Estimating Monetary Policy Rules When Nominal Interest Rates Are Stuck at Zero*

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Abstract

Did the Federal Reserve's response to economic fundamentals change with the onset of the global financial crisis? Answering this question is difficult because the U.S. overnight rate has been stuck between zero and 25 basis points since the onset of the crisis in late 2008, therefore preventing meaningful covariation between nominal short rates and economic fundamentals. Data from surveys of economic forecasts allow us to sidestep the censoring problem and to use a simple regression to estimate monetary policy rules. We find that the Fed's inflation response has significantly decreased. In terms of central bank communication, our results can be viewed as an argument that the Federal Reserve's commitment to stable inflation has become weaker in the eyes of the professional forecasters—and probably the financial markets as well.

Keywords: monetary policy, policy rule, survey data, market perceptions, censoring, zero lower bound, Blue Chip survey.
JEL codes:E53, E58.

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1 Introduction

Did the global financial crisis somehow alter the Federal Reserve's behavior? Since the 1990s, simple monetary policy rules for the nominal short rate have been widely used to analyze the behavior of central banks—most notably the Fed's behavior following Taylor (1993). The short rate is critical for the dynamics of the whole economy, not only by representing the reaction of a central bank to the current state of the economy but also by providing information of the economy's future to financial markets. Estimates of policy rules depend on meaningful covariation between nominal short rates and economic fundamentals such as the inflation and unemployment rates. But since December 2008, around the onset of the global financial crisis, U.S. nominal short rates have been stuck at their zero lower bound (ZLB).[1] Hence, policy rates are censored at zero and observed nominal short rates cannot provide the meaningful variation required to answer our research question.[2]

A textbook way of tackling a censorship problem is to apply a limited dependent variable econometric methods to the historical data. However, these methods cannot define a hypothesis test of whether or not policy response parameters changed between the pre-ZLB period (when data is always uncensored) and the ZLB period (when data is always censored).[3] The main idea of this paper is to avoid the censoring problem altogether by using data on agent expectations—obtained from surveys of economic forecasts—and answers whether or not Fed policy has changed since the global financial crisis.[4] Even while realized short rates were at

[1] In this paper, we assume that the federal funds rate is effectively at its ZLB as far as it is below 25 basis points—see Bernanke and Reinhart (2004) for reasons why the short-term rate had better not be pushed down all the way to zero. In model simulations, the ZLB creates difficulty since it implies nonlinearity in the setting of monetary policy. Given brevity of the gap between the collapse of Lehman Brothers (September 2008, often seen as the starting point of the global financial crisis) and the ZLB period, for simplicity we suppose that the crisis and ZLB started at the same time. None of our results change if we instead split our sample at September 2008.

[2] This is our censoring problem: Even when both the rate recommended by a simple rule and so the desired target rate are negative, the ZLB-constrained target rate announced by the Fed stays positive. See Rudebusch (2009) and Curdia and Woodford (2011) among others for the argument that desired target rates are negative. The censorship is with regards to the targeted policy rate, not the actual observed nominal short rate. We use the terms "policy rate" and "short rate" interchangeable in the remainder of the paper.

[3] A maximum likelihood estimator based *only* on censored observations cannot be consistent (for example, premises of Newey and McFadden 1994 Theorem 2.1 cannot be satisfied) leading to undefined asymptotic distributions and hypothesis tests. Therefore, historical data cannot satisfactorily answer whether or not a policy shift took place in response to the global financial crisis. One might be able to alter our question to a partially identified context and conduct modified statistical tests. However, that would be a different question than we answer here, which is manifest as a simple parameter break test. Statistical analysis using partial identification is beyond the scope of this paper, but it may be interesting to discover whether partially-identified models of the censored historical data confirm this paper's results.

[4] Other recent papers have also used forecast data similarly. Coibion and Gorodnichenko (2012) use surveyed forecasts to assess the role and type of informational rigidities that best describe economic agents' environment. Devereux, Smith and Yetman (2012) use forecast data to estimate cross-country risk-sharing on a panel of professionals' expectations. Our paper is closest in spirit to Devereux, Smith and Yetman's (2012) because we link forecasts (as left- and right-hand-side variables) to estimate structural parameters.

the ZLB, one-year-ahead forecasts of the short rate stayed above zero at least until August 2011, when a calendar-based forward guidance was introduced by the Federal Open Market Committee (FOMC). By using the one-year-ahead forecasts available in various issues of the Blue Chip Economic Indicators, we avoid the ZLB-induced censoring problem and estimate the Fed's monetary policy rule using conventional regression methods. No other paper, to our knowledge, has so straightforwardly evaluated the Federal Reserve's Taylor-type policy response function since the global financial crisis. Therefore our novel results shed light on an important economic question that cannot be answered using conventional techniques and data.

Prior to the global financial crisis, policy rules estimated with forecast data are comparable to those estimated with historical data: We find a short rate response to inflation just under 2 and to unemployment between $-\frac{1}{2}$ and -1, which is similar to estimates in previous literature and our own estimates using historical data. After the onset of the global financial crisis, our results using forecast data show that the Federal Reserve's inflation response significantly decreased while its unemployment response remained strong. In particular, the point estimate of the inflation response decreased by roughly half and no longer satisfies the so-called Taylor principle of responding at least one-for-one to inflationary pressures. In terms of central bank communication, our findings provide evidence that the Federal Reserve's commitment to stable inflation has become weaker in the eyes of the professional forecasters—and probably the financial markets as well. This result could be interpreted as either bad (the loss of inflation-fighting credibility) or good (successful forward guidance[5]), and we do not advocate one interpretation over the other.

In addition to avoiding censorship, the Blue Chip Economic Indicators include long-horizon forecasts of inflation, unemployment and short rate. We take these forecasts as *data* for respective long-run values of these variables, instead of letting them remain that are unobserved and under-identified as does conventional policy rule estimation using historical data. We argue that having data to discipline the inflation target and market-perceived NAIRU is a further advantage of using these forecast data.

We use our estimates to understand what is the counterfactually "unconstrained" policy rate since the onset of the ZLB. Going forward in time from this paper's draft date (February 2013), we find that the rule estimated on ZLB forecast data implies a later lift-off than the rule estimated from pre-ZLB historical or forecast data. In fact, the expected future path of short rates using the Blue Chip forecasts and our preferred policy rule estimates correspond

Previous papers do not discuss the relationship of these data to the censoring problem presented by the ZLB. Meanwhile, Swanson and Williams (2012) ask whether there has been a change in various maturity U.S. treasury prices' response to data releases, which avoids this censoring problem when longer maturities are used; however, their results do not answer the policy response question we ask here.

[5]Please see footnote 9 for details.

closely to the expected short rate path implied from overnight-index-swap (OIS) rates, which provides market-price-based supporting evidence for the policy changes we estimate.

An intellectual price we pay for our simple solution to the ZLB censorship problem is that the object estimated in this paper is market participants' *perception* of how the Federal Reserve sets policy. However, this is often assumed to coincide with the actual policy rule (by rational expectations) or else is interesting on its own as an object (see Hamilton, Pruitt and Borger 2011). In either case it remains critical for monetary economists to understand financial markets' perception of the Fed's behvaior since the global financial crisis. This paper specifically investigates if market professionals believe the Federal Reserve's response to real activity and inflation has shifted because of the financial crisis. If one interprets a central bank's credibility as its perceived response to inflation, our results shed light on whether the Federal Reserve remained credible since short rates hit the ZLB at the end of 2008.

The plan of the paper is as follows. Sections 2 and 3 describe our data and estimation methods. In Section 4, we present our main results, analyze their robustness, and use our estimates to understand the forces which market forecasters believe shape Federal Reserve policy, as well as the effects of Federal Reserve communication on markets' beliefs. Section 5 concludes.

2 Data

The main idea of this paper is to use data on agents' *expectations* to answer our research question. A key advantage of such data is that they may forecast future economic conditions that warrant uncensored policy rates, even when short rates at the time the forecast is made are stuck at the ZLB. This means that all the necessary ingredients—dependent and explanatory variables—retain meaningful variability that can be used to estimate the key policy response coefficients. In turn, we can in the usual manner form statisical hypothesis tests addressing our research question.

A brief digression on terminology may be helpful. This paper uses two types of data. The first type of data we refer to as *actual*, *historical* or *realized* data are prices or measurements that actually prevailed in the U.S. experience. Examples are the 3-month T-Bill rate during December 2005 or the unemployment rate measured by the Bureau of Labor Statistics for December 2005—these are actual, historical or realized data. The second type of data we refer to as *expectations* or *forecast* data are forecasts of future economic conditions. An example is the 3-month T-Bill rate expected to prevail in 2006Q4, as forecast in December 2005. Studies such as Ang, Bekaert and Wei (2007) suggest that surveys contain remarkably accurate forecasts, therefore we make the assumption that the survey data we use accurately represent market expectations.

Our main historical data sources are the civilian unemployment rate from the Bureau of Labor Statistics (BLS), the ex-food/energy (core) consumer price index (CPI) from BLS, and 90-day U.S. Treasury bill rate from the Federal Reserve Board of Governors. In subsequent analysis, we also use overnight index swap (OIS) data (written on the U.S. overnight rate) obtained from Bloomberg and VIX data from the Chicago Mercantile Exchange (CME). We construct actual core-CPI inflation as the 12-month log growth rate in the core-CPI index.[6]

Our main forecast data source is the Blue Chip Economic Indicators. Collected monthly since the late 1970s, these surveys provide short-to-medium horizon (one- to six-quarter ahead) forecasts of the annualized percentage change in the CPI, the 3-month T-Bill rate, and the unemployment rate. The survey is released on the 10th of the eponymous month but collected through the end of the previous month – therefore the "April 2000" survey actually represents information known to the market by the end of March 2000. Having forecasts for particular future quarters is important because we want to maintain a constant forecast horizon as much as possible. Since the surveys are monthly and forecast horizons are quarterly, strictly-speaking the forecast horizons vary by a couple of months. For example, the April 2000 survey contains a 2001:Q2 "four-quarter-ahead" forecast that is 15-months-ahead, the May 2000 survey contains a 2001:Q2 "four-quarter-ahead" forecast that is 14-months-ahead, and the June 2000 survey contains a 2001:Q2 "four-quarter-ahead" forecast that is 13-months-ahead. Our paper's main idea is to use professional forecasts to estimate professionals' perception of Federal Reserve policy response, we would like to maintain, as much as possible, a constant forecast horizon so as to minimize superfluous additional dimensions to the analysis. The fore mentioned data limitations prohibit us from strictly doing so, but we have found that these small differences in forecast horizon do not alter our results (in the pre-ZLB period during which we have a sufficient number of observations). Hereafter, we refer to the four-quarter-ahead forecasts of a month's survey as "one-year-ahead" forecasts.

The forecasts we use are expressed as the median forecast from a moderately-sized panel (30 to 60 in any given month) of professional forecasters in the financial services, consultancy, and academic industries, with emphasis on forecasters in the financial services industry.[7]

[6] CPI excluding food and energy prices is used to measure inflationary pressures to which policy responds since it strips out price fluctuations (food and energy prices) that are typically considered temporary. Congruently, core-CPI inflation is a better forecaster of future CPI inflation than headline inflation itself. Hence we find it reasonable to associate realized core inflation (in the rule estimated on historical data) with expected headline inflation (in the rule estimated on forecast data).

[7] The Blue Chip Economic Indicators show the full panel of individuals' expectations for forecasts of the current and following year of each survey month. Using this full panel would advantageously allow us to control for panel composition issues discussed by Engelberg, Manski and Williams (2011), but disadvantageously confound our control of the forecast horizon. To be concrete about the disadvantage, consider the January 2000 and December 2000 surveys: Both contain individual forecasts for variable growth rates realized in 2000

Biannually the survey also publishes long-horizon forecasts (the five-year average five years ahead) for these variables, which we convert to a monthly measure by linear interpolation. We use the 3-month T-Bill rate as our primary policy measure so that we have both its medium- and long-horizon forecasts.[8] We use CPI inflation and unemployment to represent inflation and activity pressures, respectively. We use data starting in 1986 when all variables are observed, and these series are plotted in Figures 1–3.

The long-horizon forecast of the short rate, inflation rate and unemployment rate are plotted by the dash-dotted lines in Figures 1–3, respectively. Taking the difference between the long-horizon short-rate forecast and the long-horizon inflation-rate forecast yields the long-horizon real-rate forecast, by the Fisher identity. Figure 1 shows the long-horizon forecasts of the short rate have trended down over the past three decades; much of this follows the fall in the long-horizon forecasts of inflation plotted in Figure 2. Meanwhile, the long-horizon forecast of the unemployment rate hovers around familiar values of five to six percent, in Figure 3.

Figure 1 demonstrates the main idea of our paper. Although the realized short rate (the dashed line) hits the ZLB at the end of 2008, the one-year-ahead forecast for the short rate (the solid line) remains above the ZLB until after August 2011. It is inconsequential to our exercise that this indicates that market expectations exhibited serially correlated forecast errors during the ZLB. What is important for our analysis is that the forecasts manifest a systematic relationship between short rate on one side and inflation and unemployment on the other side.

The right tail of Figure 1 demonstrates why we end our data sample in August 2011. At the August 2011 FOMC meeting, the Committee announced that "exceptionally low" short rates would likely be held "at least through mid-2013."[9] Our surveys—as well as price-based measures of market expectations such as fed funds futures or eurodollar contracts—

and 2001. This means that the January survey contains individual 12-month- and 24-month-ahead forecasts, while the December survey contains individual 1-month- and 13-month-ahead forecasts. It is unclear how to adjust the forecast horizon for these two surveys and the surveys for months in-between. Blue Chip Financial Forecasts, a separate but similar survey, gives a full panel of individual forecasts for quarterly horizons that is available electronically since 2001 – see footnote 8 for further comparison between the two surveys.

[8] It is conventional to measure policy by the federal funds rate, but this variable is not in our data. Instead, we note that over our sample period the correlation between these two series' actual values is greater than 0.99 and so this data limitation is negligible. Blue Chip Financial Forecasts *do* contain forecasts for the fed funds rate and the GDP growth rate, but do not include an unemployment rate forecast and do not provide long-horizon forecasts. Therefore, we opt for using Blue Chip Economic Indicators since it forecasts unemployment and 3-month T-Bill rates, the latter of which are extremely similar to the desired fed funds rates.

[9] Earlier, the FOMC introduced the "extended period" language in March 2009, instead of "for some time". Subsequently, the Committee extended the calendar-based forward guidance to late 2014 in January 2012 and to mid-2015 in September 2012. In December 2012, FOMC switched to its new threshold-based forward guidance (regarding 6.5% unemployment and 2.5% inflation) instead of the calendar-based forward guidance.

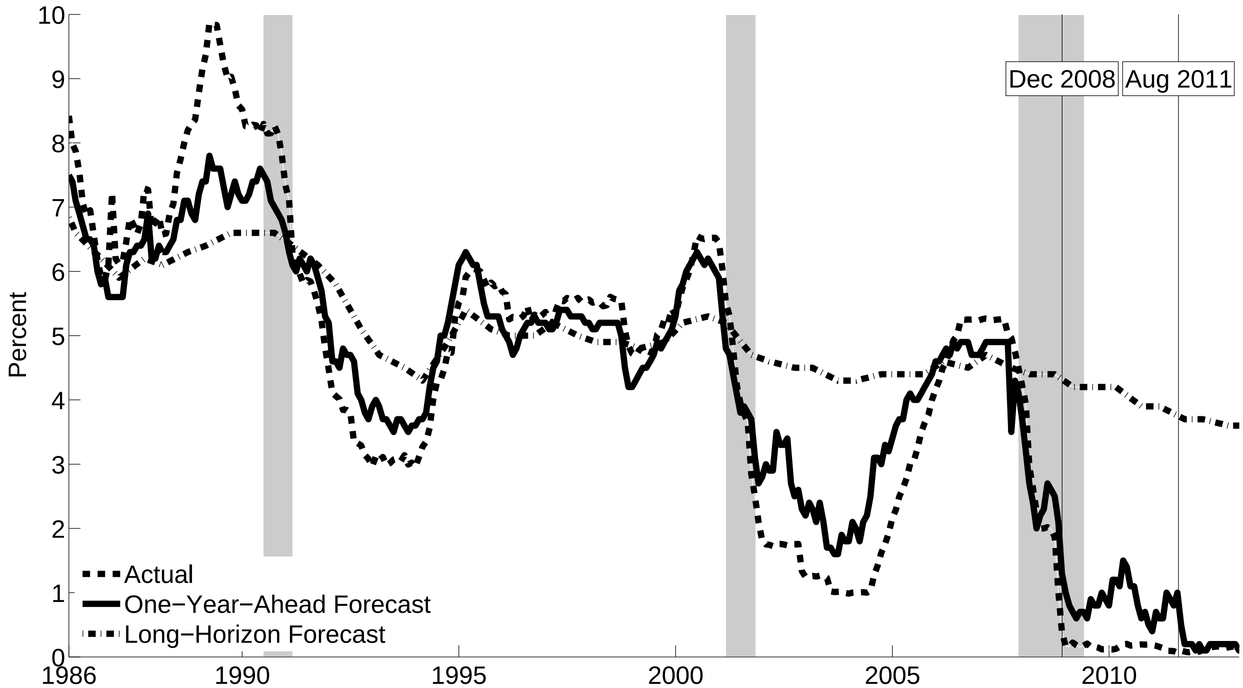

Figure 1: Short-Term Interest Rates

Notes: Data for January 1986 to August 2011. Actual values from the Federal Reserve Board of Governors, solid line; median one-year-ahead forecast from Blue Chip Economic Indicators, dashed line; long-horizon forecasts from Blue Chip Economic Indicators, dotted line.

respond immediately to this policy statement. Surveys published between September 2011 and the current draft (February 2013) exhibit medium-horizon short rate forecasts at the ZLB. Therefore this paper estimates the possible shift of perceived monetary policy using forecast data between December 2008 and August 2011. Our maintained assumption is the Federal Reserve's Taylor-type policy may have changed with the onset of the global financial crisis in 2008, but thereafter is fixed.

3 Estimating Policy Rules

A Taylor-type policy rule specification is

$$i_\tau = (1-\rho)\left[(r_t^* + \pi_t^*) + \beta(\pi_\tau - \pi_t^*) + \delta(u_\tau - u_t^*)\right] + \rho i_{\tau-1}. \tag{1}$$

This form follows, among others, Boivin (2006) in using unemployment to measure real activity. It is similar in spirit to rules using the output gap—as in Taylor (1993)—and reflects the limitations of our survey data. The policy rate i_τ responds to the inflation response coefficient β times the deviation of inflation π_τ from its long-run target π_t^*; the unemployment

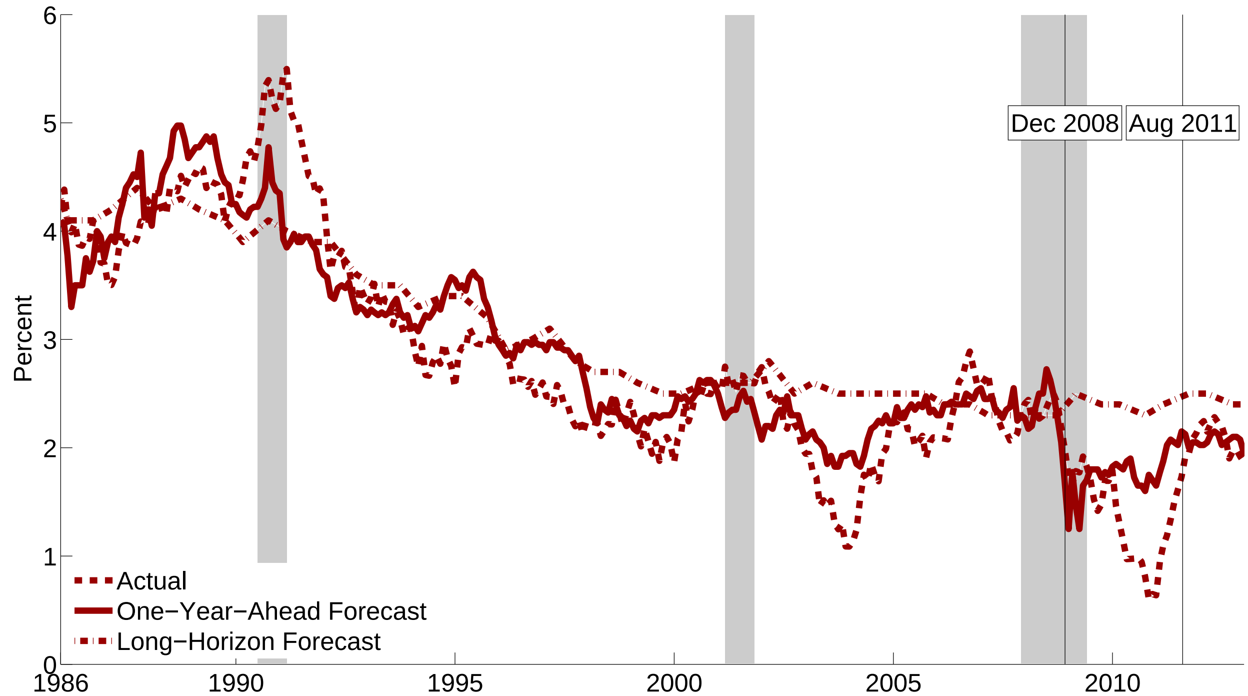

Figure 2: Inflation Rates

Notes: Data for January 1986 to August 2011. Core-inflation from BLS, solid line; median one-year-ahead inflation forecast from Blue Chip Economic Indicators, dashed line; long-horizon inflation forecasts from Blue Chip Economic Indicators, dotted line.

response coefficient δ times the deviation of unemployment u_τ from the non-accelerating inflation rate of unemployment (NAIRU) u_t^*; and the lagged short rate via "gradual adjustment" dictated by ρ. When both inflation and unemployment are at their long-run values of π_t^* and u_t^*, the nominal short rate converges to the economy's equilibrium real rate r_t^* plus inflation π_t^* as implied by the Fisher equation. The *-variables are written with t subscripts to allow for variation in the inflation target or natural rate of unemployment—we only allow for such time variation when we impose that these long-run variables are observable as long-horizon forecasts, and otherwise assume they are constants.

In existing literature, implementations of equation (1) use historical data. An obvious problem is that the *-variables—the inflation target, the NAIRU and the equilibrium real rate—are typically under-identified by the historical data.[10] What is typically estimated is the reduced form

$$i_\tau = c_0 + c_1\pi_\tau + c_2 u_\tau + c_3 i_{\tau-1}.$$

Note that $c_1 = \beta$, $c_2 = \delta$ and $c_3 = \rho$, but $c_0 = (1-\rho)(r_t^* + \pi_t^*) - \beta\pi_t^* - \delta u_t^*$ which highlights

[10]This need not be the case in larger model specifications—see for instance Cogley and Sbordone (2008).

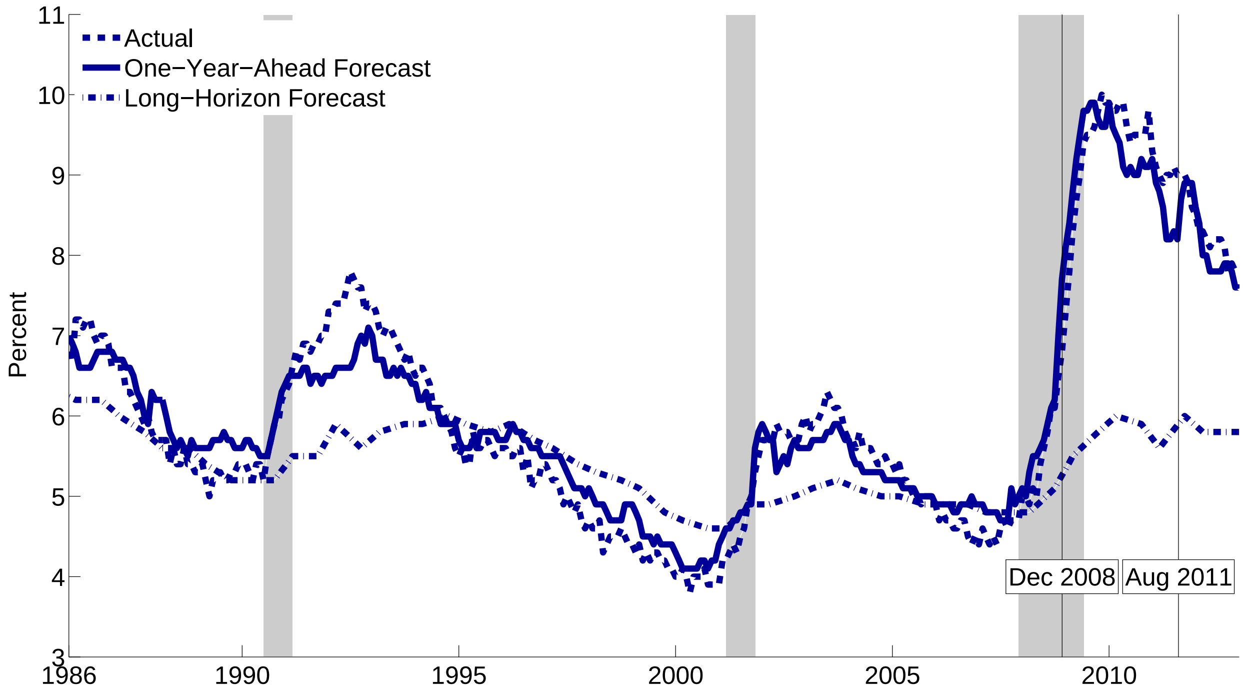

Figure 3: UNEMPLOYMENT RATES

Notes: Data for January 1986 to August 2011. Actual values from BLS, solid line; median one-year-ahead forecast from Blue Chip Economic Indicators, dashed line; long-horizon forecasts from Blue Chip Economic Indicators, dotted line.

the identification problem. See that c_0 is a function of the unobserved *-variables *and* the response parameters β, δ. Even if the *-variables are assumed to be time-invariant, we expect c_0 to shift if β or δ shift. Therefore, when estimating (1) using historical data, one must allow c_0 to break when either β or δ is allowed to break.

3.1 Rules Using Forecasts Data

Using forecast data instead of historical data provides us at least two distinctive features. First, the forecast data include one-year-ahead forecasts for unemployment, inflation, and the short rate. As mentioned in Section 2, these forecasts are not censored even after the ZLB started to bind the historical short rate. Second, these data include long-horizon forecasts of the short rate, inflation rate and unemployment rate. In macroeconomic models with well-defined steady-state growth paths, long-horizon forecasts are synonymous with the values for the equilibrium nominal interest rate, monetary policy's inflation target, and the NAIRU. Therefore, the survey of forecasts gives us a unique opportunity to pin down the value of the *-variables using *data*. This is an advantage of these data, that they can be used to avoid the identification problem intrinsic to conventional Taylor-type policy rule estimation using historical data.

The forecast-data-based rule we estimate is

$$i_{E,t} = (r^*_{E,t} + \pi^*_{E,t}) + \beta(\pi_{E,t} - \pi^*_{E,t}) + \delta(u_{E,t} - u^*_{E,t}) \tag{2}$$

where t is measured in months. Equation (2) takes *expectations* as data, and we assume that our median-forecast data reveal the representative forecaster's conditional expectation. For example: $i_{E,t}$ is the month t expectation of the short rate that will prevail one year after month t; $\pi^*_{E,t}$ is the month t expectation of the Federal Reserve's inflation target. At least three features of our main specification are worth mentioning.

First, we have made a particular horizon choice: Our main results use the the one-year-ahead forecast.[11] We do this to prevent, as much as possible, the effect of the ZLB that is operational on shorter-horizon forecasts of the short rate.

Second, (2) includes no parametric constant to be estimated and instead pins down all movements of the policy rate forecast to the inflation response $\beta\pi_{E,t}$, unemployment response $\delta u_{E,t}$, and shifts in the *-variables $(r^*_{E,t} + \pi^*_{E,t}) - \beta\pi^*_{E,t} - \delta u^*_{E,t}$. This more tightly adheres the model to the data, and is possible because the Blue Chip surveys provide long-horizon forecasts that naturally represent forecasters' beliefs about the long-run values of the respective variables.

Third, we have zeroed out the gradual adjustment parameter ρ. Regarding this choice, we point out that Rudebusch (2006) argues that serially-correlated residuals account for the persistence of short rates, reflecting variables used by policymakers but excluded by our simple analysis. Including a gradual adjustment term serves to soak up residual variation, but without providing any additional economic rationale for *what forces* move the expected policy rate. Hence, we prefer to explicitly evaluate the residual left after inflation gaps and unemployment gaps have been controlled for, which we do in Section 4.2 in order to discuss what omitted variables may have been imposed by the Taylor-type specification. In particular, we connect the estimated residuals to business-cycle-frequency financial-market risk following Atkeson and Kehoe (2009).[12]

[11] Recall our loose usage of the phrase "one-year-ahead" discussed in Section 2.

[12] Additionally: Hamilton, Pruitt and Borger (2011) find that responses to past inflation and real activity differ such that gradual adjustment may not be the most useful mechanism for smoothing the short rate's dynamics; our main results demonstrate that (2) fits the survey data extremely well without it; and, we wish to avoid the effects of the ZLB on our forecast data, and using a shorter horizon's short-rate forecast (in the adjustment term) works against this aim.

3.2 Rules Using Historical Data

To compare the forecast-data-based rule to conventional policy rule estimates based on historical data, we consider the equation

$$i_{A,t} = C + \beta\pi_{A,t} + \delta u_{A,t} \tag{3}$$

where $i_{A,t}, \pi_{A,t}, u_{A,t}$ are the *actual* values of the policy, inflation and unemployment rates in month t. Absent data to discipline their evolution, we assume that r^*_A, π^*_A, u^*_A are time-invariant constants.

3.3 Estimation Methodology

To answer our main question we test for parameter breaks around the onset of the global financial crisis in a simple least squares specification. We estimate the regression

$$i_t = \sum_{b=1}^{B} \mathbb{1}(t \in \tau_b) Rule\,(\beta_b, \delta_b, \pi_t, u_t, \pi^*_t, u^*_t) + \epsilon_t. \tag{4}$$

B is one more than the number of breaks allowed and τ_b is the subset of time periods between break periods $b-1$ and b with the convention that break period 0 is the month prior to the start of our data. $Rule()$ denotes the right-hand-side of either (2) or (3) depending on whether we are using forecast or historical data, respectively.

When we estimate Equation 4 using forecast data we use (2) and so

$$Rule\,(\beta_b, \delta_b, \pi_t, u_t, \pi^*_t, u^*_t) = (r^*_{E,t} + \pi^*_{E,t}) + \beta_b(\pi_{E,t} - \pi^*_{E,t}) + \delta_b(u_{E,t} - u^*_{E,t})$$

and the dependent variable is $i_{E,t}$. This can be estimated by ordinary least squares run without a constant and using dummy variables to control for breaks. The residual from (2) is not a "shock" to monetary policy; instead, the estimated ϵ_t represents an *expected* future policy response that is uncorrelated with future inflation or real activity, a point to which we return in Section 4.2 below.

When we estimate Equation 4 using historical data we use (3) and so

$$Rule\,(\beta_b, \delta_b, \pi_t, u_t, \pi^*_t, u^*_t) = C_b + \beta_b\pi_{A,t} + \delta_b u_{A,t}$$

and the dependent variable is $i_{A,t}$. This can be estimated by ordinary least squares including a constant and using dummy variables to control for breaks. Recall that the constant will break if we allow for $B > 1$. The residuals from (3) resemble what previous literature has interpreted as monetary policy "shocks."

Our inference is based on heteroskedasticity and autocorrelation robust (HAC) standard errors calculated as in Newey and West (1987). We found that three lags in the Bartlett kernel is sufficient to capture the serial correlation evident in the estimated residuals ϵ_t.

4 Estimation Results

We compare results obtained using historical data to our main results using forecast data from the Blue Chip Economic Indicators. We find qualitative agreement between the two estimation approaches on the pre-ZLB sample, supporting the idea that forecast and historical data reveal similar policy response functions while both types of data are uncensored. We then confirm that historical data during the ZLB provide coefficient estimates that are essentially zero because of data censorship. On the other hand, using forecast data during the ZLB we find statistically significant policy response coefficients. Furthermore, we find evidence that the inflation response diminished, with a post-crisis point estimate below 1, while the unemployment response is unchanged.

We explore whether our conclusions are robust to including an additional parameter break around the year 2000, which has been found by previous studies. When we do so, we estimate that the policy response to unemployment was extraordinarily strong in the pre-ZLB 2000s and therefore that the post-crisis unemployment response is significantly weaker. We continue to find that the policy response to inflation significantly with the onset of the global financial crisis.

We then investigate the part of forecasted policy that is not associated with forecasted inflation or unemployment. We find a significant relationship between our estimated short-rate residuals and measures of investors' perceived risk, suggesting that market participants believe the Fed sets policy in response to financial market risk as well as to fundamentals at the business cycle frequency. Finally, we use our estimates, realized data, and Blue Chip forecast data to analyze the counterfactual implied short rate since the onset of the ZLB. We find that the implied short rate forecasted from this paper's draft date (February 2013) corresponds well to price-based forecasts of future short rates obtained from OIS only if we use this paper's new post-crisis policy rule estimates and not the coefficients estimated on historical data prior to the ZLB. This lends price-based support for the survey-based estimates we calculate in this paper.

4.1 Parameter Estimates

To place our main results in context, we first report estimates obtained on historical data in Table 1.[13] In all cases, the fit is quite good and a linear function of actual inflation and unemployment explains over 75% of the variation in actual short rates. Pre-ZLB estimates agree with typical estimates of Taylor rule parameters. The pre-ZLB inflation response satisfies the Taylor principle (i.e. are greater than one) and the unemployment coefficients

[13] In this paper, we do not report the estimated constant in the tables because it does not uniquely identify a policy parameter of interest. In practice the estimated constant shifts between periods—the pre-ZLB point estimate is 5.10, and the ZLB point estimate is 0.25.

Table 1: Historical Data Results

	Full Sample	Break pre-ZLB	Break ZLB
Inflation response	1.551	1.943	-0.034
standard error	(0.108)	(0.108)	(0.035)
LR test		*< 0.001*	
Unemployment response	−0.714	−1.277	−0.008
standard error	(0.076)	(0.098)	(0.021)
LR test		*< 0.001*	
R^2	0.788	0.853	

Notes: Monthly data from Federal Reserve Board of Governors and BLS, January 1986 to August 2011. The short rate is measured by the 3-month T-Bill, inflation is measured by core-CPI inflation. In the panel denoted Break, a break is allowed at December 2008. HAC standard errors are provided in parenthesis. Rows marked *LR test* reports the p-value for the likelihood ratio (Chow) test of no break in the indicated parameter, allowing other parameters to break.

are significantly negative.

On the other hand, ZLB period estimates are indistinguishable from zero. But this result is exactly as expected since the actual short rate contains no meaningful variation (with respect to the Federal Reserve's policy response rule) since hitting the ZLB.

Now we turn to our benchmark results using forecast data reported in Table 2. Once again, the fit is quite good and a linear function of expected inflation and unemployment explains over 75% of the variation in expected short rates. This is reasonable since simple rules are widely used to communicate policy, as described in speeches by Kohn (2007) and Bernanke (2010). Pre-ZLB estimates from forecast data are similar to pre-ZLB estimates from historical data. But unlike with historical data, ZLB period estimates from forecast data are statistically significant because one-year-ahead forecasts of future policy and fundamentals contain meaningful variation even after the onset of the global financial crisis.

Therefore, we can statistically address our main question: Did the Federal Reserve's response to inflation and unemployment change after the global financial crisis? Our answers are given in the form of likelihood ratio (Chow) test results reported in the rows marked *LR test* in Table 2. In each, the p-value is of the null hypothesis that the indicated parameter is unchanged around the crisis, while other parameters are permitted to break.

There is evidence that the Federal Reserve's response to inflation significantly fell since the onset of the global financial crisis: The likelihood ratio test has a p-value of 0.07. While

Table 2: FORECAST DATA RESULTS

	Full Sample	Break: pre-ZLB	Break: ZLB
Inflation response	1.712	1.772	0.755
standard error	(0.276)	(0.280)	(0.347)
LR test		*0.067*	
Unemployment response	−0.658	−0.801	−0.804
standard error	(0.063)	(0.147)	(0.090)
LR test		*0.979*	
R^2	0.775	0.792	

Notes: Monthly data from Blue Chip Economic Indicators, median forecasts, January 1986 to August 2011. The forecasted policy rate is measured by the forecasted 3-month T-Bill, forecasted inflation is measured by forecasted CPI inflation. In the panel denoted Break, a break is allowed at December 2008. HAC standard errors are provided in parenthesis. Rows marked *LR test* reports the p-value for the likelihood ratio (Chow) test of no break in the indicated parameter, allowing other parameters to break.

pre-ZLB point estimate of 1.8 is quite similar to estimates obtained in previous literature (including the 1.9 we estimate on historical data in Table 1), we find a much smaller ZLB point estimate of 0.75, falling underneath the value of 1 that is associated with the Taylor principle of inflation stabilization (albeit not significantly). Prior to the global financial crisis, the short rate rose about 180 basis points for each percentage point rise in inflation. Since the crisis, the perceived short-rate response is about 75 basis points per percentage point of inflation.

On the other hand, we fail to find evidence that the policy response to unemployment has changed: The likelihood ratio test has a p-value of 0.98. We estimate that the policy rate falls about 80 basis points for every percentage point rise in the unemployment rate, and did so both before and after the onset of the global financial crisis. Hence, we find no evidence that Federal Reserve has shifted the market's perception of its response to unemployment since the global financial crisis.

4.1.1 A Case of Multiple Breaks

Ang, Boivin, Dong and Loo-Kung (2011) and Hamilton, Pruitt and Borger (2011) suggest that monetary policy (especially as perceived by market participants) changed going into the 2000s. Therefore we consider the effect of controlling for another breakpoint in our

Table 3: FORECAST DATA RESULTS WITH TWO BREAKS

	pre-2000	2000-2008	ZLB
Inflation response	1.215	1.821	0.755
standard error	(0.227)	(0.511)	(0.347)
LR test		*0.019*	
Unemployment response	−0.301	−1.683	−0.804
standard error	(0.093)	(0.407)	(0.090)
LR test		*< 0.001*	
R^2		0.870	

Notes: Monthly data from Blue Chip Economic Indicators, median forecasts, January 1986 to August 2011. The forecasted policy rate is measured by the forecasted 3-month T-Bill, forecasted inflation is measured by the forecasted CPI inflation. A break is allowed at January 2000 and December 2008. HAC standard errors are provided in parenthesis. Rows marked *LR test* reports the p-value for the Chow test of the following null hypothesis: All parameters break in 2000, and all but the indicated parameter break in 2008. The alternative hypothesis is that all the parameters break in 2000 and 2008.

estimation around January 2000. Table 3 reports the results.[14]

The results are qualitatively similar to our benchmark findings in Table 2. We estimate that the policy response to unemployment was extraordinarily strong in the pre-ZLB 2000s—a short rate decrease of 170 basis points for each 1 percentage point increase in unemployment. This is much larger than the response of 30 basis points in the 1980s and 1990s. From this large unemployment response during 2000–2008, we now find statistical evidence for a decrease in unemployment response during the ZLB. However, the post-crisis response is still strong (80 basis points for each percentage point of unemployment) and much higher than the unemployment response prior to 2000.

We continue to find that the policy response to inflation significantly fell following the global financial crisis, and the statistical significance of the parameter break increases (p-value of 0.02) in this alternative specification. We view this as support for the main result given in Table 2, which hereafter we discuss in greater detail.

[14]It is necessarily the case that the "ZLB" estimates in Table 3 are identical to those in Table 2.

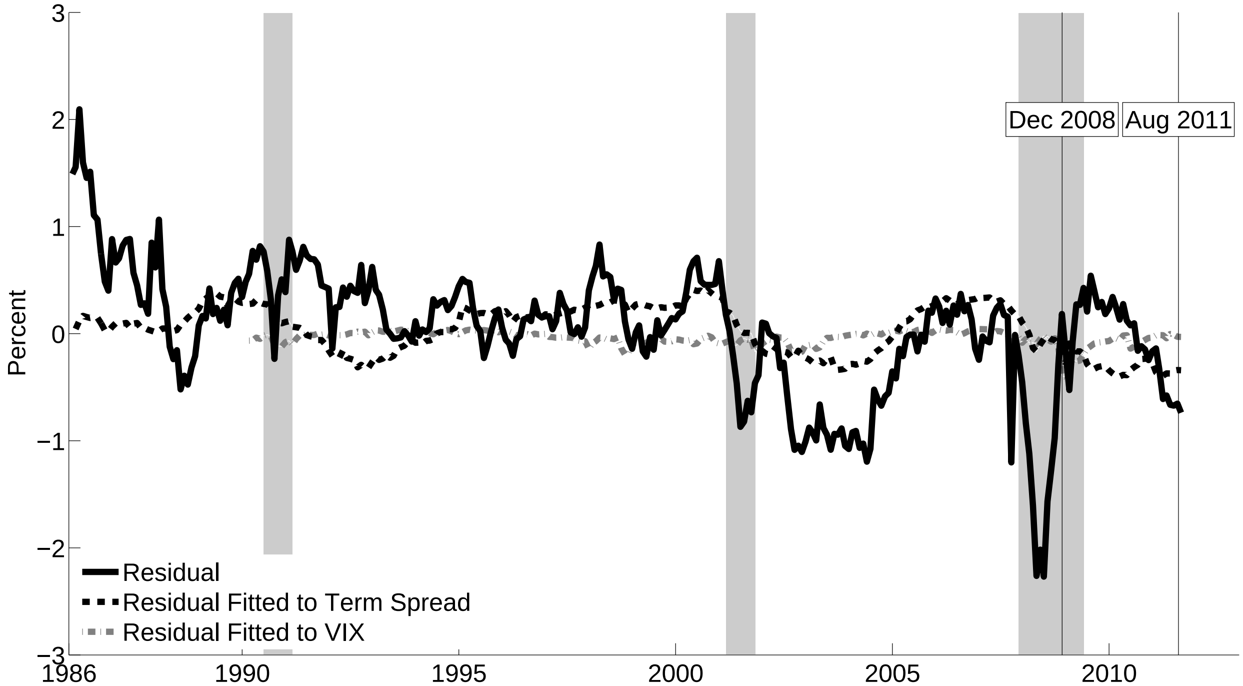

Figure 4: Residuals of the One-Year Ahead Short-Rate Equation

Notes: Residual from the benchmark model, solid line; and fitted residuals from various measures of risk. The values fitted to the term premium (difference between 10-year and 2-year yields) is the dashed line; the values fitted to the VIX from the CME is the dotted line.

4.2 Understanding the Residuals

Turning back to our benchmark results of Table 2, the solid line of Figure 4 represent the residuals from the one-break regression.[15] As previously mentioned, in a conventional policy rule regression using (3) with realized data, residuals are often interpreted as capturing policy "shocks." However, in our benchmark rule using (2) with forecast data, the residuals represent a shift of expected policy that is not accounted for by a linear combination of inflation and unemployment forecasts. We find a few features noteworthy. First, Greenspan's chairmanship starting in mid-1987 was characterized by reasonably small residuals until around 2001. This means that forecasters believed that short rates largely reflected economic conditions according to a simple Taylor rule.

In the first half-decade of the 21st century, the residuals are persistently negative. This implies that market professionals during this time expected more expansionary policy than would otherwise be called for by economic conditions. Starting in 2005 the expected expan-

[15] As mentioned above, our inference is robust to serial correlation in the residuals—Figure 4 makes clear that this robustness was required.

sionary boost is steadily removed, and by the time of Bernanke's chairmanship starting in early 2006 the residuals are nearer to zero. However, in late 2007 an expansionary boost emerges and spikes in early 2008 as the recession gains momentum. The negative residuals just as quickly vanish at the end of 2008 as expectations of future economic deterioration caught up to the very stimulative expected future policy.

What accounts for the residuals' fluctuation? Atkeson and Kehoe (2009) argue that "business cycle movements of the short rate arise as a result of the Fed's endogenous policy response to exogenous business cycle fluctuations in risk." Hence, an important component of these residuals' evolution may come from forecasters' perceived risk.[16]

We first proxy for risk by the term premium, defined as the difference between 10-year and 2-year bond yields, which previous literature suggests captures investors' perception of financial market risk at a business cycle frequency.[17] A regression of the residuals on the term spread shows a strong connection that is both economically and statistically significant: The coefficient estimate is -0.25 with HAC standard error of 0.04 and R^2 of 15%. The estimate implies that forecasters translate a 100 basis point *increase* in the term spread with about a 25 basis point *decrease* in the future policy rate, irrespective of what inflation and the unemployment rate are forecasted to be.

The dashed line in Figure 4 plots the residuals that are fitted to the term premium. The fit is reasonably good at a business cycle frequency during the 2000s until the crisis begins at the end of 2008. Thereafter, the fitted values move in an opposite direction from the residuals. We find this interesting because one of the Fed's *unconventional* policy responses (including large-scale asset purchases) during the ZLB period has been to target medium-maturity treasuries, directly affecting the measured term premium. If prior to the crisic our policy residuals are indeed capturing the market's perceived risk, then the term-premium fitted values might move contrarily during the crisis because the Fed is directly lowering the measured term premium yet not lowering overall market risk.

A second measure of financial market conditions is the CME's VIX index, which is available only since 1990, and its fitted values are plotted as the dash-dotted gray line in Figure 4. We find no evidence of a statistically significant connection between the VIX and the policy residuals. This is perhaps unsurprising given Atkeson and Kehoe's (2009) argument that the Fed responds to risk at a business cycle frequency, not high-frequency financial market conditions. Hence, the VIX appears to largely capture financial market conditions to which the Fed *does not* respond.

[16]We also ran a regression of the residuals on nowcasts of unemployment and inflation (as well as their forecasts) to check if the shifts reflect economic conditions at the time of the forecasts or dynamic adjustment. The coefficients were statistically insignificant and the variation explained minimal.

[17]We are careful here to measure the term premium in the month *before* the survey month, since the economic indicator survey is collected during the first few days of the month it is released, therefore the prior month's bond prices are what is known to survey respondents at the time they report their forecasts.

4.3 Making Use of Estimation Results

In any regression analysis, estimation results are usually used for two purposes: In-sample and out-of-sample analyses. To perform an out-of-sample analysis, it is important to obtain an in-sample estimation period that has a similar characteristic to the out-of-sample period in mind. Since it is commonly believed that many economic phenomena might have changed with the emergence of the global financial crisis, it is critical to estimate policy rules with a sample after 2008—as we do in this paper.[18] We make use of estimation results based on forecast data between December 2008 and August 2011 in three ways.

First, noting that the actual federal funds rate is essentially zero during this period and afterwards, it is of immense interest what the unconstrained nominal short-term interest would be were it not for the zero lower bound (see Rudebusch 2009). Second, as of this writing (February 2013) the target funds rate is at the zero lower bound, and one of the most important topic in financial circles is when the short rate will be lifted from the zero lower bound, and why. We use our estimation results to answer this question. Third, it is interesting to understand how the perception of financial markets evolves. Our data and estimation results shed light on how the perceptions moved in the past in response to explicit Federal Reserve communication.

4.3.1 Unconstrained Short-Term Rate

In Figure 7, the circled-red and squared-blue lines represent the inflation gap and the unemployment gap, respectively, that are constructed using each month's long-horizon forecasts subtracted from the actual values observed. Until December 2008, the solid black line is the historical short-term interest rate, but thereafter the solid line represents the short rate that our benchmark estimation produces when the independent variables are the actual inflation and unemployment gaps observed.[19] The line implies that, were there no ZLB, the unconstrained interest would have rate decreased through late 2010, when the it goes below -2.5 percent, and afterwards increased as economic conditions bottomed out.

Our estimation sample ends in August 2011, when the FOMC introduced forward guidance that was effective beyond the one-year horizon. However, this does not prevent us from extending the calculation of implied rates (using the ZLB rule) after August 2011. The

[18] Of course, it is necessary to assume that the in-sample relationship still holds out of sample after August 2011. We realize that there are significant changes in the monetary policy (e.g. forward guidance and large-scale asset purchases), but our working assumption is that the relationship of (2) remains stable both in sample and out of sample. As pointed out in Wright (2012), using asset purchases in identifying a policy change is also problematic since asset purchases affect asset prices at the announcement rather than when purchases are actually made.

[19] A one-time intercept shift is allowed on December 2008so that the implied rate smoothly pastes onto the actual short rate prior to the ZLB. Figure 4 at the December 2008 vertical line shows that this intercept shift is slight as the December 2008 residual is small.

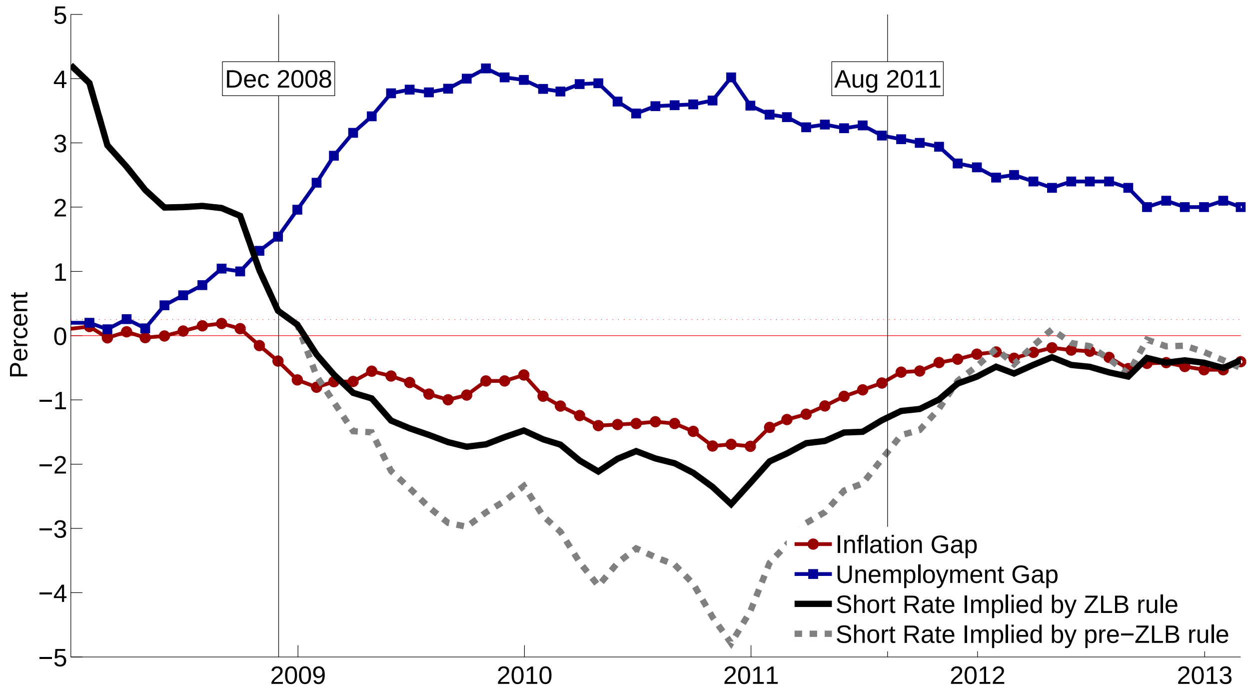

Figure 5: ESTIMATED INFLATION GAPS, UNEMPLOYMENT GAPS AND IMPLIED SHORT RATES

Notes: Actual unemployment and core-CPI inflation from BLS data combined with Blue Chip long-horizon unemployment, inflation and real rate forecasts to construct estimated gaps. Implied short rates use the long-horizon forecasts and estimated gaps along with ZLB parameter estimates in Table 2 and pre-ZLB parameter estimates in Table 1. A small intercept shift is allowed on December 2008 so that the implied rate smoothly pastes onto the actual short rate prior to the ZLB.

solid line until the end of Figure 7 is based on the actual inflation and unemployment gaps observed (using the long-horizon forecasts to construct the gaps). As economic conditions improved implied rates rose.

We also calculate an alternate implied rate in Figure 7 based on our estimates of the pre-ZLB rule estimates from historical data. The short rate implied by the pre-ZLB rule (the gray dashed line) exhibits a sharper drop than what is implied by the ZLB rule (the black solid line), since the inflation response based on the pre-ZLB rule is bigger than that based on the ZLB rule.[20]

4.3.2 Timing of the Lift-Off from the ZLB

The black solid line of Figure 6 from February 2013 until August 2014 is based on economic forecasts that are available in the most recent issue (February 2013) of Blue Chip Economic

[20]The policy rule based on pre-ZLB forecast data is similar—see Figure A1 in the appendix.

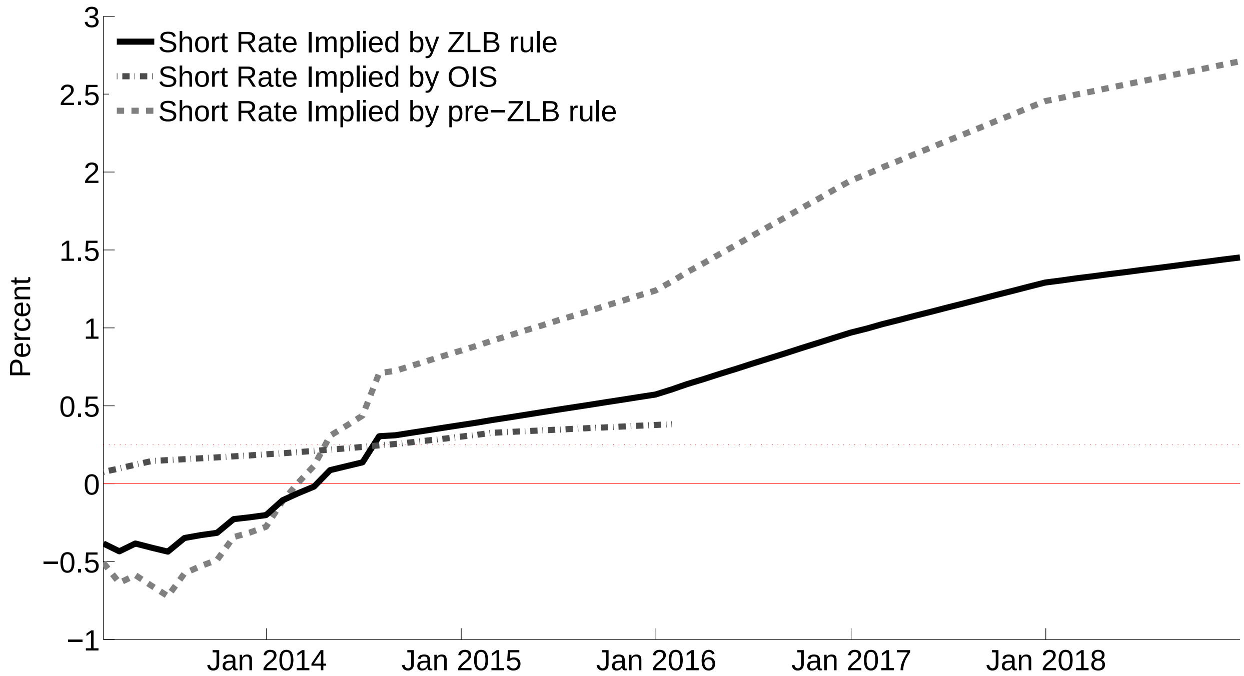

Figure 6: Expected Short Rates from Forecast Data and Overnight-Index-Swaps

Notes: Through August 2014, short rates implied by rules use unemployment and inflation forecasts from the most recent (February 2013) Blue Chip survey; thereafter we use annual forecasts from the October 2012Blue Chip issue: These forecasts combine with Blue Chip long-horizon unemployment, inflation and real rate forecasts to construct estimated gaps. Implied short rates use the long-horizon forecasts and estimated gaps along with ZLB parameter estimates in Table 2 and pre-ZLB parameter estimates in Table 1. Short rates implied by OIS used Bloomberg overnight-index-swap (OIS) implied rates with a rule-of-thumb one-half basis-point per month risk premium adjustment.

Indicators. Thereafter, the solid line is extended for the next five years using the annual forecasts available in the October 2012 issue.[21] Notice a remarkable discrepancy between the expected short rates implied by the pre-ZLB versus ZLB rules.

Figure 6 also includes a third forecast of future short rates, based on overnight-index-swaps (OIS), depicted as the dash-dotted dark-gray line extended until early 2016. The OIS-based forecastes come from market price data that were not used anywhere before in our estimation. We incorporate a rule-of-thumb risk premium adjustment of one-half basis-point per month to translate OIS rates to expected future short rates. Comparing the two solid lines, we see a close correspondence between the policy rates implied by the ZLB rule

[21] Together with the long-run forecasts, the annual forecasts for the next five years are available in March and October Blue Chip surveys. These annual forecasts are "year-over-year." Therefore we interpret each forecast as pertaining to December of that year (e.g. the forecast for 2015 is the expected value in December 2015) and then linearly interpolate between Decembers to create the smooth forecasts seen in Figure 6.

(the black line) and the policy rates implied by OIS (the gray line). In contrast, the policy rate implied by the pre-ZLB rule (the dashed gray line) estimates a far higher future path for the fed funds rate and an earlier lift-off in the first-half of 2014.

Both the ZLB rule and OIS suggest that market participants currently (as of February 2013) expect short rates to lift-off from the effective zero-lower-bound range of "0 to 1/4 percentage points" sometime in the second-half of 2014, earlier than Federal Reserve communication has indicated. In the case of OIS, this expectation is obtained via risk-adjustment that is necessary to translate asset prices to market expectations. Risk adjustment is model-dependent and therefore different models may lead to different dates for the expected lift-off date—clearly the expected lift-off date would shift to sooner (later) were intervening risk premia estimated to be larger (smaller).[22] Hence, survey-based measures of the expected lift-off date augment price-based measures since surveyed forecasts of future inflation and unemployment do not require model-based risk-adjustment. Meanwhile, the correspondence between survey-based and price-based expected short rates depends on the policy rule used to construct the former. We find it crucial to account for a structural break in the Federal Reserve's inflation response in order to properly calculate implied future policy rates that accord with price-based evidence.

Going further, our analysis provides a decomposition of the expected lift-off into different components, something not possible using OIS data alone. In particular, Figure 7 shows the forecasted inflation gap (the solid line with circles) and the forecasted unemployment gap (the solid line with squares). The figure makes it clear that the short rate is expected to rise largely in response to labor market normalization, as the unemployment gap gradually closes from 2% to 0% at the end of 2018. In contrast, the inflation gap is expected to be close sometime in mid-2016, despite the Fed's expansionary forward guidance.

Referring again to Figure 2, recall that long-horizon inflation forecasts came *down* during 2012. Therefore, small forecasted inflation gaps reflect low inflation expectations going forward, not a shift up in the market's perception of the Federal Reserve's long-run inflation target. Taken altogether, the survey data suggests that Federal Reserve communication has shifted β but not π^* in (1)—the change in Federal Reserve policy is how the economy transitions to steady-state, and not a shift in the steady-state rate of inflation.[23]

[22]Over the three years on which we focus attention, our simple rule-of-thumb adjustment is similar in magnitude to risk premia estimated by more sophisticated term structure models.

[23]Our results for the policy response to unemployment are less robust. While our benchmark results in Table 2 suggest *no change* in response, this is not robust to allowing for earlier breaks in policy, wherein we find a significant *fall* in Table 3. A fall in the unemployment response would be a contractionary policy shift, and so our results are mixed.

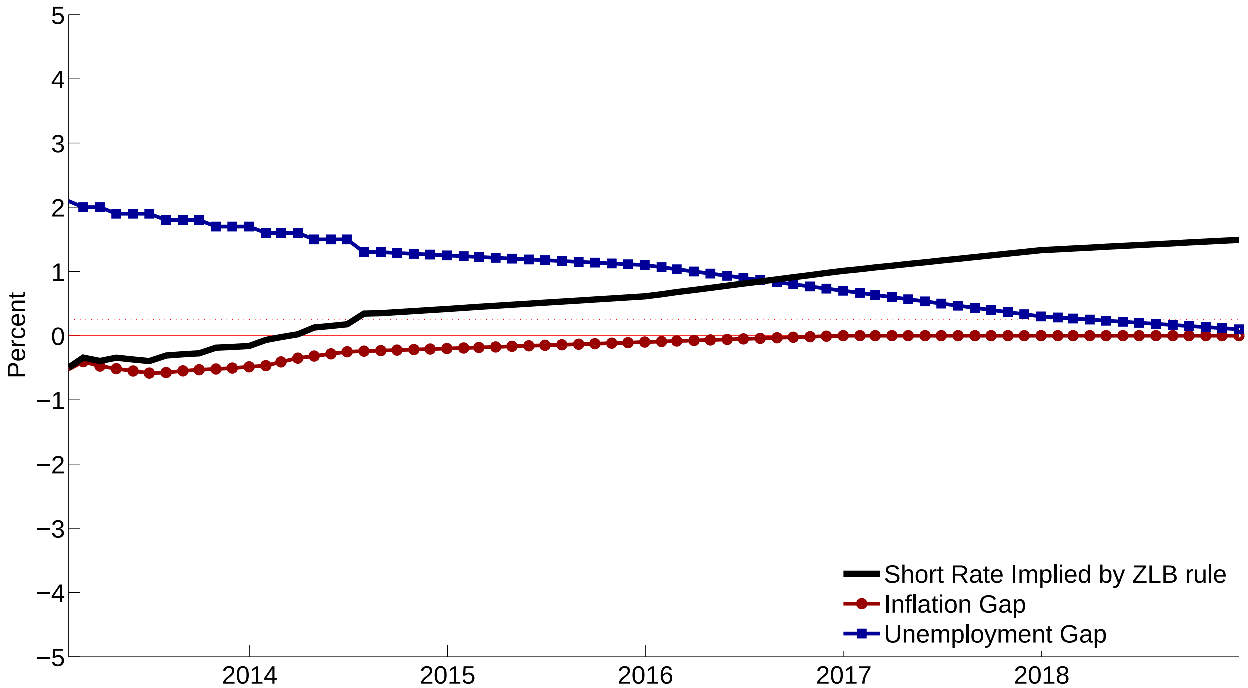

Figure 7: Estimated Inflation Gaps, Unemployment Gaps and Implied Short Rates

Notes: Through August 2014, short rates implied by rules use unemployment and inflation forecasts from the most recent (February 2013) Blue Chip survey; thereafter we use annual forecasts from the October 2012Blue Chip issue: These forecasts combine with Blue Chip long-horizon unemployment, inflation and real rate forecasts to construct estimated gaps. Implied short rates use the long-horizon forecasts and estimated gaps along with ZLB parameter estimates in Table 2. Short rates implied by OIS used Bloomberg overnight-index-swap (OIS) implied rates with a rule-of-thumb one-half basis-point per month risk premium adjustment.

4.3.3 The Evolution of Market Expectations

Based on our preceding discussion of current (February 2013) expectations for the lift-off, one might ask how the forecasted lift-off point has moved in the past. We investigate how market expectations have evolved and suggest that Federal Reserve communication may have influenced the evolution.

The solid line of Figure 8 repeats the implied short rate based on the ZLB rule, from Figures 7 and 6.[24] The left-most light-gray dashed line is based on the forecasts as of August 2011, and the left-most light-gray dotted line, as of September 2011. These two lines are significantly different, as much as 50 basis points in early 2013. In the August 2011 FOMC meeting, the Committee announced that the policy rate will be kept low "at least through

[24]The complete evolution of forecasted inflation gaps, unemployment gaps, and implied policy rates (from the ZLB policy rule) are found in Figures A2, A3 and A4, respectively, in the appendix.

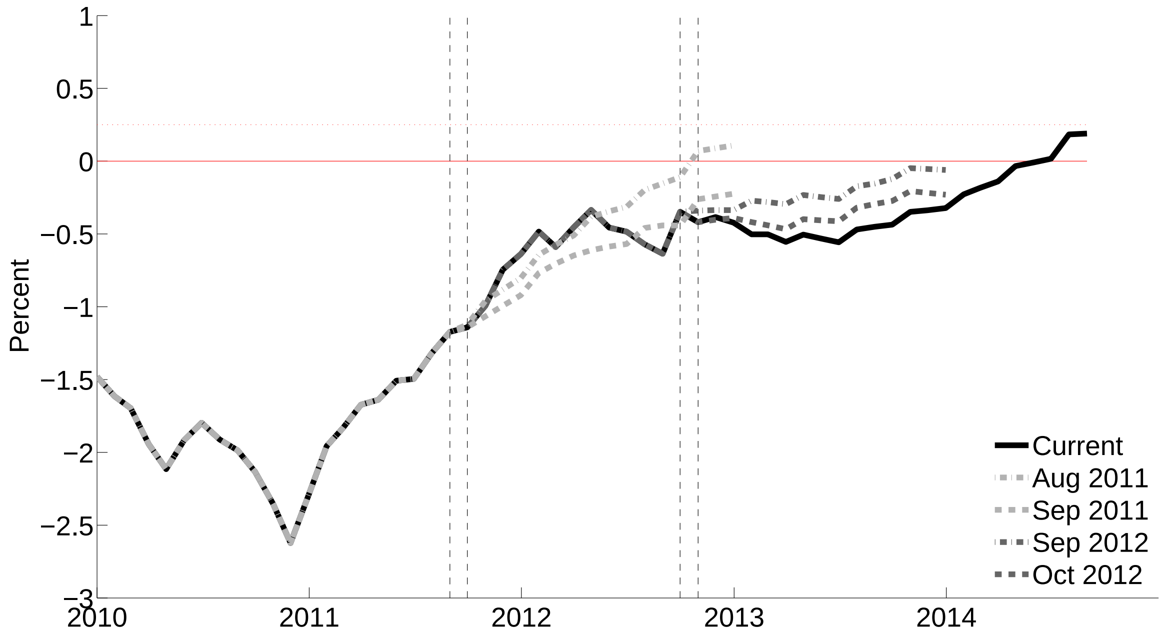

Figure 8: Evolution of Forecasted Inflation Gaps, Unemployment Gaps and Implied Policy Rates

Notes: Inflation gap, unemployment gap and implied short rates from "Current" (February 2013), August 2011, September 2011, September 2012 and October 2012 Blue Chip surveys. Implied short rates use the long-horizon forecasts and estimated gaps along with ZLB parameter estimates in Table 2.

mid-2013." The difference between the two lines can be attributed to the communication of the Federal Reserve. One can see that this policy guidance appreciably shifted out the expected lift-off date—whereas prior to the August 2011 FOMC implied short rates were expected to break the ZLB in 2013, immediately after the August 2011 FOMC implied short rates were expected not to.

As another episode when the market perception changed significantly, the right-most dark-gray dashed line and the right-most dark-gray dotted line correspond to surveys in September and October of 2012, respectively. The path of forecasted short rates moved lower from September to October. This is noteworthy since the Committee announced strengthened calendar-based forward guidance to "at least through mid-2015" at the September 2012 FOMC meeting. These two episodes are anecdotal evidence on how Federal Reserve communication affects the evolution of market expectations.

As we get closer to the normalization of the policy rate, these market expectations will be a important factor in setting up an exit strategy. Our results suggest that while the Federal Reserve's actions during the ZLB have not appreciably raised the market's perception of the Federal Reserve's inflation target, they have altered the market's perception of how the Federal Reserve responds to deviations of inflation from target. This information is important when interpreting the market's response to Federal Reserve actions going forward.

In particular, reiterating Section 4.3.2, our evidence points to very little change in the market-perceived inflation target, but a large shift in how markets believe the Federal Reserve responds to inflation gaps. Furthermore, we found no evidence that markets believe the Federal Reserve is more responsive to unemployment slack than prior to the global financial crisis. This means that future policy accommodation—short rates consistently held below what inflation and unemployment pressures suggest—would largely be interpreted as a manifestation of the Federal Reserve's higher tolerance for deviations of inflation from target, instead of a greater emphasis on reacting to unemployment.

5 Conclusion

It is crucial to policymakers that they understand how their behavior is perceived by financial markets. Given the ongoing global financial crisis, it is quite natural to ask: Have policymakers' behavior, or markets' perceptions thereof, changed? But the conventional method of empirically answering this question is unavailable because short rates are censored due to the zero lower bound. We get around this hurdle by using surveys of professional forecasters. The surveys allows us to use a simple regression to estimate the policy rule that has prevailed, at least in professional forecasters' perception, since the onset of the global financial crisis. We find that this policy rule is different than the one prevailing prior to the global financial crisis.

We find that the Fed's inflation response has significantly fallen, by more than half. This could portend troublesome times ahead when the Fed does start to combat inflation, or instead this could reflect the success of the Fed's expansionary forward guidance that "a highly accommodative stance of monetary policy will remain appropriate for a considerable time after the economic recovery strengthens." Meanwhile, the Fed's response to unemployment has stayed strong throughout the pre-crisis and crisis periods.

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A Appendix

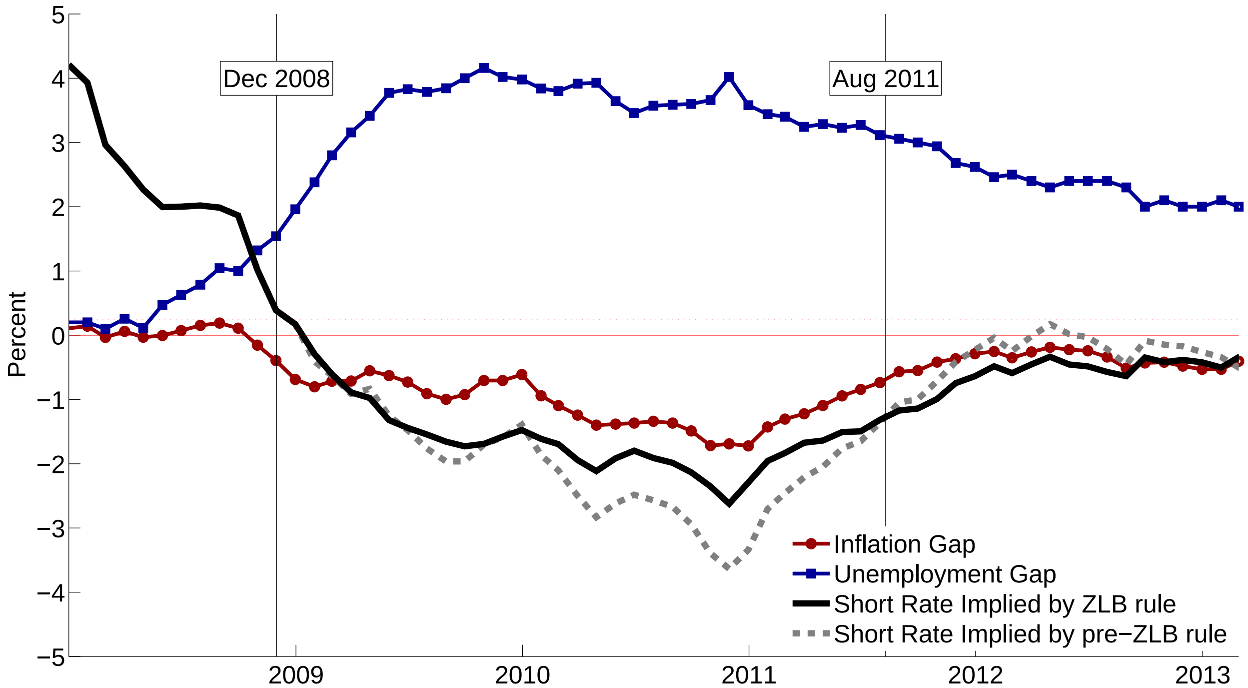

Figure A1: Estimated Inflation Gaps, Unemployment Gaps and Implied Short Rates

Notes: Actual unemployment and core-CPI inflation from BLS data combined with Blue Chip long-horizon unemployment, inflation and real rate forecasts to construct estimated gaps. Implied short rates use the long-horizon forecasts and estimated gaps along with ZLB parameter estimates in Table 2 and pre-ZLB parameter estimates in Table 2. A small intercept shift is allowed on December 2008 so that the implied rate smoothly pastes onto the actual short rate prior to the ZLB.

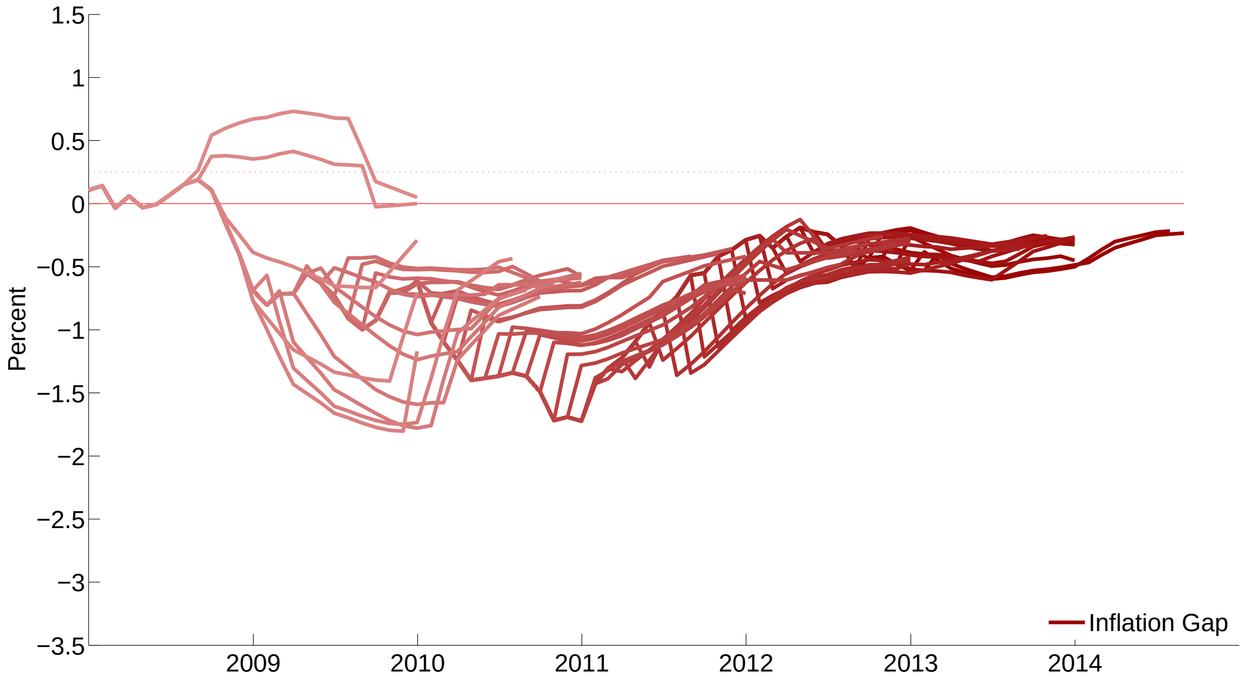

Figure A2: Evolution of Forecasted Inflation Gaps

Notes: Inflation gap from September 2008 through February 2013 Blue Chip surveys.

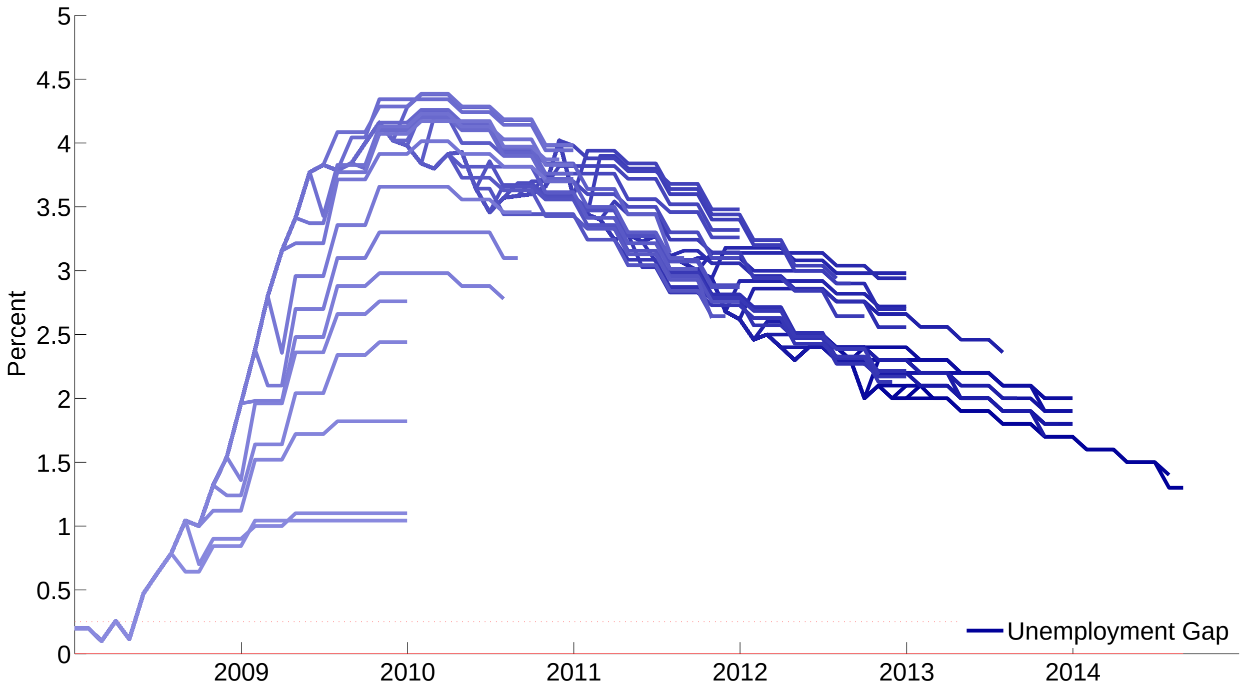

Figure A3: Evolution of Forecasted Unemployment Gaps

Notes: Unemployment gap from September 2008 through February 2013 Blue Chip surveys.

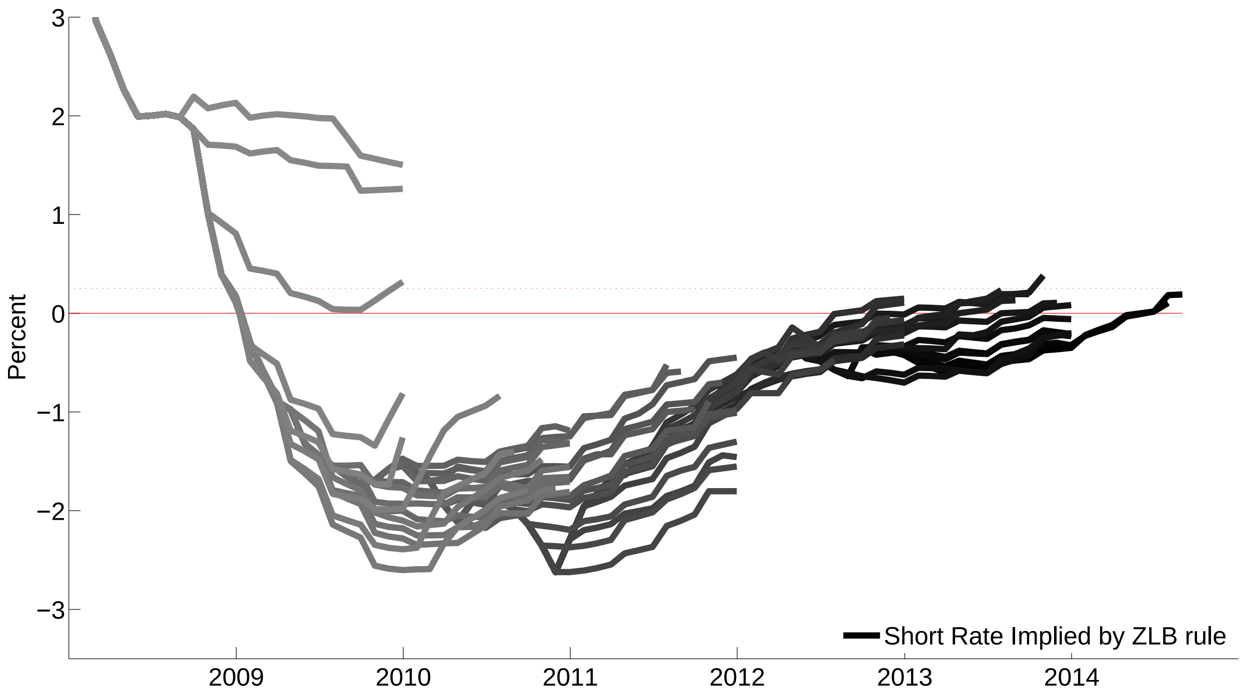

Figure A4: Evolution of Forecasted Short Rates

Notes: Implied short rates from September 2008 through February 2013 Blue Chip surveys. Implied short rates use the long-horizon forecasts and estimated gaps along with ZLB parameter estimates in Table 2.