the previous three quarters.[3] Note that even the historical values for CPI inflation may differ from those in the most recent vintage of data because of revisions made later; likewise, both revisions to the series for real GDP and shifting estimates of potential GDP imply that the Greenbook series for the "actual" output gap will differ from economists' best estimates of the output gap made today, with the benefit of additional information that has accumulated over the years since those initial estimates were made.

For simplicity, the discussion that follows refers to the series $y_{t|t-k}$ and $\pi_{t|t-k}$ as the "forecasts of the output gap and inflation for period t," while the series $y_{t|t}$ and $\pi_{t|t}$ are the updated "nowcasts" of the same variables. The changes in these series, denoted as $y_{t|t} - y_{t|t-k}$ and $\pi_{t|t} - \pi_{t|t-k}$, are "forecast revisions" made on the basis of information that accumulates between $t - k$ and t. These revisions also correspond to "forecast errors" made at $t - k$, computed using information available through t.

Focusing on the benchmark with year-ahead forecasts ($k = 4$), figure 1 plots these series. Table 2, meanwhile, reports descriptive statistics with $k = 4$ and $k = 2$ for the forecast revisions over the full sample period 1987:3 through 2013:4 and a shorter subsample that

[3] The "historical value" of CPI inflation three quarters ago is not reported in the Greenbooks from the first quarter of 1986, 1987, 1988, and 1999 and the fourth quarter of 2013. Thus, to construct $\pi_{t|t}$ for these five dates, the historical value for the relevant quarter shown in the previous Greenbook is used.

ends in 2007:4 to remove the influence of the financial crisis and Great Recession that followed. Though forecast revisions for both variables have means near zero, the graphs and summary statistics show that the initial forecasts have, at times, been subject to large errors. Even before the financial crisis, the absolute values of forecast errors were as large as 3 percentage points for the output gap and 2.5 percentage points for inflation. These results echo those from Meltzer (1987) and Sinclair, Joutz, and Stekler (2010), which show that the Fed often has difficulty discerning whether the economy will be experiencing a boom or recession one year ahead. When data from the financial crisis and its aftermath are added to the sample, the errors exceed six percentage points for the output gap and four percentage points for inflation. This increase in the magnitude of forecast errors over the extended sample is consistent with the transcripts of FOMC meetings from early 2008 that suggest the crisis was largely unanticipated. The Jarque-Bera statistics indicate that the data from the full sample also are characterized by significant skewness and kurtosis.[4]

More generally, in the bottom left-hand panel of figure 1, particularly large and negative forecast errors appear for the output gap during each of the recessions of 1990, 2001, and 2008, echoing results from Joutz and Stekler (2000) showing that the Fed consistently underestimated the severity and duration of recessions from 1965 through 1982. The bottom panels of table 2 show that forecast errors two quarters ahead ($k = 2$), though somewhat smaller than those four quarters ahead, remain sizeable and also exhibit significant departures from normality over the full sample running through 2013:4.

Whether and by how much these errors influence monetary policy decisions of the FOMC is unknown because, despite all of the research on monetary policy rules, it still is unknown whether target values for the funds rate are determined primarily by a rule, discretion, or some mix of the two. Nonetheless, both the Fed's statutory dual mandate and

[4] Since the Jarque-Bera statistic has an asymptotic chi-square distribution with two degrees of freedom, having a 5 percent critical value of approximately 6, under the null hypothesis that the errors are normally distributed, strictly speaking there is evidence of excess skewness and kurtosis in the inflation forecasts even in the sample that ends in 2007:4.

the Taylor (1993) Rule suggest that the funds rate target should be adjusted in response to movements in the output gap and the inflation rate. In this context, a forward-looking monetary policy process that acknowledges lags between a central bank's actions and the response of its goal variables would lead one to expect the FOMC to set the funds rate target with reference to forecasts of these variables. A monetary policy process of this type also would imply the use of Greenbook forecast values in lieu of actual or real-time data in any empirical exercise designed to estimate the Taylor Rule's coefficients or the implications of its use to conduct monetary policy.

As a first step in examining whether and how Greenbook forecasts may have been used by the FOMC, Table 3 presents results from Granger causality tests that assess the relationship between the federal funds rate and both Greenbook forecasts and the revisions to them. For the period 1987:3 – 2008:4, data on the federal funds rate are taken from the Federal Reserve Bank of St. Louis' FRED database, with each observation corresponding to the average value of the effective federal funds rate during the first month of the quarter. To extend the sample to cover the period from 2009:1 through 2013:4, when the FOMC's funds rate target was constrained by the zero lower interest rate bound, Wu and Xia's (2016) "shadow" federal funds rate series is used instead. This series, available through Jing Cynthia Wu's website, is derived using a model of the term structure of interest rates to estimate the effects that the FOMC's "unconventional" policy actions – both forward guidance regarding the future funds rate path and large-scale purchases of long-term U.S. Treasury and mortgage-backed securities – had on the entire yield curve. Wu and Xia (2016) show that their shadow rate displays correlations with macroeconomic variables over the zero-interest rate period similar to those seen between the federal funds rate and the same variables before 2009, suggesting that the shadow rate successfully proxies for the full effects of Federal Reserve policy though the end of the sample considered here.

In Table 3, reported *F*-statistics apply to the null hypothesis that, together, four lags of the independent variable are unhelpful in forecasting the dependent variable. With respect to the four-quarter ahead forecasts of the output gap and inflation, the first two rows of the table

show strong causation running from these forecast values to the funds rate. These results are consistent with the notion that the FOMC sets the funds rate with at least some reference to something like a Taylor Rule.[5] Since, as suggested by Tien, Sinclair, and Gamber (2018), errors in year-ahead forecasts of the output gap and inflation translate, in turn, into errors in the FOMC's setting for the funds rate, it also is of interest to ask whether there is any further evidence that the FOMC adjusts its funds rate target to compensate for these errors. Indeed, there is at least some. The third row of table 3 also shows that in the pre-crisis sample period, revisions to forecasts of the output gap, $y_{t|t} - y_{t|t-4}$, have strong predictive power for the funds rate.

The bottom rows of table 3, meanwhile, show weaker statistical relationships between two-quarters-ahead forecasts of the output gap and inflation and the federal funds rate. These results confirm that, as suggested by the Orphanides' (2001) quote from Alan Greenspan cited above, the FOMC makes its policy decisions looking more than six months ahead. With this in mind, the remainder of the paper focuses exclusively on the reaction of the federal funds rate to changes in year-ahead forecasts.

To distinguish further between the FOMC's use of forecasts and judgments in setting the funds rate target, Figure 2 plots the prescriptions of the Taylor (1993) Rule

$$r_t = 2 + \pi_{t+4|t} + 0.5(\pi_{t+4|t} - 2) + 0.5y_{t+4|t}$$

for the funds rate target r_t, using the year-ahead Greenbook forecasts as inputs for inflation and the output gap. In this standard form of the Taylor Rule, both the inflation target and the steady-state real rate of interest are assumed to equal 2 percent, and stabilization weights of 1.5 and 0.5 are attached to deviations of inflation from target and the output gap, respectively. As shown in the graph and as noted by Nikolsko-Rzhevskyy and Papell (2013), this original Taylor Rule, unlike other variants that place larger weights on the output gap, does not call for

[5] Faust and Wright (2008) emphasize that the Greenbook forecasts are conditioned on a pre-specified path for the federal funds rate, which may differ from the path that FOMC members actually expect the funds rate to follow. While this peculiar feature of the Greenbook forecasts raises complications for assessing their accuracy, the results obtained here affirm that changes in those forecasts nevertheless influence the FOMC's policy decisions.

deeply negative nominal interest rates during or after the financial crisis; Nikolsko-Rzhevskyy and Papell also emphasize that this version of the Taylor Rule is the one preferred strongly by John Taylor himself.

Figure 2 shows that, up through 2009:1 when the zero lower bound was reached, the forecast-based Taylor Rule's prescriptions share a pattern generally similar to that of realized values for the funds rate. Over the 1987:3-2008:4 period, the average deviation between the two series is less than 15 basis points. In addition, over both the full sample and the pre-crisis subsample, the Granger causality tests from table 3 show a strong tendency for the federal funds rate to move towards the value indicated by the Taylor Rule. Together, these results again suggest that the Greenbook forecasts are important inputs to the FOMC's policy decisions and appear to be used in a policy framework that is in the spirit of the Taylor Rule.[6]

Differences between the two series illustrated in the bottom panel of figure 2, however, highlight features masked to some degree by their shared broad movements. First, over the 1987:3-2013:4 sample period, the actual federal funds rate at times rises more than 3 percentage points above and falls nearly 4 percentage points below the Taylor Rule values. The standard deviation of the difference between the two series is almost exactly 1.25 percentage points. Second, the deviations display a distinct cyclical pattern. Extended periods during which the FOMC held the funds rate below the level prescribed by the Taylor Rule appear after each of the three recessions of 1990-1991, 2001, and 2007-2009. This shared pattern suggests that Taylor's (2009) critique of the Fed for holding interest rates "too low for too long" after the 2001 recession extends to the FOMC's decisions following the other two downturns as well.

Even more striking, each of the three recessions included in the sample is preceded by settings for the funds rate that are substantially above those implied by the Taylor Rule based

[6] Asso, Kahn, and Leeson (2010) find numerous references to the Taylor Rule in FOMC transcripts beginning in 1995; the causality test results here confirm their intuition that these references did indeed help shape the Committee's decisions for setting the funds rate, even though as Asso, Kahn, and Leeson also emphasize, some Committee members remained hesitant to follow the strict prescriptions of the Rule.

on Greenbook forecasts. Table 3 shows, in fact, that there is a highly significant statistical connection between lagged values of deviations from the Taylor Rule and business cycle peaks as identified by the National Bureau of Economic Research.[7] The reason the values for the two funds rate series diverge so sharply can be seen in the top panel of figure 2, where the funds rate under the Greenbook version of the Taylor Rule begins to decline several periods before each business cycle peak. If deviations from the Taylor Rule are interpreted as periods where the FOMC emphasized discretionary judgments to determine the most appropriate stance of monetary policy, these observations suggest that judgmental deviations have tended to amplify, rather than stabilize, cyclical fluctuations. And to the extent that policy decisions made under discretion are destabilizing, it appears as if the FOMC might be better-served by responding to signals of emerging macroeconomic strength and weakness that <u>are</u> embodied in Greenbook forecasts to achieve its stabilization objectives more reliably. In other words, Greenbook forecasts, despite their tendency to not fully anticipate the depth and duration of recessions, might nevertheless serve more reliably as guides for systematic policy as prescribed by the Taylor Rule.

3. An Estimated Greenbook Forecast-Based Taylor Rule with Time-Varying Parameters

Belongia and Ireland (2016), using a Bayesian vector autoregression with time-varying parameters estimated with the most recent vintage of <u>ex post</u> data on inflation and the output gap, find evidence of shifting emphasis away from inflation towards output gap stabilization as well as departures from rule-like behavior over the period from 2000 through 2007. The same methods, adapted from Cogley and Sargent (2005) and Primiceri (2005), can be applied to detect shifting policy priorities based on an estimated Greenbook forecast-based version of the

[7] These business cycle dates are tabulated on the NBER's own website and also can be downloaded from the FRED database. The finding, in table 3, of a statistically significant link between Taylor Rule deviations and business cycle peaks depends partly, but not entirely, on observations surrounding the 2001 recession. In particular, when the sample is broken up into three subsamples, 1987:3 – 1999:4, 1992:1 – 2005:4, and 2002:1 – 2014:4, and the Granger causality tests re-run using two lags of each variable to accommodate the smaller number of observations, the Taylor rule deviations help predict, at the 95 percent confidence level, the recessions of 2001 and 2008, though not the recession of 1990, individually.

Taylor Rule with time-varying parameters and stochastic volatility.[8,9] The estimated rule takes the form

$$r_t = b_t + b_{\pi,t}\pi_{t+4|t} + b_{y,t}y_{y+4|t} + b_{r,t}r_{t-1} + \sigma_t\xi_t,$$

where, as above, r_t denotes the federal funds rate at the beginning of period t and $\pi_{t+4|t}$ and $y_{t+4|t}$ are one-year-ahead Greenbook forecasts for inflation and the output gap made at the beginning of period t. The serially uncorrelated shock ξ_t has the standard normal distribution; hence, σ_t denotes the time-varying volatility of deviations from this estimated rule. The specification also allows for interest-rate smoothing, captured by the term involving the lagged funds rate on the right-hand side, to account for the gradual adjustment of the funds rate back to the target implied by the original Taylor (1993) Rule seen in figure 2. Here, as in Boivin (2006), the identifying assumption that allows this estimated equation to be interpreted as describing the FOMC's policy response to changing macroeconomic conditions is that the shock ξ_t is uncorrelated with the Greenbook forecasts $\pi_{t+4|t}$ and $y_{t+4|t}$. This assumption would hold if, for example, Greenbook forecasts for period t are assembled without knowledge of the FOMC's judgmental deviation from the time-varying rule in the same period t.[10]

The four time-varying coefficients from this policy rule are collected into the 4x1 vector

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[8] In commenting on earlier work by Cogley and Sargent (2001), Sims (2001) and Stock (2001) both emphasize the need to allow simultaneously for time-varying parameters and stochastic volatility to disentangle the effects of both sources of changing dynamics on macroeconomic time series.

[9] An extensive literature, beginning with Clarida, Gali, and Gertler (2000), looks for evidence of time-variation in the parameters of estimated Taylor Rules. Most closely related to the present study, Boivin (2006) and Murray, Nikolsko-Rzhevskyy, and Papell (2015) use Greenbook forecasts to estimate forward-looking versions of the rule to detect shifts that are more complex or subtle than the one-time change in 1979 considered by Clarida, Gali, and Gertler (2000). Boivin (2006) estimates a model with continuous parameter drift using data that run from 1969 through 1998; the analysis here can viewed as extending his analysis to cover the period from 1987 through 2013. Murray, Nikolsko-Rzhevskyy, and Papell (2015) estimate a Markov-switching model that identifies, among others, a single regime covering the most recent period from 1985 through 2007. By allowing for continuous parameter drift over the same interval, the model used here can characterize more sharply the short-lived but recurring changes in policy that, in Figure 2, appear to have occurred around business cycle turning points.

[10] In particular, the assumption becomes more likely to hold if, as noted earlier, the Greenbook forecasts are conditioned on a pre-specified path for the funds rate, not the path actually chosen by the FOMC.

$$B_t = [b_t \quad b_{\pi,t} \quad b_{y,t} \quad b_{r,t}]',$$

which is assumed to follow a random walk

$$B_t = B_{t-1} + \nu_t,$$

where the vector of innovations ν_t is normally distributed, independently of ξ_t, with mean zero and covariance matrix Q. The log of the time-varying volatility parameter also follows a random walk,

$$\log \sigma_t = \log \sigma_{t-1} + \eta_{t,}$$

where η_t is normally distributed, independently from both ξ_t and ν_t, with mean zero and variance ω. Normal priors for the initial values

$$B_0 \sim N(B, 4V_B)$$

and

$$\log \sigma_0 \sim N(\log 0.25\,, 1),$$

and inverse Wishart priors for Q and ω,

$$Q \sim IW(5k_Q^2 V_B, 5)$$

and

$$\omega \sim IW(2k_W^2, 2),$$

are calibrated by setting

$$B = [b \quad b_\pi \quad b_y \quad b_r] = [0.50 \quad 0.75 \quad 0.25 \quad 0.50]',$$

$$V_B = \begin{bmatrix} 0.250^2 & 0 & 0 & 0 \\ 0 & 0.375^2 & 0 & 0 \\ 0 & 0 & 0.250^2 & 0 \\ 0 & 0 & 0 & 0.250^2 \end{bmatrix},$$

$k_Q = 0.00035^{1/2}$, and $k_W = 0.02$.

The prior mean B for B_0 implies long-run coefficients $b_\pi/(1-b_r)$ and $b_y/(1-b_r)$ on inflation and the output gap equal to the values 1.5 and 0.5 that appear in the original Taylor (1993) Rule and an intercept term consistent with earlier assumptions that the steady-state real interest rate and inflation target both equal 2 percent. The diagonal elements of V_B then imply that the prior standard deviation of each element of B_0 equals its prior mean. The prior mean for log σ_0 is based on the notion that typical deviations from the time-varying rule should be of

magnitude similar to 0.25 percentage points, though the large prior variance admits considerable uncertainty regarding the scale of these deviations. Finally, while the setting for k_Q is taken directly from Cogley and Sargent (2005), the slightly larger value k_W was chosen to allow for the possibility of greater time variation in the shock volatility parameter.

Together with these priors, quarterly data are fed through a "Metropolis-within-Gibbs" sampling algorithm to draw blocks of parameters from their conditional posterior distributions. First, the multi-move routine outlined by Carter and Kohn (1994) and Fruhwirth-Schnatter (1994) generates draws for the sequence of coefficients in B_t. Next, Kim, Shephard, and Chib's (1998) algorithm, which approximates the true, log chi-squared distribution for each of the volatility coefficients with a mixture of seven normal distributions, yields a sequence of draws for σ_t. Within this algorithm, the state variable selecting the specific normal distribution from which each parameter is drawn gets sampled before the value for the volatility parameter itself; Del Negro and Primiceri (2015) emphasize the importance of this ordering of the steps. Also as suggested by Del Negro and Primiceri (2015), a Metropolis-Hastings step is added to this part of the algorithm to account for the error between the true distribution of the volatility parameters and the mixture-of-normals approximation. Finally, updated draws for the parameters in Q and ω are taken from their inverse Wishart conditional posterior distributions.

After a burn-in period consisting of 1 million sweeps through this algorithm, the results are based on a sampling phase in which draws from one out of every ten of the next 2.5 million sweeps are saved, making a total of 250,000 draws for each parameter. Convergence and adequate mixing of the Markov Chain Monte Carlo scheme is verified by initializing the algorithm from different randomly chosen starting points to confirm that none of the results is affected and, more formally, by monitoring the convergence diagnostic and relative numerical efficiency statistics described by Geweke (1992).

Figure 3 illustrates how each parameter is estimated to vary over the 1987:2 – 2007:4 subsample, truncated to avoid potential distortions associated with the zero lower interest rate bound. In panels from the top three rows, solid blue lines track the median of the posterior distributions and dashed red lines show the associated 16-84 percentile bands. Despite

allowing for the possibility of more substantial stochastic volatility through the larger setting for k_W, the shock volatility coefficient σ_t appears very stable over the entire sample period, following a smooth and very slight downward trend from 0.17 in 1987:3 to 0.16 in 2007:4. Graphs in the bottom row of figure 3 show how time variation in the estimated response coefficients work to make the estimated Taylor Rule track the actual funds rate extremely closely, with deviations that are small and serially uncorrelated, rarely exceeding 25 basis points in absolute magnitude. Patterns in the estimated response coefficients, however, display time variation that adds detail to the Granger causality test results discussed in the previous section.

Specifically, the top two panels of Figure 3 reveal a consistent pattern according to which the FOMC's immediate concern for movements in the output gap forecast, as measured by the response parameter $b_{y,t}$, increases relative to its concern for inflation, as measured by $b_{\pi,t}$, shortly before, during, and after each of the last three recessions. The left-hand panel of the middle row shows, however, that the estimated interest-smoothing parameter $b_{r,t}$ also exhibits marked declines during the same episodes, so that in the bottom row, the implied long-run responses $b_{\pi,t}/(1- b_{r,t})$ and $b_{y,t}/(1- b_{r,t})$ to <u>both</u> inflation and output forecasts decline as well.

Table 4 summarizes the changes in the impact and long-run coefficients estimated to have occurred, from peak to trough, during the 1990 and 2000 recessions. Median estimates of each parameter at each date are shown, together with the posterior probability that the parameter declines from the date of the peak to the date of the trough. The numbers confirm that while the changes in the impact coefficients are modest, they are magnified by larger declines in the interest-rate smoothing parameter, so that with a high degree of statistical confidence, the total, long-run responses of the funds rate to changes in the output gap and, especially, inflation can be said to be much smaller during than just before both recessions.

These results reinforce the impression, gleaned from Figure 2, that by hesitating to respond to signs of weakness in the economy just prior to the onset of recessions, and then by

failing to raise rates more quickly in response to an improving economy during recoveries, the FOMC may have worked to amplify, rather than ameliorate, business cycle fluctuations. Hetzel (2012) characterizes the Federal Reserve's "stop-go" policies of the 1960s and 1970s in similar terms, with the FOMC's practice of keeping the federal funds rate elevated after cyclical peaks constituting the "stop" phase and then holding the funds rate down following cyclical troughs as representing the "go" phase. Meltzer (1991) characterizes the monetary policy of the 1960s and 1970s in similar fashion with special emphasis on the practices that led, in his analysis, to a procyclical policy that exacerbated business cycle fluctuations. Finally, Meltzer (2005, p.155) quotes Atlanta Federal Reserve Bank President Malcom Bryan, who recognized as early as 1961 the FOMC's tendency "to overstay our position of tightness and be too tight, and then to overstay our position of ease and be too easy." To eliminate the vestiges of stop-go that come to light here, the results suggest, once again, that there may be gains to the Fed from adhering to an unchanging interest rate rule like Taylor's (1993), with response coefficients on inflation and the output gap that remain constant over the business cycle.[11]

Figure 4 and the bottom panel of table 4 show and summarize results when the time-varying Taylor Rule is estimated over the full sample period, with the Wu-Xia shadow funds rate replacing the actual funds rate from 2009:1 through 2013:4. For the period covered previously, in figure 3, the volatility and response coefficients display very similar patterns when re-estimated in figure 4. For the more recent period beginning in 2009:1, the estimated impact coefficients on both the output gap and inflation decline noticeably, while the interest rate smoothing coefficient rises. If, in this context, the Wu-Xia shadow rate accurately captures deliberate adjustments to monetary policy made through forward guidance and

[11] A more detailed, structural model of the macroeconomy would be needed to provide a complete, quantitative analysis of the counterfactual scenario in which the FOMC abandoned discretion entirely and adhered, instead, to the strict prescriptions of a Taylor Rule with constant response coefficients on inflation and output gap forecasts. That same structural model also could be used to characterize a fully optimal monetary policy rule that might differ in important ways from Taylor's (1993) original specification. The adoption of a constant coefficient benchmark rule analysis here, however, deliberately avoids imposing the restrictive and potentially controversial assumptions required to construct and estimate a structural model of that kind and still suggests that better macroeconomic performance could have been achieved by closer adherence to that benchmark rule.

quantitative easing, these results suggest that those policy actions were "unconventional" not only in their mechanics but also in the extent to which they responded only weakly to changes in the Fed's own forecasts of the output gap and inflation. Again, this raises the question of whether better macroeconomic outcomes could have been achieved through closer adherence to the original Taylor Rule.

4. Conclusion

Although the Federal Reserve has never officially outlined the details of its policymaking strategy, in practice FOMC members appear to base their decisions on a mixture of forecasts prepared by research staff at the Federal Reserve Board and their own personal judgments. Results presented here confirm that the Fed's Greenbook forecasts for the output gap and inflation exert a significant influence on the FOMC's settings for the federal funds rate target, and that revisions to or errors in these forecasts have, at times, prompted subsequent adjustments to the target.

While the FOMC's policy response to both inflation and a measure of real economic activity is consistent with the Fed's statutory dual mandate and the prescriptions of a Taylor Rule, comparisons between the actual federal funds rate and the values predicted by a Taylor Rule based on Greenbook forecasts occasionally reveal substantial deviations between the two, presumably reflecting the use of judgment or discretion by the FOMC Chair and the Committee's individual members. Over a period spanning 1987 through 2013, these deviations display a consistent cyclical pattern, according to which the FOMC holds the funds rate below the value prescribed by the Taylor Rule during expansions and above the value prescribed by the Rule as the Greenbook forecasts signal weakness before business cycle peaks.

Estimates of an interest rate rule with time-varying parameters indicate that these deviations reflect an underlying hesitancy for the FOMC to adjust its federal funds rate target in response to changing economic conditions both before and after recessions, behavior reminiscent of the more extreme, "stop-go" policies of the 1960s and 1970s. These observations suggest that if the Fed retains its current approach to monetary policymaking, in

which Greenbook forecasts serve as inputs to the process for setting a target for the federal funds rate, the FOMC would achieve better stabilization outcomes by placing more weight on the Greenbook's assessments of changing economic conditions and less weight on its own individual judgments. In this sense, the results offer support to one component of recently proposed legislation that would require the FOMC to make its policy decisions with more consistent reference to a form of the Taylor Rule with more stable coefficients.

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Table 1. Summary of Notation

$y_{t+k\mid t}$	Greenbook forecast at t of the output gap at $t+k$
$y_{t+4\mid t}$	Forecast at t of the output gap at $t+4$
$y_{t\mid t-4}$	Forecast at $t-4$ of the output gap at t
$y_{t\mid t}$	Nowcast at t of the output gap at t
$y_{t\mid t}-y_{t\mid t-4}$	Forecast revision/error between $t-4$ and t of the output gap at t
$y_{t+2\mid t}$	Forecast at t of the output gap at $t+2$
$y_{t\mid t-2}$	Forecast at $t-2$ of the output gap at t
$y_{t\mid t}-y_{t\mid t-2}$	Forecast revision/error between $t-2$ and t of the output gap at t
$\pi_{t+k\mid t}$	Greenbook forecast at t of inflation between $t+k-4$ and $t+k$
$\pi_{t+4\mid t}$	Forecast at t of inflation between t and $t+4$
$\pi_{t\mid t-4}$	Forecast at $t-4$ of inflation between $t-4$ and t
$\pi_{t\mid t}$	Nowcast at t of inflation between $t-4$ and t
$\pi_{t\mid t}-\pi_{t\mid t-4}$	Forecast revision/error between $t-4$ and t of inflation between $t-4$ and t
$\pi_{t+2\mid t}$	Forecast at t of inflation between $t-2$ and $t+2$
$\pi_{t\mid t-2}$	Forecast at $t-2$ of inflation between $t-4$ and t
$\pi_{t\mid t}-\pi_{t\mid t-2}$	Forecast revision/error between $t-2$ and t of inflation between $t-4$ and t

Table 2. Descriptive Statistics for Greenbook Nowcast-Forecast Revisions

	Sample	
	1987:3 – 2013:4	1987:3 – 2007:4
Output Gap Revisions: Four Quarters Ahead		
Mean	–0.16	0.06
Standard Deviation	1.49	1.27
Maximum	2.80	2.80
Minimum	–6.10	–3.10
Jarque-Bera Statistic	41.36***	3.90
CPI Inflation Revisions: Four Quarters Ahead		
Mean	0.22	0.22
Standard Deviation	1.13	0.91
Maximum	3.15	2.68
Minimum	–4.03	–1.33
Jarque-Bera Statistic	18.88***	8.96**
Output Gap Revisions: Two Quarters Ahead		
Mean	–0.03	0.06
Standard Deviation	0.93	0.82
Maximum	2.00	2.00
Minimum	–3.60	–2.30
Jarque-Bera Statistic	19.96***	2.41
CPI Inflation Revisions: Two Quarters Ahead		
Mean	0.13	0.14
Standard Deviation	0.84	0.63
Maximum	2.03	1.68
Minimum	–4.40	–1.43
Jarque-Bera Statistic	240.45***	2.50

Note: Superscripts *** and ** indicate that the Jarque-Bera statistic rejects the null hypothesis of no excess skewness and kurtosis at the 0.01 and 0.05 significance levels.

Table 3. Patterns of Granger Causality Between Greenbook Forecasts, Forecast-Nowcast Revisions, and the Federal Funds Rate

Dependent Variable	Independent Variable	Sample 1987:3 – 2013:4	Sample 1987:3 – 2007:4
Forecasts Four Quarters Ahead			
Federal Funds Rate	Output Gap Forecast	3.80***	8.64***
Federal Funds Rate	CPI Inflation Forecast	3.61***	3.29**
Federal Funds Rate	Output Gap Revision	1.29	4.48***
Federal Funds Rate	CPI Inflation Revision	0.18	0.54
Federal Funds Rate	Taylor Rule	7.61***	11.56***
NBER Peak	Taylor Rule Deviation	3.09**	2.71**
Forecasts Two Quarters Ahead			
Federal Funds Rate	Output Gap Forecast	4.10***	8.00***
Federal Funds Rate	CPI Inflation Forecast	0.19	0.48
Federal Funds Rate	Output Gap Revision	1.21	3.36**
Federal Funds Rate	CPI Inflation Revision	0.56	0.96
Federal Funds Rate	Taylor Rule	0.74	2.84**
NBER Peak	Taylor Rule Deviation	1.60	2.28*

Notes: Granger causality tests are based on a regression of the dependent variable on four of its own quarterly lags and four quarterly lags of the independent variable. The table shows the *F*-statistic for the null hypothesis that the coefficients on the independent variable are all zero; superscripts ***, **, and * indicate that the null hypothesis of no Granger causality is rejected at the 0.01, 0.05, and 0.10 significance levels.

Table 4. Time Variation in Taylor Rule Parameters

	b_π	b_y	b_r	$b_\pi/(1-b_r)$	$b_y/(1-b_r)$
1987:3 – 2007:4 Sample					
1990:2	0.34	0.15	0.80	1.71	0.77
1991:1	0.31	0.17	0.74	1.17	0.65
Pr(1990:2 > 1991:1)	0.81	0.25	0.94	0.96	0.74
2000:4	0.32	0.15	0.83	1.91	0.89
2001:4	0.22	0.20	0.65	0.61	0.55
Pr(2000:4 > 2001:4)	0.82	0.23	0.97	0.98	0.78
1987:3 – 2013:4 Sample					
1990:2	0.31	0.11	0.83	1.82	0.65
1991:1	0.29	0.13	0.74	1.12	0.49
Pr(1990:2 > 1991:1)	0.59	0.16	0.99	0.99	0.81
2000:4	0.28	0.10	0.87	2.21	0.83
2001:4	0.23	0.15	0.63	0.62	0.40
Pr(2000:4 > 2001:4)	0.57	0.16	0.99	0.99	0.84
2007:3	0.26	0.10	0.86	1.90	0.78
2009:2	0.23	0.11	0.78	1.08	0.50
Pr(2007:3 > 2009:2)	0.61	0.38	0.80	0.81	0.69

Notes: Entries show the median of the posterior distribution for the impact coefficients b_π and b_y on inflation and the output gap, the interest rate smoothing coefficient b_r, and the long-run response coefficients $b_\pi/(1-b_r)$ and $b_y/(1-b_r)$ to inflation and the output gap at the indicated dates, as well as the posterior probability that the parameter on the date just before the recession is greater than the same parameter at the end of the recession.

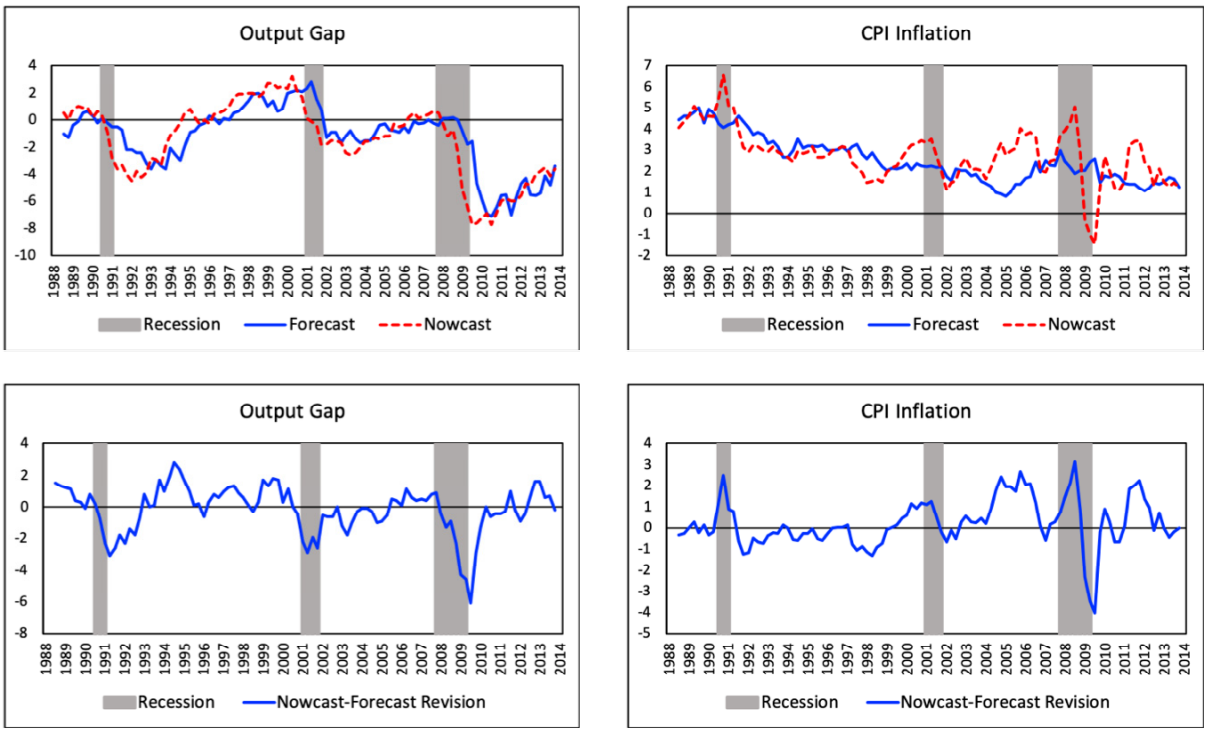

Figure 1. Greenbook Forecasts, Nowcasts, and Nowcast-Forecast Revisions. Forecasts of the output gap and year-over-year CPI inflation for quarter *t* are made in quarter *t* –4; nowcasts for quarter *t* are made in quarter *t*; revisions correspond to the difference between the two. Recessions, as identified by the NBER, are shaded in gray.

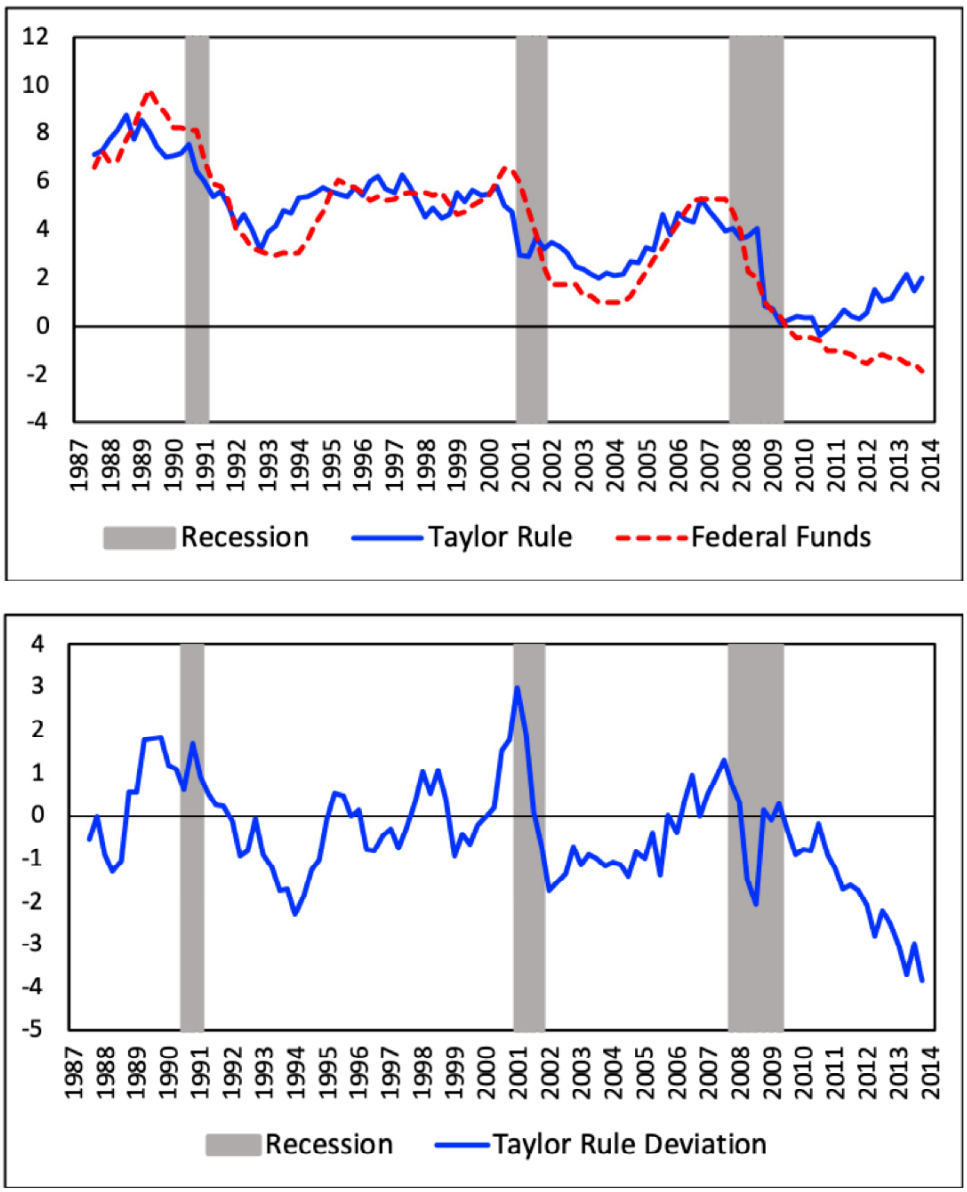

Figure 2. Greenbook Forecast-Based Taylor Rule and Deviations. The top panel compares the setting for the federal funds rate prescribed by a version of the Taylor (1993) Rule, using year-ahead Greenbook forecasts for the output gap and CPI inflation, to the actual federal funds rate or, after 2008, the Wu-Xia (2016) shadow federal funds rate. The bottom panel plots the difference between the actual funds rate and the value indicated by the Taylor Rule. Recessions, as identified by the NBER, are shaded in gray.

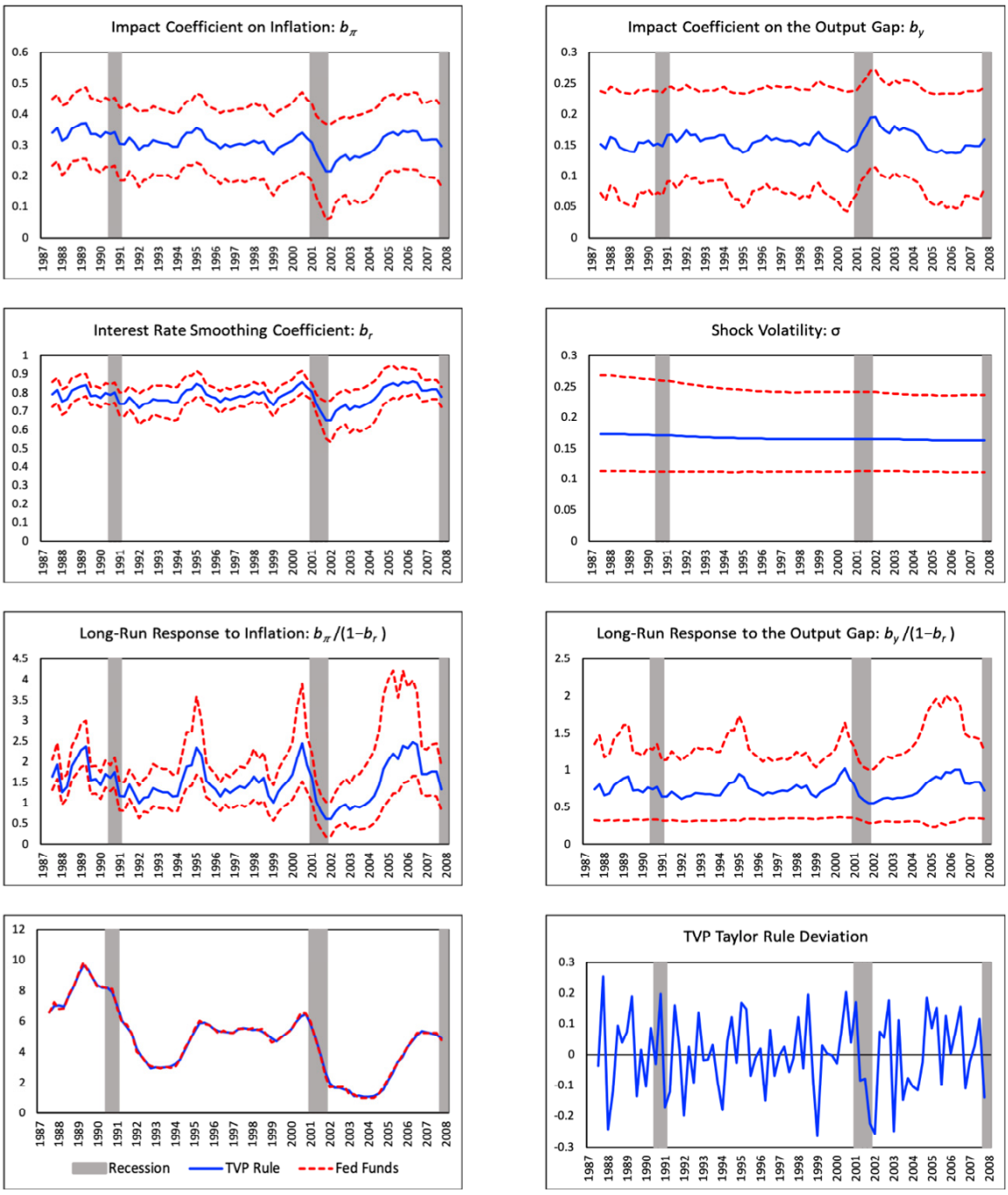

Figure 3. Time-Varying Parameters from an Estimated Greenbook Forecast-Based Taylor Rule: 1987:3 – 2007:4. Each panel in the top three rows shows the median (solid blue line) and 16th and 84th percentiles (dashed red lines) for the indicated parameter at the indicated date. The panel on the bottom left compares the setting for the federal funds rate implied by the median parameter estimates of the time-varying Taylor Rule to the actual federal funds rate; the panel on the bottom right shows the difference between the actual funds rate and the value indicated by the time-varying rule. Recessions, as identified by the NBER, are shaded in gray.

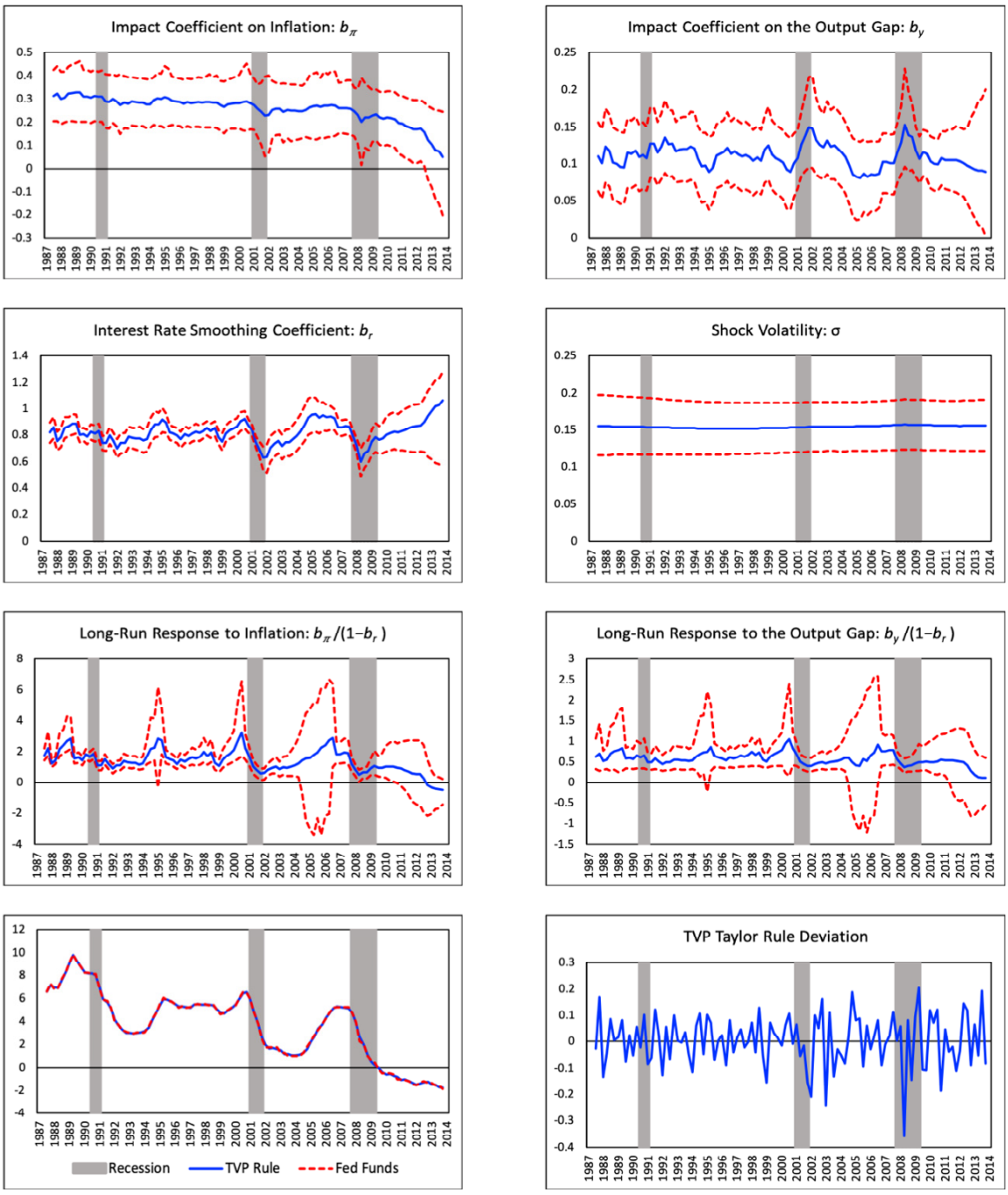

Figure 4. Time-Varying Parameters from an Estimated Greenbook Forecast-Based Taylor Rule: 1987:3 – 2013:4. Each panel in the top three rows shows the median (solid blue line) and 16th and 84th percentiles (dashed red lines) for the indicated parameter at the indicated date. The panel on the bottom left compares the setting for the federal funds rate implied by the median parameter estimates of the time-varying Taylor Rule to the actual federal funds rate; the panel on the bottom right shows the difference between the actual funds rate and the value indicated by the time-varying rule. Recessions, as identified by the NBER, are shaded in gray.

Appendix

This appendix contains additional tables and figures, showing that statistical results obtained using CPI inflation resemble those using PCE price inflation instead, when each of the models from the paper is re-estimated over the sample period from 2000:1 through 2013:4 for which Greenbook forecasts of both measures of inflation are available.

Table A1. Descriptive Statistics for Greenbook Nowcast-Forecast Revisions

	Sample	
	2000:1 – 2013:4	2000:1 – 2007:4
CPI Inflation Revisions: Four Quarters Ahead		
Mean	0.59	0.84
Standard Deviation	1.32	0.88
Maximum	3.15	2.68
Minimum	–4.03	–0.65
Jarque-Bera Statistic	26.12***	1.25
PCE Inflation Revisions: Four Quarters Ahead		
Mean	0.36	0.56
Standard Deviation	1.00	0.75
Maximum	2.20	2.03
Minimum	–3.20	–0.85
Jarque-Bera Statistic	17.18***	1.19
CPI Inflation Revisions: Two Quarters Ahead		
Mean	0.31	0.48
Standard Deviation	1.02	0.66
Maximum	2.03	1.60
Minimum	–4.40	–1.43
Jarque-Bera Statistic	131.13***	4.08
PCE Inflation Revisions: Two Quarters Ahead		
Mean	0.18	0.30
Standard Deviation	0.75	0.57
Maximum	1.45	1.45
Minimum	–3.20	–1.05
Jarque-Bera Statistic	102.96***	1.13

Note: Superscripts *** and ** indicate that the Jarque-Bera statistic rejects the null hypothesis of no excess skewness and kurtosis at the 0.01 and 0.05 significance levels.

Table A2. Patterns of Granger Causality Between Greenbook Forecasts, Forecast-Nowcast Revisions, and the Federal Funds Rate

Dependent Variable	Independent Variable	Sample 2000:1 – 2013:4	Sample 2000:1 – 2007:4
Forecasts Four Quarters Ahead			
Federal Funds Rate	Output Gap Forecast	2.08*	1.28
Federal Funds Rate	CPI Inflation Forecast	3.89***	4.38**
Federal Funds Rate	PCE Inflation Forecast	3.44**	5.67***
Federal Funds Rate	Output Gap Revision	0.67	0.72
Federal Funds Rate	CPI Inflation Revision	0.61	3.81**
Federal Funds Rate	PCE Inflation Revision	0.50	3.23**
Federal Funds Rate	Taylor Rule (CPI)	2.88**	5.68***
Federal Funds Rate	Taylor Rule (PCE)	2.23*	5.86***
NBER Peak	Taylor Rule Deviation (CPI)	3.81***	3.81**
NBER Peak	Taylor Rule Deviation (PCE)	3.55**	4.18**
Forecasts Two Quarters Ahead			
Federal Funds Rate	Output Gap Forecast	1.55	1.17
Federal Funds Rate	CPI Inflation Forecast	0.11	1.25
Federal Funds Rate	PCE Inflation Forecast	0.21	3.13**
Federal Funds Rate	Output Gap Revision	0.15	0.38
Federal Funds Rate	CPI Inflation Revision	0.53	2.97**
Federal Funds Rate	PCE Inflation Revision	0.80	2.08
Federal Funds Rate	Taylor Rule (CPI)	0.18	1.22
Federal Funds Rate	Taylor Rule (PCE)	0.25	4.27**
NBER Peak	Taylor Rule Deviation (CPI)	0.85	2.00
NBER Peak	Taylor Rule Deviation (PCE)	1.25	2.28*

Notes: Granger causality tests are based on a regression of the dependent variable on four of its own quarterly lags and four quarterly lags of the independent variable. The table shows the *F*-statistic for the null hypothesis that the coefficients on the independent variable are all zero; superscripts ***, **, and * indicate that the null hypothesis of no Granger causality is rejected at the 0.01, 0.05, and 0.10 significance levels.

Table A3. Time Variation in Taylor Rule Parameters

2001:1 – 2013:3 Sample	b_π	b_y	b_r	$b_\pi/(1-b_r)$	$b_y/(1-b_r)$
CPI Inflation					
2000:4	0.25	0.10	0.88	2.08	0.87
2001:4	0.13	0.13	0.66	0.37	0.38
Pr(2000:4 > 2001:4)	0.72	0.24	0.99	0.95	0.88
2007:3	0.24	0.10	0.87	1.87	0.82
2009:2	0.20	0.10	0.81	0.97	0.49
Pr(2007:3 > 2009:2)	0.65	0.49	0.74	0.75	0.68
PCE Inflation					
2000:4	0.27	0.09	0.89	2.43	0.88
2001:4	0.15	0.12	0.67	0.46	0.36
Pr(2000:4 > 2001:4)	0.75	0.26	0.99	0.94	0.85
2007:3	0.25	0.10	0.87	1.96	0.77
2009:2	0.20	0.09	0.81	0.96	0.43
Pr(2007:3 > 2009:2)	0.68	0.52	0.73	0.75	0.66

Notes: Entries show the median of the posterior distribution for the impact coefficients b_π and b_y on inflation and the output gap, the interest rate smoothing coefficient b_r, and the long-run response coefficients $b_\pi/(1-b_r)$ and $b_y/(1-b_r)$ to inflation and the output gap at the indicated dates, as well as the posterior probability that the parameter on the date just before the recession is greater than the same parameter at the end of the recession.

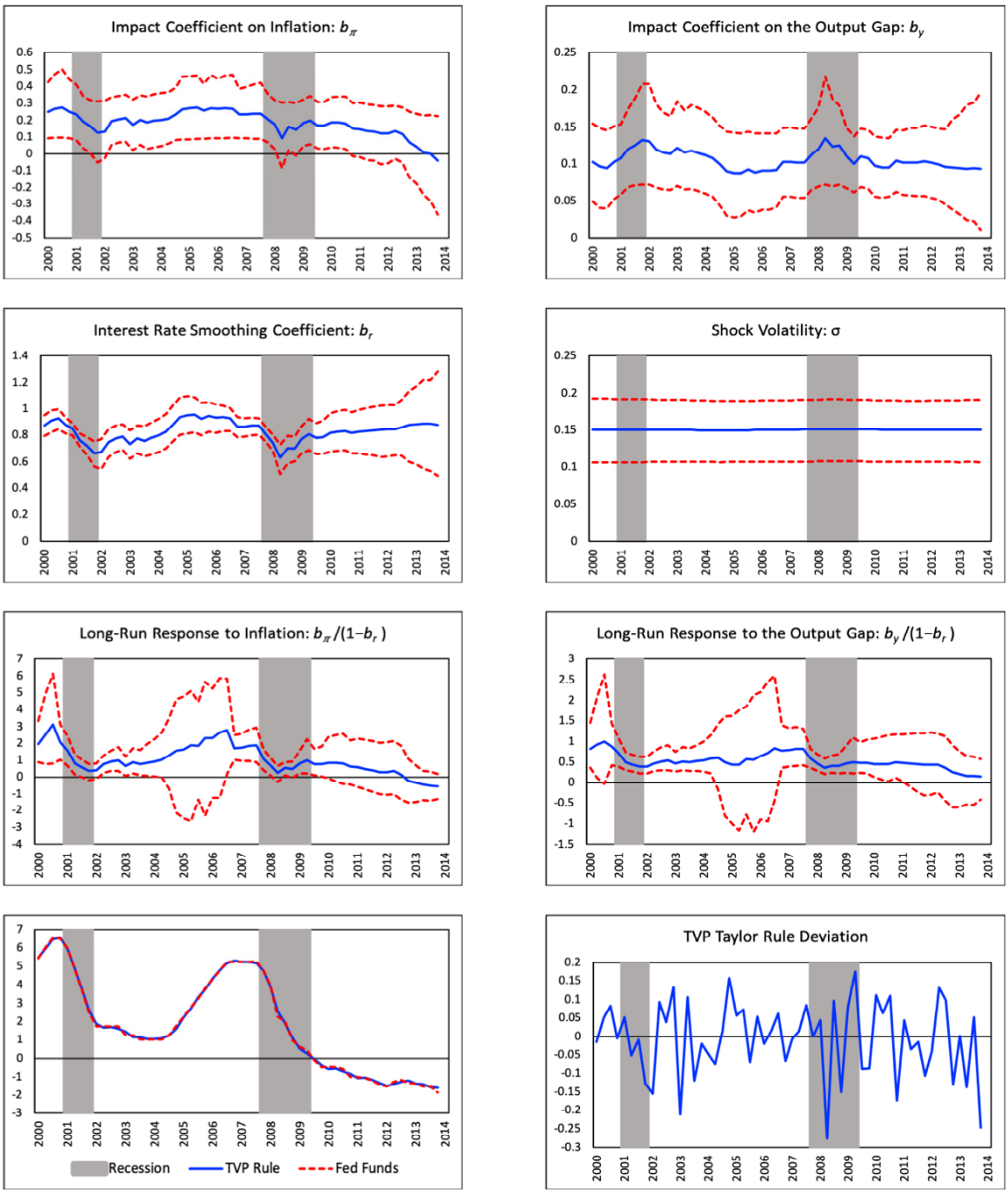

Figure A1. Time-Varying Parameters from an Estimated Greenbook Forecast-Based Taylor Rule: 2000:1 – 2013:4. Inflation is measured using the CPI. Each panel in the top three rows shows the median (solid blue line) and 16th and 84th percentiles (dashed red lines) for the indicated parameter at the indicated date. The panel on the bottom left compares the setting for the federal funds rate implied by the median parameter estimates of the time-varying Taylor Rule to the actual federal funds rate; the panel on the bottom right shows the difference between the actual funds rate and the value indicated by the time-varying rule. Recessions, as identified by the NBER, are shaded in gray.

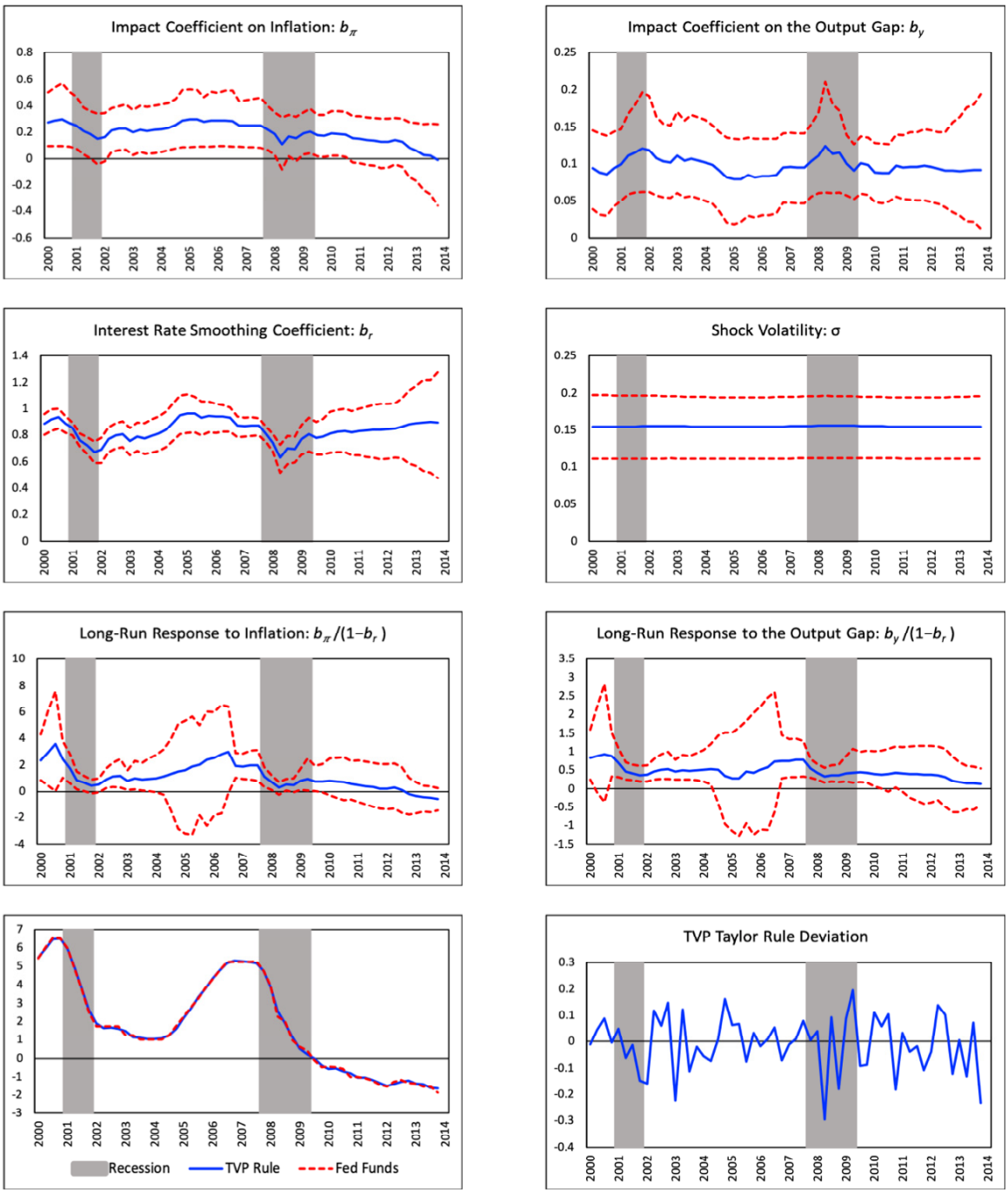

Figure A2. Time-Varying Parameters from an Estimated Greenbook Forecast-Based Taylor Rule: 2000:1 – 2013:4. Inflation is measured using the PCE price index. Each panel in the top three rows shows the median (solid blue line) and 16th and 84th percentiles (dashed red lines) for the indicated parameter at the indicated date. The panel on the bottom left compares the setting for the federal funds rate implied by the median parameter estimates of the time-varying Taylor Rule to the actual federal funds rate; the panel on the bottom right shows the difference between the actual funds rate and the value indicated by the time-varying rule. Recessions, as identified by the NBER, are shaded in gray.