Nowcasting and the Taylor Rule

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Abstract

Actual federal funds rates in the U.S. have, at times, deviated from the recommendations of a simple Taylor rule. This paper proposes a "nowcasting" Taylor rule that preserves the form of the Taylor rule but encompasses realistic assumptions on information observable to policymakers. Because contemporaneous inflation rates and output gaps are not observable at the time policy is set, policymakers must form "nowcasts." The optimal nowcast will depend, in part, on forecast uncertainty whenever policymakers' have asymmetric costs to over- and under-predicting inflation and output. This paper estimates nowcasts and forecast uncertainty from the probability forecasts in the Survey of Professional Forecasters. Empirical evidence shows that actual policy rates are consistent with those recommended by a nowcasting Taylor rule.

JEL Classifications: G12; G14; D82; D83
Key Words: Nowcasting, asymmetric loss, forecast uncertainty, monetary policy.

1 Introduction

As macroeconomic research has increasingly stressed the benefits of rules-based monetary policy, the Taylor (1993) rule has become the standard against which historical monetary policies have been judged. The Taylor rule provides a simple guide to monetary policymakers: the federal funds rate should be adjusted in response to deviations of the contemporaneous inflation rate from its long-run target and the output gap (i.e. deviations of contemporaneous output, in percentage points, from potential output).[1] Research that estimates Taylor rules with historical data finds coefficient estimates in line with the Taylor (1993) rule.[2] However, the historical fit of the Taylor rule features a number of departures, including the "too long for too low" period of 2003-2005 (Taylor (2007)). During this period, the Taylor rule prescribed that the federal funds rate should be increased in 2003, a full year before policymakers began tightening rates. Accounting for policy deviations from Taylor rule recommendations has important practical consequences. Among economists and policymakers there has been a debate over the role of low interest rates in propagating the housing bubble (Bernanke (2010), Taylor (2007)). And, whether monetary policy adheres (or should adhere) to a Taylor rule is of immediate concern as the Federal Reserve begins returning monetary policy to a normal stance.

Given that the Taylor rule does not adequately describe the actual policymaking process, a critical issue is whether the deviations from the Taylor rule represent systematic or discretionary responses to economic shocks. This paper explores the ability of the Taylor rule to empirically fit historical policy rates by focusing on the forecasting problem faced by monetary policymakers: implementing a Taylor rule requires observing the contemporaneous inflation rate and output gap something that policymakers cannot do. Instead, policymakers (and financial market participants) often rely on "nowcasts" of the current state of the economy. A point of departure for this paper is the observation that, depending on the form of their loss function, policymakers' nowcasts may be affected by their subjective forecast uncertainty. Forecast uncertainty may bias policymakers' nowcasts if they have an asymmetric loss function. There is evidence that professional forecasters and policymakers have asymmetric loss functions (see Patton and Timmermann (2007), Capistran (2008), Capistran and Timmermann (2009), and Clements (2010)). With an asymmetric loss, a policymaker may fear inflation that is higher than expected more than inflation that is below its forecast. Similarly, policymakers may seek to avoid over predicting the output gap and missing a recession. Under suitable conditions, the optimal nowcast under an asymmetric loss will include a precautionary term that depends on two factors: (1.) their aversion to the over or under prediction and (2.) their forecast uncertainty. If policymakers fear under predicting inflation, then they will adjust up their forecast of inflation up by a factor that is increasing in forecast uncertainty. Forecast uncertainty may lead to caution when adjusting interest rates.

This paper utilizes a unique aspect of the Survey of Professional Forecasters to identify nowcasts of inflation and the output gap. The Survey of Professional

[1]Taylor (1993) recommends the policy rate should be set to 1 plus 1.5 times the inflation rate plus 0.5 times the output gap.

[2]See Rudebusch (2006) for an extensive review of this literature.

Forecasters, in addition to soliciting information on point forecasts of the current and future economy, also elicits probability forecasts that allow the econometrician to estimate individual subjective probability distributions (Engleberg, Manski, and Williams (2009b), Clements (2009), D'Amico and Orphanides (2008)). Following Engleberg, Manski, and Williams (2009b) this paper estimates the individual subjective probability distributions in the SPF from which a measure of aggregate forecast uncertainty is constructed. Because professional forecasters are similar to Federal Reserve economists in many dimensions, this forecast uncertainty measure provides a reasonable proxy for forecast uncertainty by policymakers. The SPF then provides data on nowcasts: it includes forecasts of the current state of the economy and a measure of uncertainty on that forecast. A "nowcasting Taylor rule" replaces contemporaneous inflation and output gap with its nowcasting values, assuming a flexible loss function. This paper demonstrates that nowcasting Taylor rules can account for historical data on federal funds rates.

An estimated nowcasting Taylor rule provides evidence of an asymmetric loss function by Fed policymakers in line with Capistran (2008). Over the sample period 1993-2009, the best fitting Taylor rule is consistent with policymakers averse to under predicting inflation and over predicting the output gap. Furthermore, estimated policy coefficients are in line with Taylor's original rule. While the estimated rule improves on the overall historical fit, to fully explain the "too low for too long period" policymakers must be averse to over predicting inflation during 2003-2005 a period where uncertainty was abnormally skewed towards low inflation outcomes.

That nowcasting can help explain the "too low for too long" period is not surprising in light of the policy statements issued by the FOMC during this period. The estimated measures of inflation forecast uncertainty indicate that forecasters placed greater probability that inflation rates might become significantly less than 1% even though actual inflation rates did not drop that low. Policy statements beginning in May 2003 warn about rising downside inflation risks. These statements persist until policy rates increase during 2004, at the same time that inflation forecast uncertainty declines in the SPF.

The previous literature addresses policy rate deviation from a Taylor rule through variations on the benchmark rule. One empirically successful variant is an inertial Taylor rule, where the actual policy rate is only partially adjusted to the level at which the Taylor rule would predict.[3] Inertial rules predict systematic deviations from the Taylor rule. An alternative specification is a Taylor rule extended to include (persistent) exogenous policy shocks meant to capture persistent discretionary devia-

[3]Partial adjustment, or inertia, may be desirable as a means of influencing future expectations (Woodford (2003)) or in uncertain economic environments.

tions from the Taylor rule. A recent literature seeks to disentangle systematic versus discretionary persistent deviations of federal funds rates from those prescribed by the Taylor rule (see Rudebusch (2006), Coibion and Gorodnichenko (2011b)).

This paper advances an alternative explanation for the systematic deviations: uncertainty of the current state of the economy combined with policymaker preferences that are asymmetric in evaluating deviations of inflation and output gap from target. Since reasonable people can disagree over the specifications of the Taylor rule, one may wonder why a nowcasting Taylor rule should be preferred to the alternatives. There are several arguments in favor of the nowcasting rule. First, the Taylor rule is ubiquitous and its recommendations have an impact on policy deliberations. The nowcasting Taylor rule builds on the insights of this rule but incorporates realistic assumptions about the available information and forecasting problem faced by policymakers. Second, it explains deviations of the federal funds rate from the recommendations of the Taylor rule not because of discretion on the part of policymakers but because of a systematic response to forecast uncertainty. This systematic response is easy to interpret as it arises because of nowcasting and an asymmetric loss function. The extrinsic inertial view in estimated Taylor rules presents deviations as persistent, unobservable discretion by policymakers. Third, while the intrinsic inertial rules have the benefit of managing future expectations, this is only true in models with full-information rational expectations, a strong assumption (Evans and Honkapohja (2001)).

It seems reasonable, on the other hand, to think that policymakers will exercise caution when their forecast uncertainty is high and to partially adjust actual rates to the level recommended by the nowcasting rule. To examine this issue, a partial adjustment nowcasting Taylor rule is estimated. The estimates show that an inertial nowcasting Taylor rule improves the fit over non-inertial rules, however including the nowcasts and forecast uncertainty improves the rule's fit to historical policy rates.

This paper is related to a burgeoning literature on bounded rationality and adaptive learning in macroeconomics. Ever since the influential work of Evans and Honkapohja (2001), a number of researchers have begun incorporating realistic models of econometric forecasting into macroeconomic models by replacing rational expectations with adaptive learning rules. Milani (2007) shows that one can explain macroeconomic persistence with a learning model without relying on mechanical sources of persistence such as serially correlated shocks and habit persistence. A literature also finds support for real-time forecasting and learning in survey data. See, for example, Branch and Evans (2006), Burnett, Mumtaz, Paustian, and Pezzini (2010), de Bruin, Manski, Topa, and van der Klaauw (2010), Pfajfar and Zakelj (2010), and Anderson, Becker, and Osborn (2010). This paper is unique in the learning literature by focusing on both forecasts and forecast uncertainty.

This paper proceeds as follows. Section 2 provides an overview on the empirical performance of Taylor rules and introduces the nowcasting Taylor rule. Section 3 presents estimates of forecast uncertainty in the Survey of Professional Forecasters. Section 4 presents the results for the empirically estimated nowcasting Taylor rules. Section 5 concludes.

2 Nowcasting and the Taylor Rule

2.1 Historical Taylor Rules

The original Taylor (1993) rule is a simple policy rule that prescribes the setting of the federal funds rate as the real interest-rate plus a linear combination of deviations of inflation from target and the output gap:

$$i_t = r^* + \pi_t + 0.5(\pi_t - \bar{\pi}) + 0.5x_t \tag{1}$$

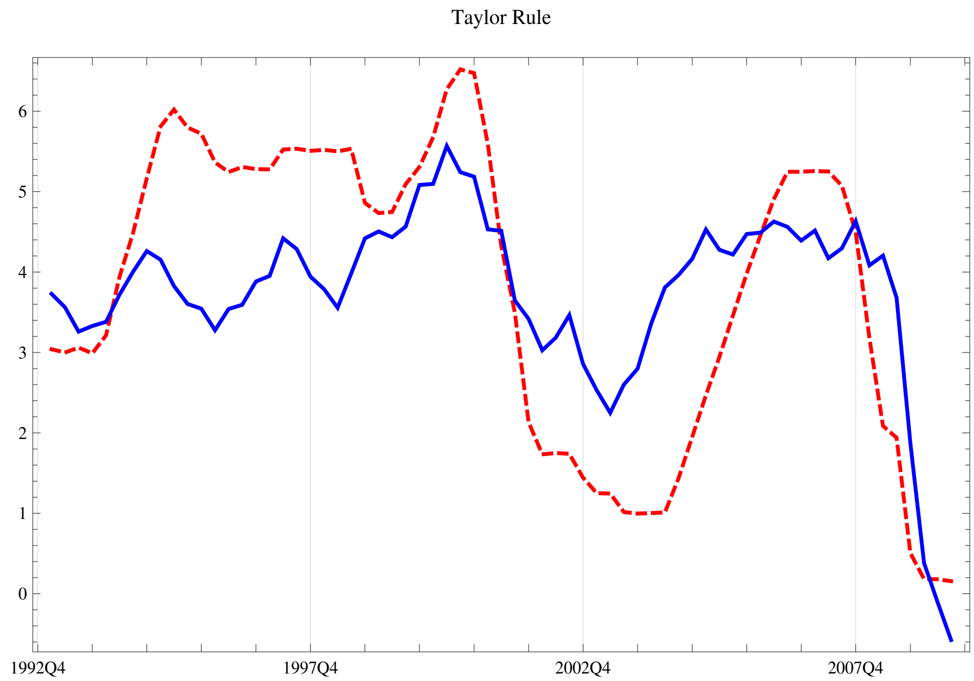
where i_t is the (average) federal funds rate, r^* is the real interest rate, $\bar{\pi}$ is the central bank's target inflation rate, π_t is a four-quarter average inflation rate, and x_t is the output gap. Taylor (1993) set $r^* = 2, \pi^* = 2$. Taylor (1999) demonstrates that, at least through the 1990's, the simple form of the Taylor rule provides a reasonable description of historical Federal Reserve policy. Deviations of the federal funds rate from what would be predicted by the Taylor rule has launched a substantial research agenda to find nominal interest rate rules that can fit actual policy rates. Federal funds rates that deviate from the level that would be recommended by the Taylor rule has helped fuel criticism of U.S. monetary policy. For example, Taylor (2007) has criticized Federal Reserve policy during the 2000's, and in particular during 2003, for having kept interest rates "too low for too long." The source of Taylor's criticism is clearly seen in Figure 1, which plots the Taylor rule over the period 1987.3-2009.4.

This figure was generated by measuring inflation as the four-quarter average rate from the personal consumption expenditure price index excluding food and energy, i.e. $\pi_t = (1/4)\sum_{j=0}^{3}\pi_{q,t-j}$, where $\pi_{q,t} = 400\ln(P_t/P_{t-1})$, and the output gap is the difference between real GDP and potential output as measured by the Congressional Budget Office.[4]

This figure demonstrates a departure in the federal funds rate from the Taylor Rule during two periods, 1995-1999 and 2002-2005. The period 2003-2004, the federal

[4]Throughout the paper the inflation rate is computed from the core PCE, following Rudebusch (2006), though the main conclusions are robust to alternative measures of inflation.

Figure 1: Taylor Rule. Dashed line is the actual federal funds rate, the solid line is the federal funds rate recommended by the Taylor rule.



funds rate, as viewed in the context of the Taylor rule, went "too low for too long": the Taylor rule prescribes a minimum rate of 2.25% and for policymakers to begin increasing rates in early 2003. There has been considerable debate among economists and policymakers over the source and significance of this departure. Some have pointed to the "too low for too long" period as an important ingredient to the housing bubble, though others dispute this (Bernanke (2010)).

It is well-known that empirical estimates of the Taylor rule are sensitive to data specifications. For example, whether inflation is measured with the implicit price deflator, the CPI, or core inflation rates. Even more problematic are measures of the output gap which rely on difficult to obtain estimates of potential output. Data revisions also complicate historical comparisons.

The "too low for too long" feature of policy rates (relative to the Taylor rule) is robust to alternative measurements of inflation and the output gap, as well as different response coefficients. To see the robustness of this feature of the data, consider the generalization of the Taylor rule

$$i_t = \alpha_0 + \alpha_\pi \pi_t + \alpha_x x_t \tag{2}$$

A literature on historical policy rules, for example Rudebusch (2006),Judd and Rudebusch (1998), and Clarida, Gali, and Gertler (2000) estimate the parameters of the generalized Taylor Rule that best fits historical data. Rudebusch estimates the equation with least squares over the period 1987:Q4 to 2004Q4 and found estimates of $\alpha_0 = 2.04, \alpha_\pi = 1.39, \alpha_x = 0.92$. The nowcasting analysis below focuses on the period 1993:Q1 to 2009:Q4, because of data availability in the Survey of Professional Forecasters, and the best fitting historical Taylor rule over this period is $\alpha_0 = 1.5, \alpha_1 = 1.28, \alpha_x = 0.63$, whose coefficients are somewhat close to the Taylor rule.

Figure 2 plots various alternative specifications for the Taylor rule to illustrate the robustness of the Taylor-rule deviation over the 2003-2005 period. The upper left quadrant plots the Taylor rule estimated over the sample 1993-2009, the upper right quadrant plots the Taylor rule with Rudebusch's parameter estimates, the lower right quadrant plots the Taylor rule where the inflation and output gap measures have been replaced with real-time data[5] The lower right quadrant plots the real time Taylor rule with coefficients estimated over the period 1993-2009. In each figure, it is clear that the actual federal funds rate was lower, and remained lower for a longer period, than would be recommended by variants of the Taylor rule.

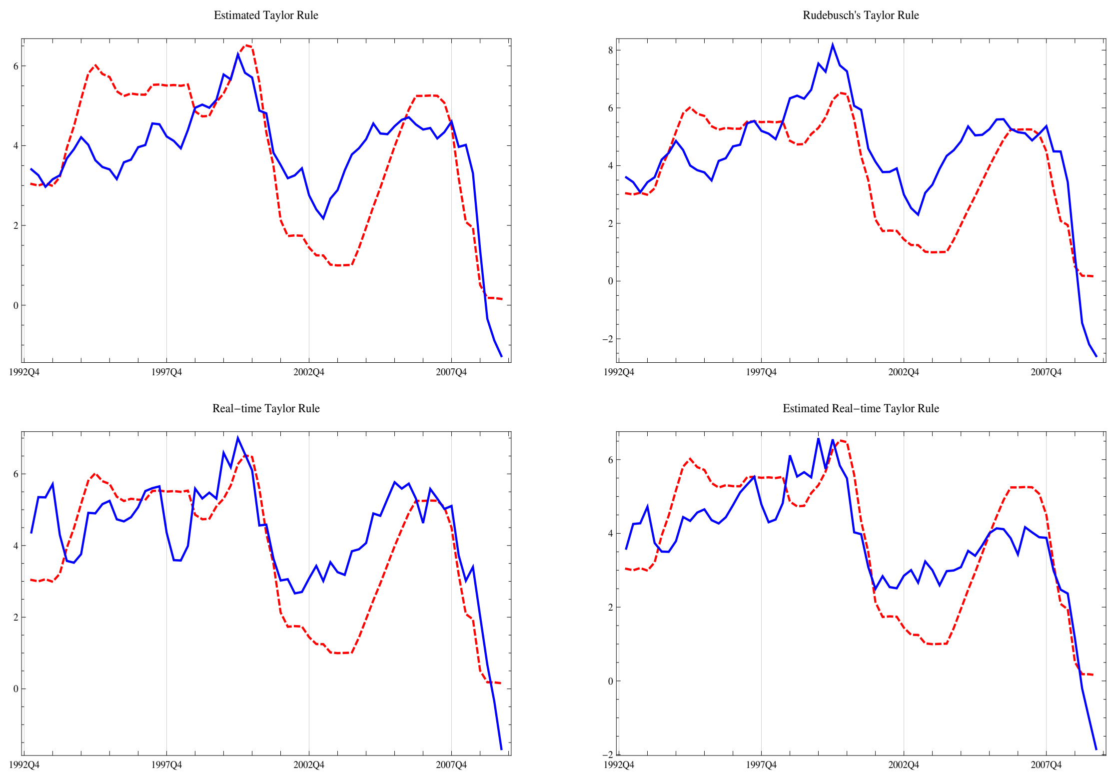
The failure of the Taylor rule specifications above to provide a convincing historical account of federal funds rates led to a considerable body of research that examines alternative policy rules. There are, broadly speaking, two avenues that can help reconcile policy rules with historical federal funds data. The first alternative is to incorporate inertia into the Taylor rule via a partial-adjustment mechanism. For example, following Rudebusch (2006) an estimated inertial Taylor rule over the period 1993.1-2004.4 is

$$\begin{aligned} i_t &= .14\hat{i}_t + .86 i_{t-1} + \varepsilon_t \\ \hat{i}_t &= -.5 + 2.28\pi_t + 1.014 x_t \end{aligned}$$

The $\hat{i}$ corresponds to the desired interest rate according to an estimated Taylor rule, but the actual policy rate only adjusts the previous rate partially towards the target. Rudebusch (2006) and Coibion and Gorodnichenko (2011b) demonstrates that this policy rule provides a close fit to historical rates. Systematic and sluggish responses

[5] The real-time inflation measure is calculated from the implicit GDP deflator, second release, as recorded by the Federal Reserve Bank of Philadelphia. The real-time output gap is the difference between the second release of real GDP (from the FRB Philadelphia) and the CBO's real-time estimate of potential output made during director's testimony for that year, as recorded by the ALFRED database at the Federal Reserve Bank of St. Louis. It should be noted that the Taylor rule plotted in Figure 2 with Rudebusch's estimates does not coincide exactly with the same plot in Rudebusch (2006) because of differences in data vintages.

Figure 2: Alternative Taylor Rule Specifications



by the central bank to economic shocks might arise if policymakers are uncertain about the current and future course of the economy and will adjust interest rates slowly as information accumulates, or as a mechanism to manage expectations about future economic conditions. Rudebusch (2001) notes that econometric estimates of inertial rules can be misleading if the estimated policy rule omits other persistent economic factors that the central bank may be responding to, or if the central bank exercises discretion and deviates from the Taylor rule in a persistent way.[6]

2.2 Nowcasting Taylor Rules

Whether deviations from a Taylor rule reflect gradualism or discretionary policymaking is an unresolved issue. One alternative explanation is that the Taylor rule does not provide a good approximation to actual Fed policymaking. The literature has proposed a number of other forms of the Taylor rule that might provide a better fit

[6]See Coibion and Gorodnichenko (2011b) for a recent analysis.

to historical policy choices. For example, Mankiw argues in favor of a policy rule that feeds back on inflation and unemployment, while Orphanides and Wieland (2008) find such a rule can provide a good description of the federal funds rate if real-time estimates of the natural rate of unemployment are included in the policy rule. Others have suggested that the Fed is actually forward-looking in their policy deliberations, and so a policy rule that depends on expected future inflation and the output gap might provide a better fit. Some alternatives with good empirical support move away from the Taylor rule itself and include other variables such as the output growth rate (see Coibion and Gorodnichenko (2011a)).

This paper's focus, though, remains on the Taylor rule as a systematic guide to policy that specifies a linear rule that responds to inflation and the output gap. The Federal Reserve often cites the Taylor rule – or one in which the parameters are estimated – to provide guidance on the appropriate target for the federal funds rate.[7] Taylor's original arguments for adhering to a simple rule still apply, and because of the widespread popularity of the rule, it seems reasonable to expect that central banks are guided, in part, by the original Taylor rule.[8]

Instead of a different specification for the policy reaction function, this paper emphasizes the forecasting problem faced by policymakers. Although most macroeconomic models are built on the assumption of rational expectations and full information, in practice private sector agents and policymakers face uncertainty about the current and future state of the economy. Many economic agents expend a considerable effort and expense forming accurate "nowcasts" of the economy. This paper begins with the observation that in practice monetary policymakers typically do not observe the current state of the economy rendering it impossible to include contemporaneous inflation and output gap measures in the policy rule. In its place, central banks respond to nowcasts of inflation and the output gap (Banbura, Giannone, and Reichlin (2010)). The question addressed by this paper is whether extending the Taylor rule to respond to nowcasts of inflation and the output gap can improve the empirical fit of the Taylor rule.

A nowcasting Taylor rule is

$$i_t = \alpha_0 + \alpha_\pi \hat{E}_t \pi_t + \alpha_x \hat{E}_t x_t \tag{3}$$

where $\hat{E}_t$ is the policymaker's forecast of current economic variables, i.e. the nowcast. If contemporaneous inflation and output gap are observable to the policymaker then

[7] In Chairman Bernanke's testimony for the Semiannual Monetary Policy Report to the Congress he engaged in a lengthy justification of current policy based on an estimated Taylor rule.

[8] The analysis below estimates a nested specification that compares nowcasting and interest rate smoothing.

(3) reduces to the benchmark Taylor rule. However, if they are not observable then the policymaker must construct a forecast, based on all information through time t, of π_t, x_t.

What form should these nowcasts take? Of course, the best forecast is the one that minimizes mean-square forecast error. Whether policymakers' optimal forecast will be the best linear unbiased predictor, though, depends on their loss function. There is an extensive literature that provides evidence that forecasters hold asymmetric loss functions (Patton and Timmermann (2007),Capistran (2008), and Capistran and Timmermann (2009)), where they evaluate positive and negative forecast errors differently. With asymmetric loss, it is well-known that forecasts may be biased by including a precautionary term that minimizes the likelihood of errors in the more costly direction. Capistran and Timmermann (2009) provide evidence of asymmetry in the loss functions of forecasters in the SPF. They argue that such asymmetries might arise because of the underlying primitives of the agent, psychological biases, or because of client-forecaster strategic considerations.

Asymmetric loss functions on the FOMC are even more likely. It is reasonable to assume that policymakers evaluate higher than expected inflation as more serious than inflation coming in below target. Conversely, an output gap that is lower than expected is likely to provide greater concern to policymakers than the opposite scenario. Since rate setting is conducted by a committee with each individual holding a distinct loss function, it is likely that in aggregate the loss function will be asymmetric. Capistran (2008) provides empirical evidence that the Greenbook forecasts of the Federal Reserve overpredicts inflation in fear of the large costs associated with a loss of credibility. This paper takes nowcasting, and asymmetric loss, as a given and looks to U.S. data to see if a nowcasting Taylor rule can give a plausible accounting of actual policy rate setting.

Following Zellner (1986), Patton and Timmermann (2007),Capistran (2008), Capistran and Timmermann (2009), and Clements (2010), this paper assumes policymakers form their forecasts to minimize a flexible loss function that takes a Linex form. The Linex has several advantages. First, it rises approximately exponentially in one direction, and approximately linear in the other. Its shape depends on a single parameter, so that for small values the loss is quadratic in forecast errors. However, for larger positive (negative) values of the shape parameter the losses in the positive (negative) direction are larger. It can be shown that, under suitable conditions on the subjective distribution for inflation and the output gap, that optimal nowcasts are of the form[9],

$$\begin{aligned}\hat{E}_t\pi_t &= E_t\pi_t + \phi_\pi \hat{\sigma}^2_{\pi,t} \\ \hat{E}_t x_t &= E_t x_t + \phi_x \hat{\sigma}^2_{x_t}\end{aligned}$$

where E_t is the conditional expectation, and $\hat{\sigma}^2$ is the subjective forecast uncertainty. If policymaker's have a symmetric loss function, then $\phi_\pi = \phi_x = 0$. When $\phi_j > 0, j = x, \pi$, then the forecaster considers under predictions more costly and so will include a precautionary term $(\phi_j \hat{\sigma}_j)$ that biases the nowcast. The more costly it is to under/over predict, and the more likely that the forecaster will under/over predict, then the central bank will add the precautionary term to avoid under/over prediction. Using a unique aspect of the SPF, this paper is able to identify the subjective nowcasts $\hat{E}\pi_t, \hat{E}x_t$, and then examine whether for values of $\phi_j \neq 0$ the nowcasting Taylor rule can provide a compelling historical narrative.

3 Data

This section discusses the data on "nowcasts" estimated from the Survey of Professional Forecasters.

3.1 Identifying Nowcasts: Methodology

This subsection discusses in detail the methodology, and potential empirical issues, of identifying "nowcasts." The next subsection presents key features of the estimated nowcasts.

A nowcasting Taylor rule requires data on forecasts ("nowcasts") of contemporaneous inflation and output gaps as well as measures of forecast uncertainty. Beginning in 2005, the Federal Reserve began reporting to Congress the full distribution of FOMC members' forecasts of the current and future state of the economy. One could use that cross-sectional distribution as a proxy for uncertainty in the current state of the economy. There are two limitations to that approach. First, the data set is too short and does not cover the "too low for too long" period. Second, cross-sectional distributions of point forecasts do not necessarily indicate the underlying forecast uncertainty. To really measure uncertainty one needs data on the full subjective probability distribution.

[9]These arise from the F.O.C. in the case of a linex loss function and the variables are perceived to follow a conditionally Gaussian distribution.

To measure nowcasts this paper analyzes the probability forecasts from the Survey of Professional Forecasters. The Survey of Professional Forecasters asks forecasters, each quarter, to provide point forecasts for inflation and output growth, among other things, as well as to report the histogram of their forecasts; that is, in the SPF forecasters also report the probability that inflation is between 0 and 1%, 1 and 2%, 3 and 4%, and so on. From these data, it is possible to estimate the subjective probability distribution for each forecaster and to measure an individual's forecast uncertainty by looking at the spread in their distribution. Because professional forecasters are as knowledgeable as economists working for the Federal Reserve, it is reasonable to expect that forecast uncertainty in the SPF is highly correlated with forecast uncertainty in the FOMC.

Following Engleberg, Manski, and Williams (2009b), and D'Amico and Orphanides (2008) we construct estimates of the full probability distribution of each individual forecaster in the SPF, and then average moments across forecasters. For each individual histogram, the subjective forecast distribution is estimated non-parametrically by a smooth kernel density estimator and parametrically via a generalized beta distribution (see Engleberg, Manski, and Williams (2009b)). The beta distribution imposes a single peak to the subjective distribution, which is a strong assumption, that however makes estimates of the moments from the distribution more reliable. D'Amico and Orphanides (2008) estimate the distributions assuming a normal distribution, however the beta distribution is better able to capture the shifting skewness of the distributions that are a key element of the nowcasting story. Empirical explorations with the non-parametrically estimated distributions suggest that many forecasters have multi-peaked subjective distributions. However, as will be illustrated below either estimation methodology produces similar measures of uncertainty.[10]

That forecasters report probabilities attached to bins implies some subtle empirical issues. Since the survey respondent's probability is attached to a bin, rather than a number, some assumption needs to be made on how the reported probability is distributed across the bin. The "bounds" approach (see Clements (2010)) places upper and lower bounds on the measures of central tendency by assuming that all weight is placed on either the lower or upper endpoint of the bins. For the purposes of this paper, it suffices to calculate the interquartile range (IQR) or standard deviation and so the analysis that follows assumes that when a forecaster reports a given probability attached to a bin they place that probability on the midpoint value of the bin. For example, a 10% probability that inflation will lie between 1 and 2% are treated as a 10% probability that inflation will be 1.5%. As an alternative, assigning the probabil-

[10] All qualitative results are robust to parametrically or non-parametrically measured moments. Mathematica programs available from the author include either measure as an option in estimating nowcasting Taylor rules.

ity to the end points has no impact on the IQR and standard deviation uncertainty measures. The measures of uncertainty, though, will be overstating the dispersion in subjective distributions if forecasters do not assign probabilities to each bin in this uniform manner. For example, it is possible that a forecaster reporting a 10% probability in the $(1, 2]$% bin and 90% in the $(2, 3]$% bin is assigning 10% probability to 1.99% and 90% probability to 2.01 percent. In this case, assigning the probability mass to the midpoint of the bin clearly overestimates the subjective uncertainty. Conversely, it is possible that uncertainty is understated if forecasters assign probabilities to the furthest end points in two adjoining bins. Again, a forecaster reporting a 10% probability in the $(1, 2]$% bin and 90% in the $(2, 3]$% bin could actually be assigning 10% to 1.01% and 90% probability to 2.99 percent. The approach taken in this paper is a reasonable compromise, though it would be straightforward to extend the analysis to place upper and lower bounds on the measures of uncertainty.

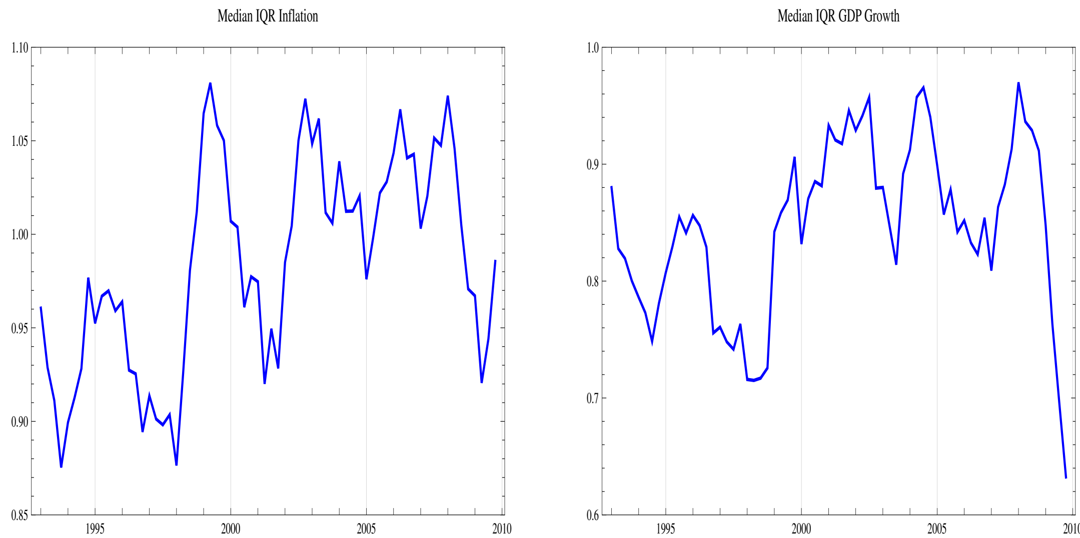
Having estimated the distribution for each individual, in each survey quarter, it is straightforward to measure overall forecast uncertainty. From each individual's distribution, forecast uncertainty is calculated as the IQR (preferred measure) or the standard deviation. In each survey quarter, aggregate forecast uncertainty is measured as the median IQR across individuals.

The sample period is 1993:Q1-2009:Q4 where forecasters are asked for their probability forecasts of real GDP and the bin specifications are consistent. One other potential issue is that this is an unbalanced panel of forecasters. Forecasters often drop out of the survey permanently or reappear at later survey dates. Because the composition of forecasters in the survey changes, the median measures of uncertainty might not provide the best estimate of overall forecast uncertainty. In computing median point forecasts, Engleberg, Manski, and Williams (2009a) warn against analyzing median forecasts when the panel's composition changes and focus on subsamples with a fixed set of forecasters. This paper abstracts from these issues and leave the robustness of the results to a panel with a fixed composition to future research.[11]

One issue that has received considerable attention in the empirical literature on survey expectations is "digit preferencing" by forecasters. One feature of survey data is that the histogram of survey expectations often displays peaks at certain digits such as $1\%, 3\%, 5\%, 10\%$. Some researchers interpret these findings as evidence of a "digit preference" by forecasters. This is less of an issue in the SPF than say the Michigan Survey of Consumers, where professional forecasters often submit non-integer

[11]There is considerable noise in the quarterly measures of uncertainty in part because of the changing composition of the panel. To address this issue, the estimation results take a four quarter moving average of the IQR estimates.

Figure 3: Median Uncertainty in the SPF



forecasts.[12] There is no evidence of digit preferencing in the probability forecasts.

The Taylor rule relates the federal funds rate to changes in inflation and the output gap. The SPF probability forecasts, over this sample, ask forecasters for their forecast of real GDP growth. To construct a measure of output gap uncertainty, using real GDP growth uncertainty, requires the identifying assumption that all forecast uncertainty comes at the business cycle frequency and not in forecasts of potential GDP. This is a strong identifying assumption, but one that is necessary because of data limitations.

3.2 Forecast Uncertainty in the SPF

Figure 3 plots the main estimated time series for uncertainty in the SPF. The left panel plots inflation uncertainty and the right panel plots real GDP growth uncertainty. This figure illustrates significant time series variation in forecast uncertainty of the current economy. Uncertainty tends to be cyclical, but the timing may precede, coincide or lag the recession. For example, uncertainty in GDP growth was elevated beginning two years before the beginning of the 2001 recession, but inflation uncertainty was declining at the start of the recession. Similarly, and importantly,

[12]Branch (2007) provides evidence against the digit preferencing hypothesis in the Michigan survey.

uncertainty in both inflation and GDP growth remained elevated after the 2001 recession and during the years 2003-2004. A central bank more concerned with high than low inflation, might increase the federal funds rate more aggressively during high uncertainty periods than one would expect by solely looking at the amount by which inflation rises above its target rate. That is, because the high aversion to inflation, and high uncertainty, makes inflation above the forecast seem more likely. Similarly, if the central bank is more concerned with GDP growth falling below potential, then uncertainty in the GDP growth rate might lead the central bank to exercise caution in increasing the federal funds rate even though inflation rates and GDP growth rates might be increasing. These insights from the data will be key to why a nowcasting Taylor rule can provide an improved historical fit to federal funds rate data.

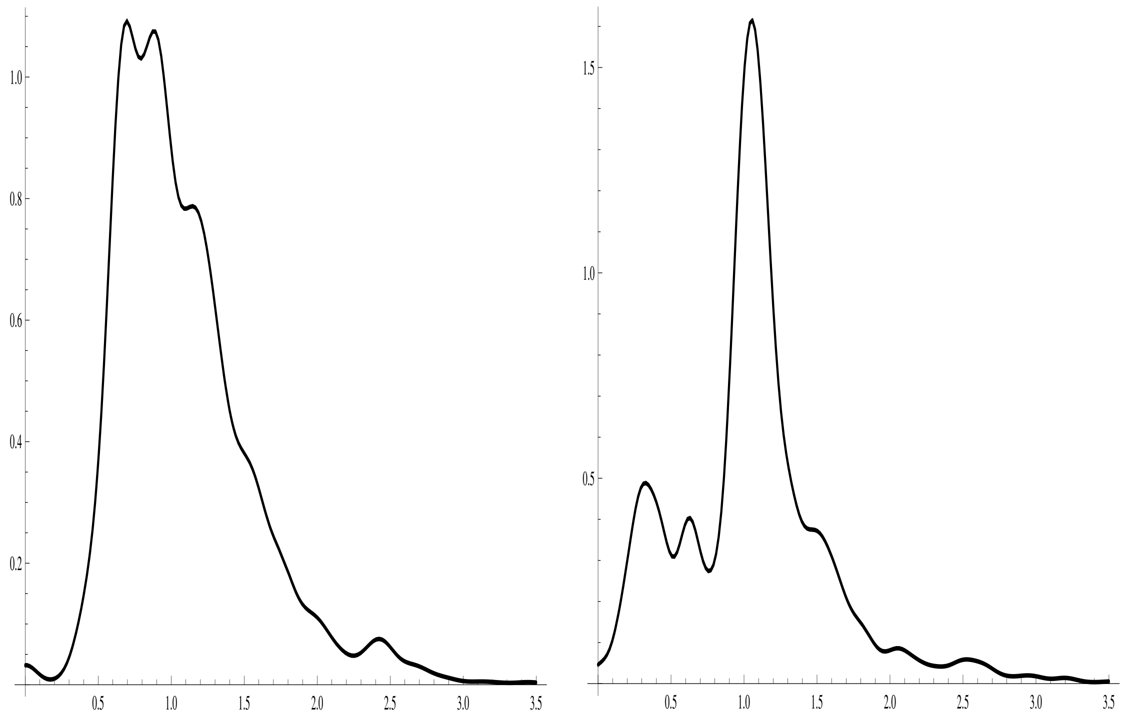
Figures 4-5 plot the full distribution of inflation and output uncertainty, respectively. These figures plot the (smooth) histograms of the IQR measures for the individual forecasters over the full sample 1993:Q1-2009:Q4. The left most plot in each figure is for IQR's from the estimated beta distribution and in the right plot the IQR's are computed from the nonparametrically estimated distributions. While Figure 3 gives the time series of median uncertainty, these figures give the distribution of individual uncertainty in the whole sample. These figures illustrate a left skew, but also a large mass on uncertainty measures of 2% or more.

Of course, the distribution of uncertainty only gives insight to the degree of uncertainty, it does not indicate if forecasters are more uncertain about low inflation versus high inflation, or low growth versus high growth. The skewness of the forecast distribution gives information about how the nature of uncertainty changes. Figure 6 plots the median skew of the individual histograms estimated with the beta distribution. The right panel plots the skewness for the GDP growth probability forecasts and the left panel plots the skewness for inflation forecasts.

The skew for GDP growth follows the pattern that one would expect. During, and immediately following, a recession (e.g. the period between 2001 and 2003) output growth forecasts place a greater weight on low growth realizations. During the expansion of the mid to late 1990's GDP growth forecasts place a greater relative weight on high growth realizations. There are a number of interesting features exhibited in the skewness for the inflation probability forecasts in Figure 6. During the late 1990's forecast distributions are skewed toward low inflation outcomes. This reflects the "new economy" view that the high productivity growth rates would lead to strong GDP growth and low inflation rates.

Importantly, over the period 2002-2005 inflation probability forecasts are skewed towards low inflation. This period is the flip side of the late 1990's; during the late 1990's forecasters are placing subjective probability on outcomes with both low

Figure 4: Distribution of Inflation Uncertainty: beta(left) nonparametric(right).



inflation and low GDP growth. This is a key insight of this paper: the combination of relatively high forecast uncertainty that is skewed towards low inflation rates can provide a partial justification for the low federal funds rate during the period 2003-2005.

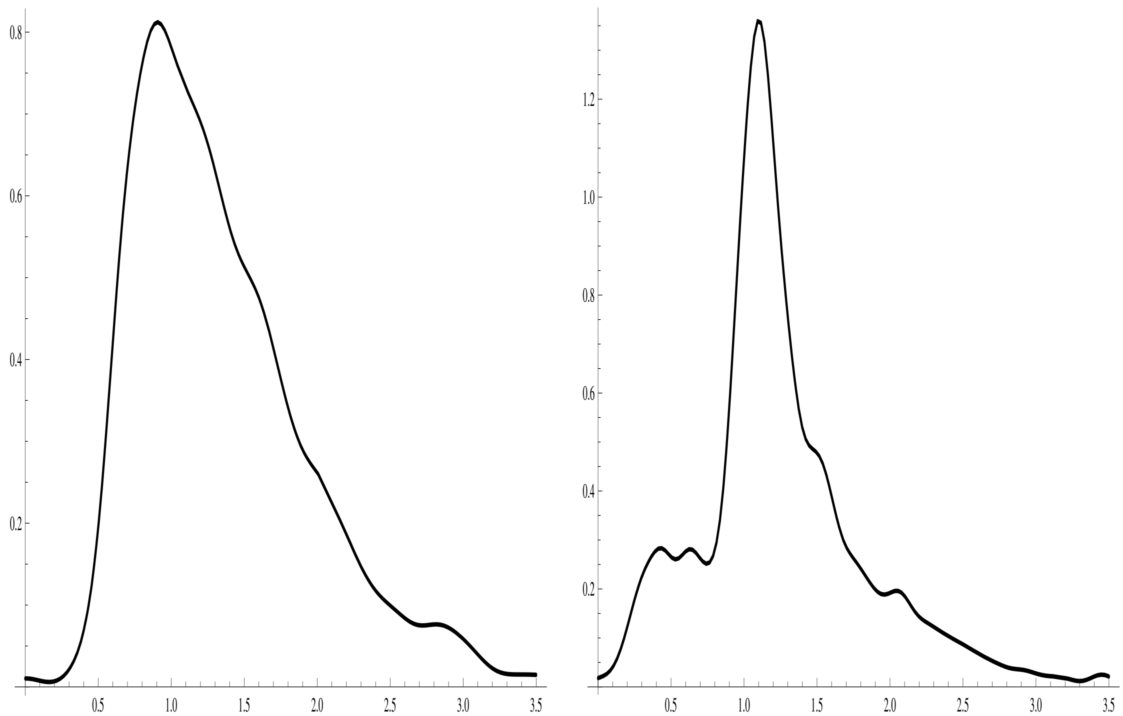
4 Empirical Results

This section considers the empirical performance of several variants of the nowcasting Taylor rule

$$i_t = \alpha_0 + \alpha_\pi \left(E_t\pi_t + \phi_\pi \hat{\sigma}^2_{\pi,t} \right) + \alpha_x \left(E_t x_t + \phi_x \hat{\sigma}^2_{x,t} \right) \quad (4)$$

where $\hat{\sigma}^2_{j,t}, j = \pi, x$ are the median estimated IQR's from the SPF. The main idea is to see whether incorporating uncertainty about the state of the economy, identified using forecast uncertainty from the Survey of Professional Forecasters, can improve the empirical fit of a Taylor rule, i.e. nowcasting Taylor rules.

Figure 5: Distribution of GDP Growth Uncertainty: beta(left) nonparametric(right).



4.1 A Nowcasting Taylor Rule

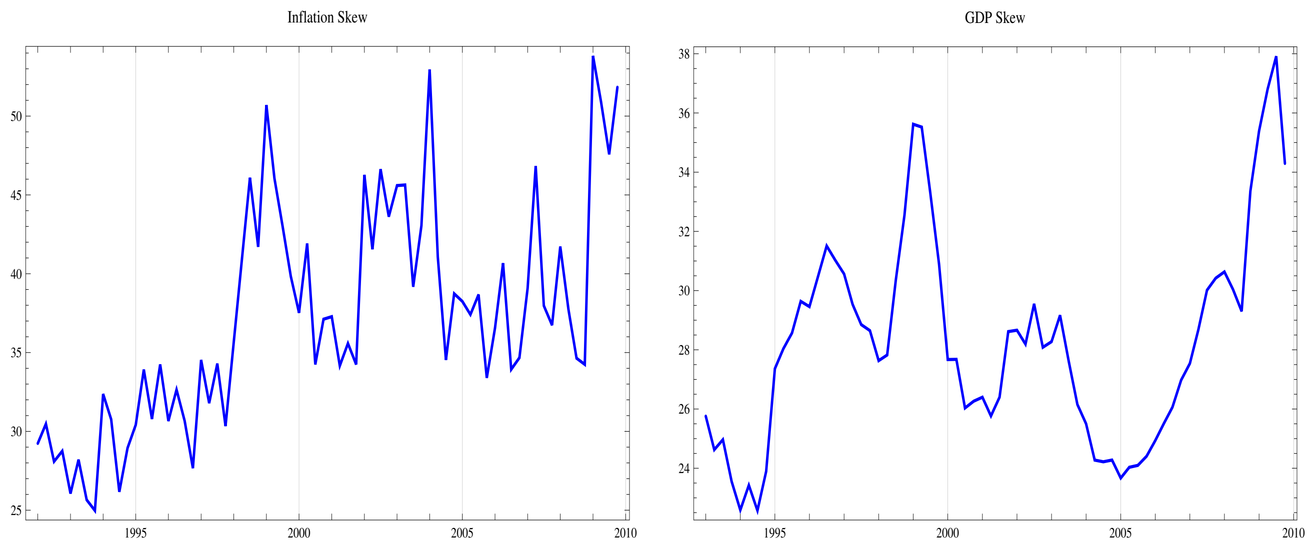
This section begins the analysis by examining how nowcasting and uncertainty can alter the historical fit of the Taylor rule. The next subsection presents estimates of a nowcasting Taylor rule. Figure 7 plots the Taylor rule (1), a nowcasting Taylor rule that includes forecast uncertainty, i.e.,

$$i_t = 1 + 1.5\left(E_t\pi_t + \phi_\pi\hat{\sigma}^2_{\pi_t}\right) + 0.5\left(E_t x_t + \phi_x\hat{\sigma}^2_{x,t}\right),$$

and the actual federal funds rate. Figure 7 plots the rule when $\phi_\pi = 2.058, \phi_x = -8.827$, values which minimize squared deviations of the nowcasting Taylor rule from the federal funds rate over the period 1993-2009. Recall that $\phi_\pi > 0$ implies policymakers with a concern for under predicting inflation, and $\phi_x < 0$ reflects a precaution against over predicting the output gap.

Figure 7 illustrates that incorporating forecast uncertainty into the Taylor rule can improve the fit, and especially over the 2003-2005 period. The Taylor rule dictates

Figure 6: Skewness

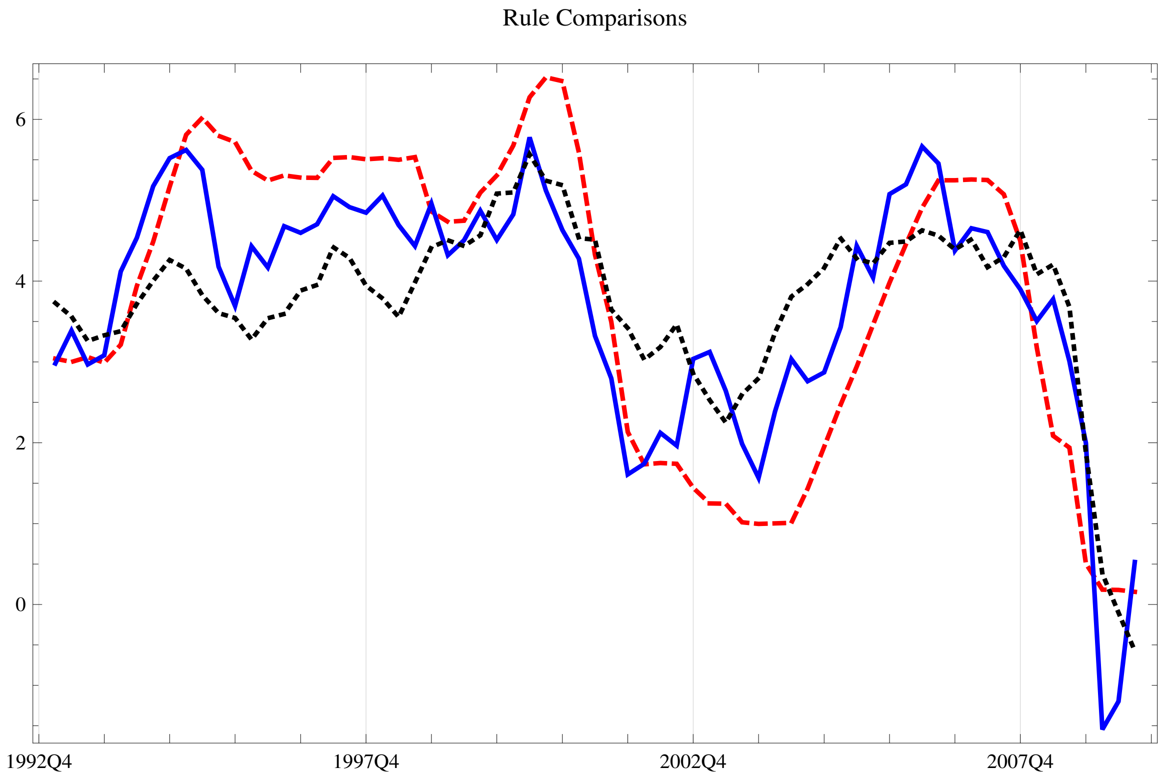


that the policy rate should be about 100-200 basis points or more above the actual setting of the Federal funds rate. The nowcasting Taylor rule narrows that gap having a maximum gap of 50 basis points (with the exception of 2002:4) as the rule prescribes interest rates beginning to increase at the beginning of 2003:Q2.

4.2 Estimated Nowcasting Taylor Rules

The nowcasting Taylor rule in Figure 7 , improves the historical fit but, nevertheless, still advises that the federal funds rate should start increasing in 2003:Q2 while historically the Federal Reserve did not start increasing rates for another year. To further improve the fit, this subsection instead examines rules whose coefficients are estimated over the entire sample 1993-2009. Estimation provides insights into the degree to which forecast uncertainty can affect the Taylor rule's empirical performance. To estimate the nowcasting Taylor rule, a least-squares regression is run for both the nowcast Taylor rule (4) and the generalized Taylor rule without nowcasting (2). For the Taylor rule two different specifications are estimated. The first uses final inflation and output gap data and the second uses the SPF median estimate of current inflation and the real-time estimate of the output gap. The policy rule coefficients for the Taylor rule are found by a least-squares regression, while for the nowcasting Taylor

Figure 7: Taylor Rule versus nowcasting Taylor Rule. Solid line is the nowcasting Taylor rule, the dotted line is the Taylor rule, and the dashed line is the actual federal funds rate.



rule a non-linear regression produces the estimates.[13] Table 1 reports the results, with Newey-West standard errors in parentheses.

Across all three specifications, the coefficient on the output gap is roughly similar, and only slightly higher from what is recommended by the Taylor rule. Moreover, for the interest rate rule that responds to final inflation and output gap the reaction coefficient to inflation is on par with the nowcasting Taylor rule and estimates reported by Rudebusch (2006). However, in the interest rate rule that responds to real time estimates of the economy, in the middle column, the policy coefficient on inflation is much lower and with a value that is only slightly above one, the boundary for the Taylor principle. The nowcasting Taylor rule provides a higher R^2 than the other two

[13] The non-linear regression results fail to converge unless the constant is normalized. The value is chosen to lead to the best fit across constants. The estimated values of α_π, α_x are quantitatively similar for different values of the constant, though the values for the ϕ's can vary.

Table 1: Estimation Results (Newey-West standard errors in parentheses).

	Taylor rule	Taylor rule with real-time estimates	Nowcast Taylor rule
α_0	1.51 (1.12)	1.91 (0.90)	1.00
α_π	1.28 0.51)	1.019 (0.40)	1.48 (0.30)
α_x	0.64 (0.08)	0.66 (0.09)	0.62 (0.064)
ϕ_π	–	–	1.97 (0.83)
ϕ_x	–	–	-6.35 (2.31)
$\bar{R}^2$	0.52	0.72	0.95

interest rate rules indicating a better fit.

Figure 8 compares the predicted interest rates from these estimated rules to the historical federal funds rate time series over the sample 1993-2009. The leftmost panel compares the nowcasting Taylor rule with the estimated Taylor rule, while the left panel compares the nowcasting rule to the estimated Taylor rule with real-time data. Incorporating nowcasting and real-time data improves the fit, especially over the period 1993-1999, relative to the estimated and original Taylor rules. It should be noted that the improved fit of the Taylor rule with real time data requires a value for α_π which is much lower than typically reported in the literature and is quite a bit off from what Taylor's original rule would recommend.

To place the estimation results in Table 1 into some context, Figure 9 plots the (asymmetric) loss function given the estimates for ϕ_π, ϕ_x in Table 1. This figure shows that there is a strong asymmetry for the two forecast loss functions. Positive forecast errors increase nearly exponentially for inflation, while negative forecast errors have an asymmetrically larger effect on the loss function for the output gap.

4.3 Shifting Uncertainty Versus Shifting Coefficients

Taylor (2007) criticizes policy for deviation from the Taylor rule during 2001-2005. Another way of interpreting this criticism is that Federal Reserve policy reacted differently during this period via different values for α_π, α_x. This section addresses the issue of subsample stability and whether the "too low for too long" period can be explained by a shift in the nature, i.e. direction, of forecast uncertainty. In particular,

Figure 8: Estimated Taylor Rules versus Estimated Nowcast Taylor Rule with uncertainty. Solid line is the nowcasting Taylor rule, the dotted line is the Taylor rule, and the dashed line is the actual federal funds rate.

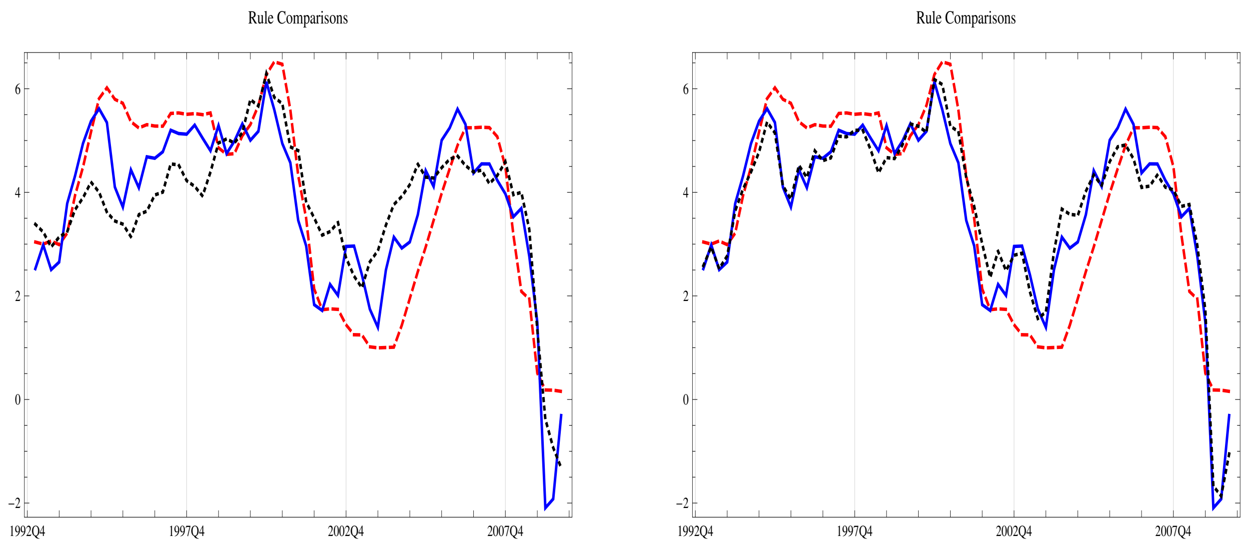


Figure 6 illustrates that over the period 2003-2005 both uncertainty is high and the direction of that uncertainty is skewed towards low inflation rates. The best-fitting nowcasting Taylor rule is consistent with the Federal Reserve being asymmetrically concerned with inflation rates that are above target *except* for the period 2002-2005 when they are relatively more concerned with low inflation rates.

This subsection addresses the extent to which the systematic part of monetary policy differed over the "too low for too long" period by estimating the nowcasting Taylor rule over this period. Table 2 presents estimates for the nowcasting Taylor rule over the period 2001:1-2005:2. Surprisingly, the response coefficients for inflation and the output gap are close to their full sample values and very close to the values in the original Taylor rule. However, these parameter estimates also show a change in the sign on the inflation uncertainty coefficient ϕ_π, and a insignificant coefficient estimate for ϕ_x. A negative estimated coefficient ϕ_π suggests that policymakers were more concerned with inflation rates that might come in below what they expect. Importantly, the results in Table 2 are consistent with a policy rule that responds aggressively against expected inflation but that is relatively more concerned with the possibility of low inflation. As will be seen below, this is consistent with the policy narrative over this period.

Figure 9: Plot of Linex loss function using estimated parameters ϕ_π, ϕ_x: $\exp(\phi_j \varepsilon_j) - \phi\varepsilon_j - 1$, where ε_j is the forecast error for variable $j = \pi, x$.

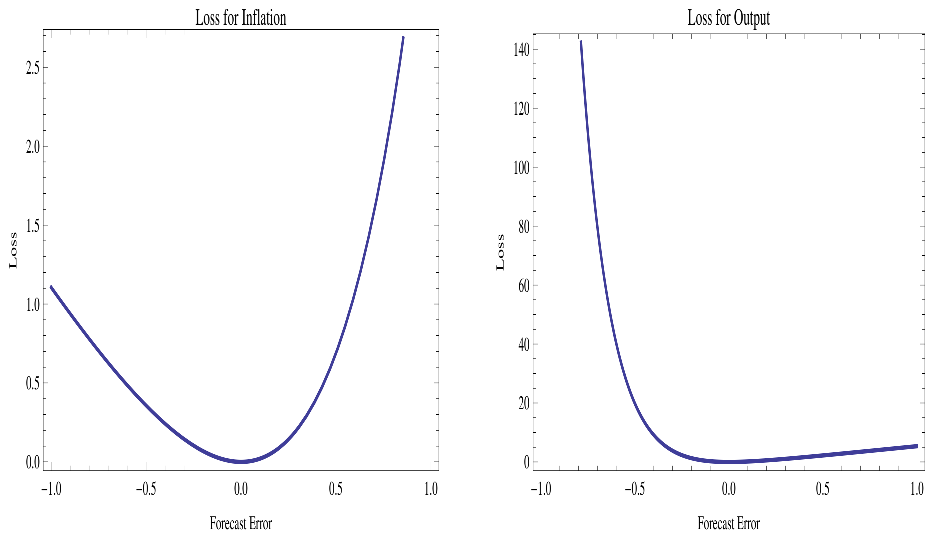


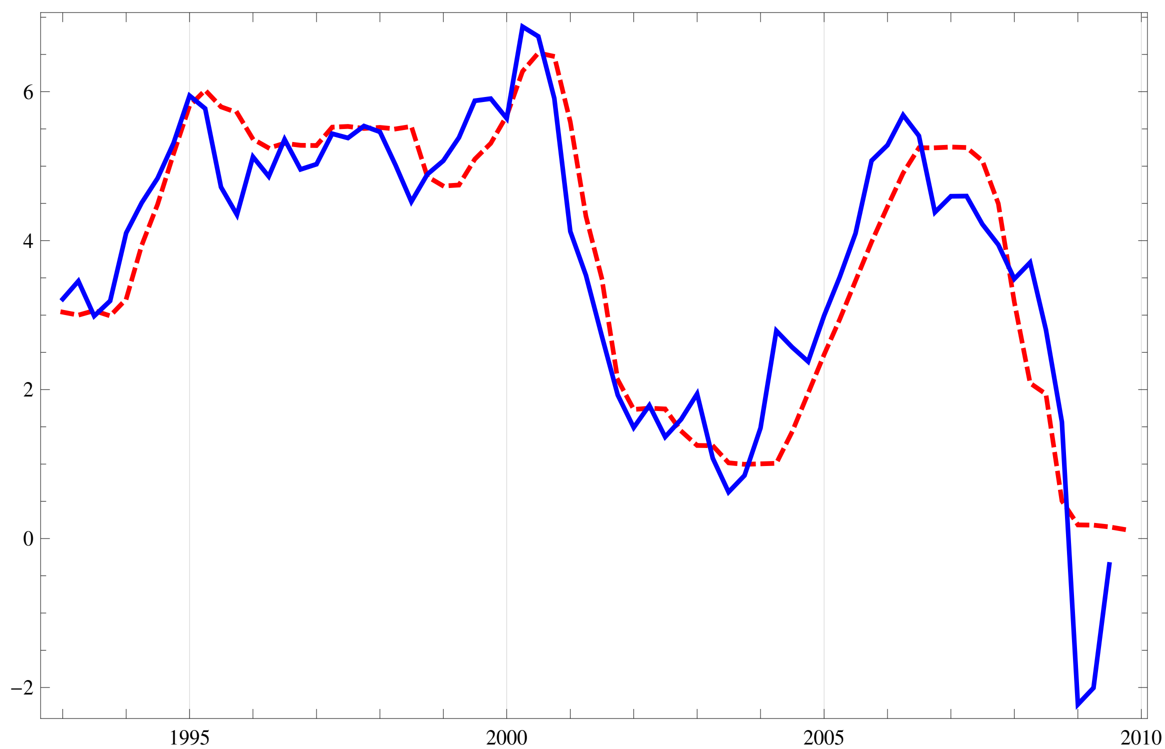
Figure 10 plots the Nowcast Taylor rule, against the actual federal funds rate, assuming that $\alpha_\pi = 1.473, \alpha_x = 0.620$, $\phi_\pi = 1.92$, and $\phi_x = -6.36$ during the periods 1993:1-2000:4 and 2005:3-2009:4, and the coefficients take the values in Table 2 during 2001:1-2005:2. The thought experiment is whether the nature of uncertainty shifts towards lower inflation rates during the "too low for too long" period can lead to a policy rule that provides a good empirical fit to the actual federal funds rate. As is evident from Figure 10, with shifting uncertainty the nowcasting Taylor rule provides a good fit to the actual federal funds rate.

Of course, one could also estimate a Taylor rule over the same subsamples and provide an improved fit. Table 3 presents sub-sample coefficient estimates for the Taylor rule (2). Figure 11 then plots the predicted federal funds rate for a Taylor rule with *policy* coefficients that are estimated across the subsamples, 1993-2000, 2001-2004, 2005-2009. The results from estimating the rule on these subsamples is a Taylor rule that adheres to the Taylor principle before and after 2001-2005, but that responds very passively to inflation during the "too low for too long" period. In fact the policy coefficient estimates are implausible over the 2001-2004 period. These coefficient estimates are consistent with Taylor (2007) criticism of Federal Reserve policy over this period. Figure 11 demonstrates that such a rule provides a nearly perfect fit of actual federal funds rates.

Table 2: Nowcasting Taylor rule over the "too low for too long" period 2001:1-2005:2.

	Nowcasting Taylor Rule
α_0	1.0
α_π	1.56 (0.76)
α_x	0.47 (0.06)
ϕ_π	-0.80 (.12)
ϕ_x	1.78 (4.95)

Figure 10: Best fitting Nowcast Taylor Rule. Solid line is the nowcasting Taylor rule and the dashed line is the actual federal funds rate.



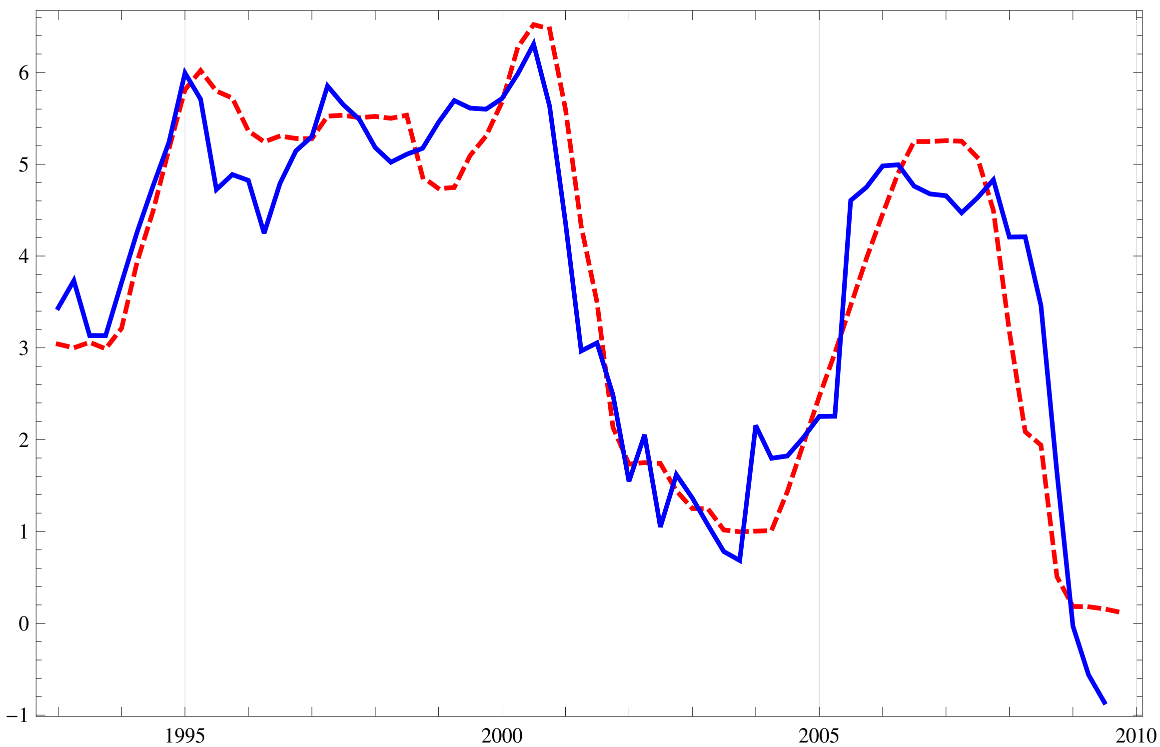
4.4 Further Discussion

The results presented above are not able to distinguish between a shifting uncertainty explanation versus shifting coefficient explanation of the Taylor rule. However,

Table 3: Shifting Coefficients in the Taylor rule.

	1993-2000	2001-2004	2005-2009
α_0	1.3256	5.93704	2.3824
α_π	1.71278	-1.64	1.0217
α_x	0.673	1.055	.653

Figure 11: Best fitting Taylor Rule with shifting coefficients. Solid line is for a nowcast Taylor rule without uncertainty.



additional supporting evidence for shifting uncertainty can be found in the policy statements following regular FOMC meetings. Some indication in the change in uncertainty arises in the FOMC statements during 2003. In particular, the statement at its January 29,2003 meeting summarized its uncertainty about the state of the economy as

> In these circumstances, the Committee believes that, against the back-

> ground of its long-run goals of price stability and sustainable economic growth and of the information currently available, the risks are balanced with respect to the prospects for both goals for the foreseeable future.

While a significant change occurs in its statement following the May 6, 2003 meeting[14]

> Although the timing and extent of that improvement remain uncertain, the Committee perceives that over the next few quarters the upside and downside risks to the attainment of sustainable growth are roughly equal. In contrast, over the same period, the probability of an unwelcome fall in inflation, though minor, exceeds that of a pickup in inflation from its already low level. The Committee believes that, taken together, the balance of risks to achieving its goals is weighted toward weakness over the foreseeable future.

The FOMC statements continue to mention the low inflation rate throughout 2003 and into 2004 adopting the language "With inflation quite low and resource use slack, the Committee believes that it can be patient in removing its policy accommodation." Then in the May 4, 2004 statement they find that "Similarly, the risks to the goal of price stability have moved into balance."

Interestingly, the change in the statements towards a concern with low inflation occurs at the same time there is a large increase in the Median IQR measure of inflation uncertainty (see Figure 3), at the time in which uncertainty in real GDP growth is decreasing. The change in language also occurs precisely at the time that there is a large change in the skewness of the SPF probability forecasts, indicating both an increase in uncertainty and a bias towards lower inflation rates. This happens at the same time that inflation rates move lower, but not low enough to justify a federal funds rate of 1% that is held at that level for most of 2003-2004. An estimated Taylor rule can only rationalize the historical federal funds rate by assuming that the Federal Reserve adjusts interest rates less than one for one with inflation, which would run against most policy views at that time.

A nowcasting Taylor rule, one with a heightened concern with the *possibility* of low inflation rates can reconcile historical federal funds rate and the Taylor rule. The "too long for too low" period can be reconciled as follows. Not being able to perfectly observe the current state of the economy at the time that interest rates are set, policymakers must form "nowcasts". Uncertainty would have no effect if policymakers

[14]The March statement from the FOMC declines to provide a risk assessment because the beginning of the Iraq war led to large uncertainties that led the committee to not be able to "characterize the current balance of risks with respect to the prospects for.. price stability..."

treat deviations of inflation and output from target symmetrically. However, if there is any asymmetry in the policymaker's loss function, then uncertainty would impact the policy setting process. In particular, for most of the sample period the historical federal funds rate is consistent with a Taylor rule when policymakers treat inflation above target asymmetrically with those below the target. In such settings, they may increase interest rates in response to increases in the inflation rate more aggressively when uncertainty about the inflation rate is high. The 2003-2005 period can be reconciled with a nowcasting Taylor rule by noting that uncertainty about inflation was high and that uncertainty was skewed towards low inflation rates. A policymaker concerned with inflation being below target then may be more cautious in increasing interest rates. These findings from the estimated nowcasting Taylor rule are consistent with the FOMC statements over this period.

4.5 An Inertial Nowcasting Taylor Rule

As mentioned above, one standard variant on the Taylor rule is to include a partial adjustment mechanism that proxies for policy setting gradualism. The partial adjustment mechanism builds in policy inertia and is a fairly standard component to policy rules in macroeconomic models. The empirical results above show that the nowcasting Taylor rule can significantly improve the fit of the model without introducing an interest rate smoothing element in the policy rule. This subsection demonstrates that forecast uncertainty and nowcasting can improve the fit of an inertial policy rule.

This subsection presents estimates for the following inertial policy rule:

$$\begin{aligned} i_t &= (1-\rho)\hat{i}_t + \rho i_{t-1} \\ \hat{i}_t &= \alpha_0 + \alpha_\pi \left(E_t \pi_t + \phi_\pi \hat{\sigma}^2_{\pi,t} \right) + \alpha_x \left(E_t x_t + \phi_x \hat{\sigma}^2_{x,t} \right) \end{aligned}$$

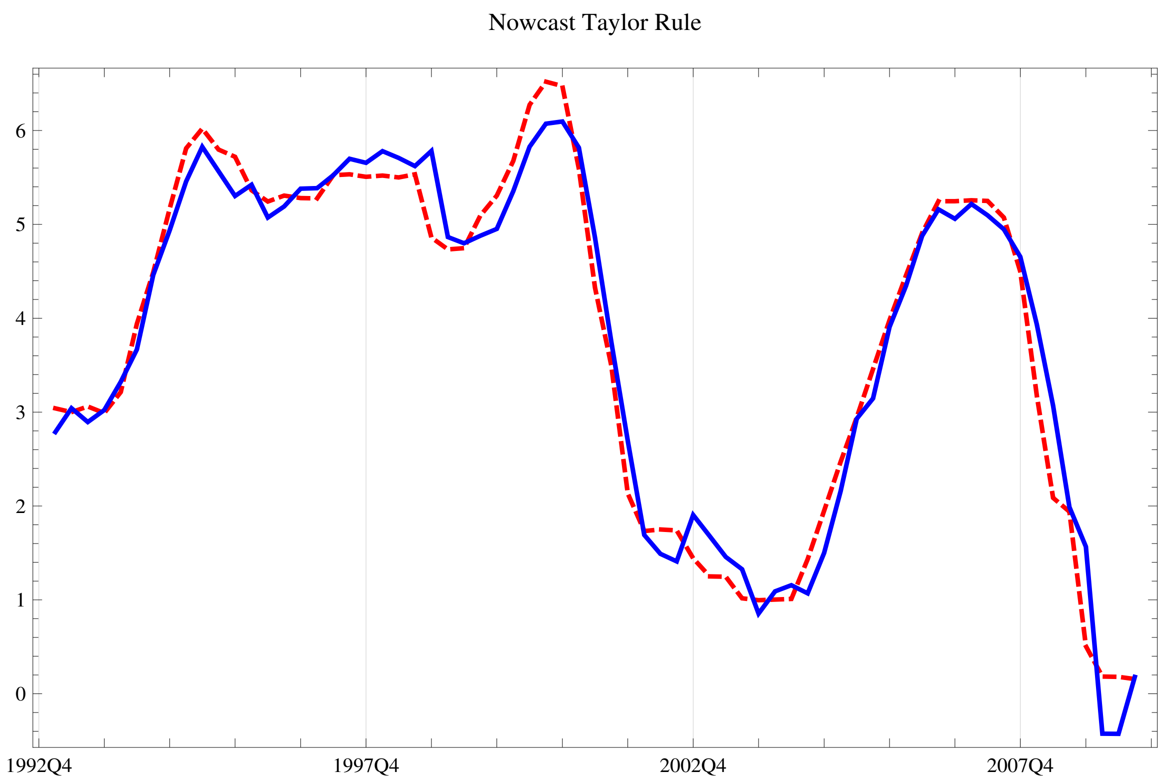
where $\hat{i}_t$ is the desired policy rate and the actual rate is partially adjusted toward the desired rate. Table 4 presents the results.

The estimated coefficients show that the presence of inertia does not have a large impact on the systematic response of monetary policy to nowcasted inflation and output. However, there is a strong estimated persistence in policy rate decisions. Notice, though, that the degree of persistence in the estimated $\rho = 0.75$ is significantly lower than the value of 0.85 that was estimated in the inertial rule in section 2. Moreover, interest rate smoothing improves the fit of the nowcasting rule with an adjusted $R^2 = 0.99$ compared to $R^2 = 0.95$ without inertia. Figure 12 plots the inertial nowcasting Taylor rule and demonstrates a near perfect fit to historical policy rates.

Table 4: An Inertial Nowcasting Taylor rule.

	Inertial Nowcasting Taylor Rule
α_0	1.0
α_π	1.67 (0.09)
α_x	0.69 (0.06)
ϕ_π	2.29 (1.01)
ϕ_x	-14.79 (3.72)
ρ	.766 (.038)

Figure 12: Inertial nowcasting Taylor rule. Solid line is for an inertial nowcast Taylor rule and the dashed line is the federal funds rate.



5 Conclusion

There is, by now, a clear theoretical consensus that central banks should conduct rules-based monetary policy. A considerable body of research shows benefits, in particular, to adopting nominal interest rate rules that are reaction functions to observable economic indicators such as inflation and the output gap. The most famous of these rules is the Taylor (1993) rule that says the federal funds rate should equal 1 plus 1.5 times the inflation rate plus 0.5 times the output gap. Empirically estimated Taylor rules, however, provide evidence that the Federal Reserve does not follow a Taylor-type rule. There are noticeable periods during the mid 1990's and the "too low for too long" period of 2003-2005 in which the actual policy rate is hundreds of basis points off of the level recommended by the Taylor rule. Taylor (2007), among others, has argued that the "too low for too long" deviation from the Taylor rule was a contributing factor to the housing bubble and ensuing financial crisis.

This paper reconsiders the empirical fit of the Taylor rule. The departure point is the observation that current inflation and output – the indicators in the Taylor rule – are not contemporaneously observable to policymakers. Rather, policymakers when setting policy rates are likely to be uncertain about the current state of the economy and form "nowcasts" that are the basis for policy decisions. The form of the optimal forecast of current inflation and output gap – that is, nowcasts – depend on the policymakers' loss function. Following a large and growing literature (see Elliott and Timmermann (2008)) this paper assumes a flexible functional form that allows for the possibility of an asymmetric loss function. An asymmetric loss function would arise if policymakers were more concerned with inflation being above forecast than below, or that the economy might grow slower than expected. Asymmetric loss functions for policymakers is an intuitive assumption and empirical evidence has been provided by Capistran (2008). Under an asymmetric loss, the optimal forecast depends on the point forecast and a precautionary term that reflects the forecast uncertainty.

Nowcasts are empirically identified in the Survey of Professional Forecasters who asks forecasters for both point and probability forecasts. Following Engleberg, Manski, and Williams (2009b), the subjective probability distribution is estimated for each forecaster, in each quarter, and from these estimated distributions the aggregate forecast uncertainty is computed. The SPF provides a good proxy to forecast uncertainty in the Federal Reserve because professional economists and policymakers have similar incentives and backgrounds. Using this data, the paper formulates and estimates a nowcasting Taylor rule.

The nowcasting Taylor rule provides a significant improvement over the Taylor (1993), especially over the 2003-2005 period. Including forecast uncertainty can explain the "too low for too long" puzzle in the following sense. The subjective probability distributions during the 2003-2004 period shifted towards greater uncertainty about the inflation rate and that uncertainty was skewed towards inflation rates below 1%. Over this period, the economy was recovering, GDP growth uncertainty was declining, and the Taylor rule suggested increasing policy rates. However, the nowcasting Taylor rule predicted that the federal funds rate should decline, be held at a low level, and not increase until 2004 because of the high uncertainty that inflation was actually below the forecasted level. Policymakers concerned with the *possibility* of inflation lower than expected would be advised to hold rates lower for a considerable period of time. These results are in line with the historical narrative of the FOMC policy statements issued over this period.

More generally, the results of this paper highlight the important role that forecast uncertainty might play in the economy and the policymaking process. With the exception of D'Amico and Orphanides (2008) and Clements (2009) there has been little empirical work looking to higher order moments of agents' subjective expectations. In most macroeconomic models, closed under the assumption of rational expectations, forecast uncertainty does not play an important role. A growing literature on adaptive learning in macroeconomics (see Evans and Honkapohja (2001)) highlights implications of replacing rational expectations with point forecasts generated from an econometric learning rule. This paper suggests that future work should incorporate both point forecasts and forecast uncertainty into adaptive learning models.

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