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How Has Empirical Monetary Policy Analysis Changed After the Financial Crisis?*

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Abstract

In the wake of the Great Recession, the Federal Reserve lowered the federal funds rate target essentially to zero and resorted to unconventional monetary policy. With the nominal FFR constrained by the zero lower bound (ZLB) for an extended period, empirical monetary models cannot be estimated as usual. In this paper, we consider whether the standard empirical model of monetary policy can be preserved without breaks. We consider whether alternative policy instruments (e.g., the size of the balance sheet) can be considered substitutes for the FFR over the ZLB period. Furthermore, we construct a shadow rate via the method proposed in Krippner [2012] to represent an alternative measure of the stance of monetary policy and compare this with the shadow rate of Wu and Xia [2014]. We ask whether the shadow rate is a sufficient representation of the policy instrument or if the financial crisis requires other modifications. We find that, if using a dataset that spans the pre-ZLB period throughout the ZLB environment, the shadow rate acts as a fairly good proxy for monetary policy by producing impulse responses of macro indicators similar to what we’d expect based on the post-WWII, non-ZLB benchmark. However, the linear model exhibits a significant structural break at the onset of the ZLB and the shadow rate may still be insufficient for examining the ZLB period in isolation.

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1 Introduction

Since the onset of the Financial Crisis and Great Recession, monetary policy in the U.S. and around the world has taken unprecedented measures in an effort to stimulate the economy. The Federal Reserve, for example, lowered its primary policy instrument—the federal funds target—essentially to zero.\(^1\) At that point, the primary policy instrument became ineffective due to the nominal bound at zero and the Fed was forced to resort to unconventional monetary policy.\(^2\)

From the standpoint of academics, this period presents an important problem for assessing the effects of monetary policy. Many monetary models use the effective nominal fed funds rate as the primary policy instrument. With the nominal funds rate constrained by the zero lower bound (ZLB) for an extended period, empirical monetary models cannot be estimated as usual.

The empirical literature offers a number of remedies. First, we could treat the ZLB period as special, using either breaks or dummies to represent changes in economic relationships.\(^3\) Second, we could include alternative policy instruments, such as the size of the balance sheet or dummies representing the implementation of unconventional policies. These two alternatives have the disadvantage of increasing the number of estimated parameters for a period that, presumably, represents a short sample. Third, we could replace the FFR as the conventional stance of monetary policy with a proxy that is allowed to violate the ZLB and that captures the effects of both conventional and unconventional policy.

Since the financial crisis, academics have proposed such measures of the accommodation in monetary policy when the short rate is at the zero lower bound. Recently, Krippner [2012] and Wu and Xia [2014] have used the shadow rate methodology to construct alternative measures of the stance of policy. Krippner [2012] builds on Black [1995] and Gorovoi and Linetsky [2004], modeling interest rates as options by calculating the value of a call option to hold cash.\(^4\) The modifications in

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\(^1\)Friedman [2010] describes a detailed timeline of the sequence of steps taken by the Fed along with significant market events. Williams [2011] presents a review of the unconventional monetary policy tactics employed to combat the financial crisis.

\(^2\)Unconventional monetary policy used in the U.S. included quantitative easing (QE), large scale asset purchases (LSAPs), and forward guidance. Walsh [2010] discusses the channels through which quantitative easing could stabilize the economy. Wright [2011] analyzes how long-term interest rates respond to LSAP’s in a ZLB environment. Gagnon et al. [2011] present the mechanisms through which these purchases affect the overall macroeconomy. Campbell et al. [2012] discuss the effects of forward guidance.

\(^3\)This option could be considered the most extreme as it suggests that the effect of monetary policy is potentially time-varying [see, for example, Aastveit et al. [2014]]. If the effectiveness of policy varies, the Fed must reconsider at each moment the conduct of policy and the appropriate instruments.

\(^4\)Black [1995] modified the typical Gaussian affine term structure model (GATSM) to eliminate the occurrence of
Krippner [2012] generate closed-form solutions for bond prices and yields. Rather than describing yields in a ZLB environment directly, Wu and Xia [2014] construct an analytical approximation of forward rates in discrete time. This allows for a more straightforward estimation approach than the other shadow rate methodologies and produces closed-form expressions for the shadow forward rates. Both models calculate a shadow short-term interest rate which would be seen in financial markets if the cash option did not exist. In principle, the Fed may have dropped the fed funds rate further if not for the nominal bound at zero. The shadow rate has been considered a proxy for the stance of monetary policy in an environment in which the zero lower bound is binding. From this foundation one can develop a full model of the shadow term structure based upon the shadow short rate depicting the fundamental policy objectives.

Most previous empirical models of the effects of policy were linear. If these shadow short rates are proper measures of the monetary accommodation, the underlying model would, in the best of worlds, still be linear and consistent across sub-periods. In this paper, we compare some of these new measures of monetary policy. We consider whether the standard empirical model of monetary policy can be preserved without breaks by using these measures. That is, we ask whether, during the ZLB period, there exists a linear relationship between the alternative instruments and standard macroeconomic variables so that the standard linear VAR can be preserved.

The question going forward is whether these new alternative shadow short rates are sufficient representations of monetary policy or if the financial crisis requires other modifications to the monetary model. We ask the following questions: (1) How large are the biases in the estimated impulse responses if one uses the FFR for the full sample? (2) Does adding policy dummies and the balance sheet of the Fed mitigate these biases? (3) Does replacing the effective funds rate a shadow short rate mitigate these biases? (4) Which shadow short rate does a better job at mitigating these biases?

We find that the shadow rate acts as a fairly good proxy for monetary policy, if using a dataset that spans the pre-ZLB period throughout the ZLB environment, by producing impulse responses.
of macro indicators similar to what we’d expect based on the post-WWII, non-ZLB benchmark. However, the linear model exhibits a significant structural break at the onset of the ZLB and the shadow rate may still be insufficient for examining the ZLB period in isolation.

The balance of the paper is organized as follows: Section 2 establishes the benchmark specification using standard empirical models to describe Fed policy in a normal, pre-ZLB environment. Section 3 examines how we can model some of the actions taken by the Fed at the zero lower bound in these standard models. In this section, we consider whether standard empirical models of monetary policy can be salvaged, either using new measures of policy, allowing for breaks in the effects of policy, and/or accounting for unconventional policy instruments. Finally, Section 4 concludes.

2 The Benchmark Specification

The short rate—often, an overnight rate—is one of the primary instruments for conducting monetary policy. When adverse shocks are large, monetary accommodation can drive the short rate close to zero. In practice, no-arbitrage conditions prevent nominal rates from falling below zero since agents can substitute out of bonds into cash. This feature of nominal interest rates can prevent a proper evaluation of the stance of monetary policy when the short rate is at or near zero and other instruments must be relied upon to conduct policy. In this section, we estimate a standard monetary VAR for the pre-crisis period (1960:I-2007:IV) and then naively extend the analysis with data for the financial crisis period.

Before we can determine whether empirical models of monetary policy have changed, we must first establish a baseline. We estimate a quarterly four-variable VAR(4) in output, inflation, commodity prices, and a policy instrument. For the baseline model, we include the effective FFR as the policy instrument:

\[ Y_t = A(L) Y_{t-1} + \varepsilon_t, \]

where \( A(L) \) is a polynomial in the lag operator, \( \varepsilon_t \sim N(0, \Sigma) \), and we suppress the constant and

\[ \text{Our measure of output is the annualized quarterly difference in the log of GDP taken from the BEA. Inflation is taken as the difference in the log of the CPI taken from the BLS. Commodity prices are the log differences in the Producer Price Index: All Commodities. All data are seasonally adjusted.} \]
any trends for notational simplicity. The monetary shock is identified by assuming that FFR can react to macro variables but the macro variables cannot contemporaneously react to shocks to the FFR. Partitioning $A(L)$ into blocks will facilitate exposition: Let $X_t$ represent the three macro variables of interest and $R_t$ represent the FFR. Then, we can rewrite the VAR as:

$$
\begin{bmatrix}
X_t \\
R_t
\end{bmatrix} = 
\begin{bmatrix}
A^X(L) & A^{RX}(L) \\
A^{XR}(L) & A^R(L)
\end{bmatrix}
\begin{bmatrix}
X_{t-1} \\
R_{t-1}
\end{bmatrix} + 
\begin{bmatrix}
\varepsilon^X_t \\
\varepsilon^R_t
\end{bmatrix},
$$

where $A^X(L)$ represents the effects of changes in the lagged macro variables on each other, $A^{RX}(L)$ represents the effects of policy on the macro variables, $A^{XR}(L)$ represents the feedback from macro variables to policy, and $A^R(L)$ represents the possible persistence in FFR.

The baseline data sample covers the period from 1960:I to 2007:IV, which starts after the Korean War price control period and ends prior to the financial crisis and generally corresponds with the standard VAR used for monetary analysis prior to the FFR hitting the zero lower bound.

The first column of Figure 1 shows the impulse responses for the VAR(4) outlined above using the effective nominal FFR as the policy instrument and data for the period ending in 2007:IV. The responses shown are to a 25 basis point shock to the effective nominal FFR ordered last in the VAR and identified using the Cholesky decomposition. The responses are computed for each draw of the sampler, generating the posterior coverage. The plots show the median response (black line) as well as the 95-percent posterior coverage intervals (blue shaded regions). The impulse responses are as expected: An increase in the policy rate causes output to fall and inflation to rise in the short run.

We next examine one of the challenges faced by academics posed by the ZLB period. We first estimate a linear VAR for the full sample (1960:I-2013:III) to show how the impulse responses would change if one did not account for the use of alternative monetary instruments. This VAR is what one would obtain by naïvely extending the sample through the ZLB period without accounting for

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6To preserve consistency with results in later sections, the VAR presented here is estimated with Bayesian methods. The prior is a zero mean Normal-inverse Wishart distribution. The posterior distributions are simulated using the Gibbs sampler.
the use of alternative monetary instruments.

The second column of Figure 1 shows the impulse responses for the VAR(4) outlined above using the effective nominal FFR as the policy instrument through the ZLB period. The plots show the median responses (dark green line) as well their associated 68-percent posterior coverage intervals (green shaded region) for the naive full-sample VAR extending the data through 2013:III. The thick dark blue lines and blue shaded regions give the impulse response median point estimates and their 68-percent posterior coverage for the benchmark specification in which the data end in 2007:IV. The responses resemble those of the baseline in both quantitative and qualitative terms—a contractionary policy shock results in a decrease in output, a recognizable price puzzle with increasing inflation, and increasing commodity prices.

The nominal funds rate does not move during the ZLB period. The ZLB period does not qualitatively change the resulting impulse responses to a monetary shock but does produce a slight quantitative bias. However, this exercise does not tell us much about the ZLB period itself since the conventional policy instrument effectively does nothing during this period. While the estimates are slightly biased, we can still effectively describe what happens in normal times but we do not know what happens in the ZLB period.

2.1 Testing for Parameter Instability

To model the ZLB period, one could impose a break at the time that the effective nominal funds rate hit the bound.\textsuperscript{7} We compare the pre- and full-sample VAR by conducting formal tests to determine the extent to which the model changed during the financial crisis. First, we compare Bayes Factors to determine the likelihood of parameter instability between the pre-ZLB and the crisis/ZLB period. We construct a dummy variable to indicate data from the crisis and post-crisis recovery ZLB period and test for varied responses of macro variables to the policy instrument over the transition to the ZLB environment. In each of the first three VAR equations, we include an interaction between the ZLB dummy variable and all lags of the policy rate. Therefore, the break

\textsuperscript{7}We assume that the onset of any potential parameter instability would take place after 2007:IV. Throughout 2008, the U.S. economy experienced substantial negative shocks, forcing the Fed to make drastic cuts in the FFR towards the ZLB. Once dropping the FFR target as low as possible at the end of 2008, the Fed sought unconventional measures to produce additional stimulus. We seek to measure how the overall macroeconomic dynamics may have changed throughout this transition.
model allows for a change in the VAR coefficients on the policy rate.\(^8\)

We take twice the log of the Bayes Factor comparing the break model to the no-break model in order to convert the test statistic into a scale comparable to that of the likelihood ratio test statistic. Let \(\pi (Y|M_i)\) be the marginal likelihood of the data, given model \(M_i\) and define model \(M_0\) and \(M_1\) as the no-break and break model models, respectively.\(^9\) Therefore, the Bayes Factor is computed as:

\[
B_{01} = \frac{\pi (Y|M_i)}{\pi (Y|M_0)},
\]

and we compute

\[
B_{01} = 2 \ln (B_{01}).
\]

We use the scale suggested in Jeffreys [1961] to interpret the strength of evidence against model \(M_0\) and in favor of model \(M_1\), where values of \(B_{01} > 6\) are considered strong evidence in favor of the break model. Negative values of \(B_{01}\) indicate that the no-break model is preferred.

Table 1 here

The first line of Table 1 shows \(B_{01}\) for the model comparison using the effective FFR as the monetary instrument for the entire post-war sample (1960:I-2013:III) and for the post-Great Moderation sample (1984:I-2013:III). We find strong evidence against the model with constant parameters using each of the two sub-samples, respectively. The results favor the model with parameter instability over the baseline model, thus suggesting some added explanatory value by allowing the parameters to change when the economy encounters the ZLB.

Table 1 here

3 Monetary Policy at the ZLB

Ideally, we want to be able to account for the effects of the Fed’s unconventional policy action during the times in which the FFR does not fluctuate. Using the FFR alone to represent policy would

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\(^8\) This treatment is equivalent to modeling \(A^{RX}(L)\) of the VAR in Section 2 differently in each period.

\(^9\) We compute the marginal likelihood using the output of the Gibbs sampler with the method described in Chib [1995].
suggest that the Fed was inactive during the depths of the financial crisis and did little to stimulate the recovery. Therefore, we need a way to incorporate the policy accommodation associated with the balance sheet liquidity programs and the use of forward guidance. In the next section, we augment the VAR with announcement effects and the Fed’s balance sheet to determine whether accounting for alternative policy instruments are sufficient to preserve the dynamic responses suggested by the benchmark VAR model. Finally, we estimate a shadow rate and use this as a proxy for the policy instrument during the ZLB period.

3.1 Adding Alternative Monetary Instruments

As we mentioned above, during the ZLB period, the Federal Reserve began to utilize alternative policy measures. These measures were intended to provide temporary injections of liquidity and often targeted yields for longer maturity assets. These policies also represented a substantial increase in the Fed’s balance sheet. One way to model the effects of these unconventional policies is include them directly in the VAR by using dummy variables.

Augmenting the standard VAR model to account for the use of these instruments is not straightforward. The policies are often thought to have both implementation effects and announcement effects—that is, the stance of policy could be thought to change both at the times the programs were announced and at the times the balance sheet actually changed. One way to add these instruments into the model is to include event dummies for announcements and to include changes in the size of the Fed’s balance sheet. Let \( B_t \) represent the difference in the size of the Fed’s balance sheet from \( t - 1 \) to \( t \) and let \( P_t \) be a dummy variable that indicates the announcement of a future Fed action. Then, the VAR becomes

\[
\begin{bmatrix}
X_t \\
R_t
\end{bmatrix} = \begin{bmatrix}
A^X (L) & A^{RX} (L) \\
A^{XR} (L) & A^R (L)
\end{bmatrix} \begin{bmatrix}
X_{t-1} \\
R_{t-1}
\end{bmatrix} + \begin{bmatrix}
A^{BX} (L) & A^{PX} (L) \\
0 & 0
\end{bmatrix} \begin{bmatrix}
B_{t-1} \\
P_{t-1}
\end{bmatrix} + \begin{bmatrix}
\varepsilon_t^X \\
\varepsilon_t^R
\end{bmatrix},
\]

where the zero restrictions impose orthogonality between the unconventional policies and the effective funds rate.

\(^{10}\)One might even argue that markets anticipated the announcements, either independently or through speeches made by FOMC members, further complicating the identification of these effects.
We can then determine whether accounting for alternative policy instruments is sufficient to preserve the structure of the VAR into the ZLB period: Does including $A^{BX}(L)$ and $A^{PX}(L)$ make the VAR consistent across the ZLB period? The second line of Table 1 shows the results of the Bayes Factor comparing VARs with exogenous controls for $B_t$ and $P_t$ in the equations for $X_t$, with and without parameter instability at the ZLB. The evidence against the model with constant parameters is even stronger than when using only the FFR, as in the previous section. The additional $B_t$ and $P_t$ terms come into play primarily around the early stages of the financial crisis and over the period witnessing drastic cuts in the FFR towards the ZLB. Incorporating these additional dynamics emphasizes the variation underlying the structural form of the model and amplifies the importance of allowing for parameter instability. This very strong evidence favoring changing coefficients over constant coefficients suggests that accounting for the unconventional policy via event dummies is not sufficient to maintain linearity.

Figure 2 compares the impulse responses to a shock to the FFR in the benchmark to the VAR that includes $B_t$ and $P_t$. As in the previous analysis, the right-hand column shows the median point estimate and 68-percent posterior coverage intervals for the impulse responses estimated using the full-sample VAR, with $B_t$ and $P_t$. The dark blue lines and blue shaded regions replicate the benchmark results. The median point estimates of the full-sample seem to deviate only slightly from the benchmark, with a more significant change for the response of commodity prices, but the posterior coverage is considerably wider. Introducing additional structure into the model and requiring estimation of the coefficients on $B_t$ and $P_t$ degrade the precision with which the rest of the model parameters are estimated.

Figure 2 here

Similar to the results above, accounting for the FFR, the balance sheet, and significant policy events produces a sufficient representative of policy for the full post-war period, including a majority of non-ZLB data. However, augmenting the model in this way may be an inefficient approach for future empirical work once the policy environment returns to a normal, non-ZLB environment and these unconventional policies are no longer in use. The Fed has a variety of alternative policy programs in its arsenal but does not need to use them when it can adjust the FFR effectively.
Including $B_t$ and $P_t$ introduces more parameters to estimate and more structure in the model, especially if imposing identifying restrictions in terms of their relationships with the other variables in the model. In response to this, we pose the question: can we find a proxy measurement of $R_t$ that captures the stance of policy across all periods? We attempt to answer this question in the remainder of the paper.

### 3.2 Shadow Short Rates

One of the Fed’s stated objectives in conducting unconventional monetary policy was to affect interest rates for longer maturity assets, suggesting that examining the term structure of interest rates could uncover a potential alternative policy instrument. Because the nominal short rate is constrained during the ZLB period, Black [1995] proposed a model with a fictitious shadow bond with the same maturity as the policy instrument and an unconstrained shadow interest rate. The nominal short rate, $R_t$, can then be expressed as the maximum of the shadow short rate, $r_t$, and zero:

$$R_t = \max \{r_t, 0\}.$$  

When the nominal rate binds at the ZLB, the shadow rate is unconstrained and can fall below zero. Krippner [2012], Wu and Xia [2014], and Christensen and Rudebusch [2013] estimate versions of this shadow rate using financial market data spanning the full term structure. Krippner [2012] modifies the Black [1995] framework of modeling interest rates as options by calculating the value of a call option to hold cash. This methodology includes two latent factors with a series of restrictive normalizations in order to apply the option-pricing framework. Krippner [2012] uses numerical integration to generate closed-form solutions for bond prices and yields within the shadow term structure. Christensen and Rudebusch [2013] apply the option-based pricing approach formalized by Krippner [2012] to estimate the first three-factor shadow rate model using data on Japanese government bond yields. Alternatively, Wu and Xia [2013] construct an analytical approximation of forward rates in discrete time. This allows for a more straightforward estimation approach than the other shadow rate methodologies. The authors include three latent factors and apply the normalization technique introduced by Joslin et al. [2011].
Krippner [2012] and Wu and Xia [2014] argue that the shadow rate can be used to measure the stance of monetary policy when nominal rates hit the ZLB. The shadow rate, however, is a purely financial construct that does not take into account its effects on macro variables. If we are to use the shadow rate in empirical models of monetary policy, we need to know whether standard VAR models can be extended through the ZLB period by replacing the effective FFR with the exogenously constructed shadow rate or if the ZLB period, in and of itself, requires an alternative model.

Following the methodology of Krippner [2012], we construct the shadow rate use data on the full yield curve, out to the 30-year Treasury bond. The dataset spans 1986:IV through 2013:III so, in principle, we can derive a shadow rate for this entire period. However, we will only need the shadow rate values to proxy for the FFR once hitting the ZLB. The details of Krippner’s model and the estimation procedure are described in the appendix. Krippner’s method generates a monthly shadow rate. However, in order to use this as the policy instrument in the VAR(4) analysis, we aggregate over the quarter by averaging the estimated values for the shadow rate over each quarter. The shadow rate developed in Wu and Xia [2014] is made publicly available on Federal Reserve Bank of Atlanta website. We convert the monthly frequency to a quarterly frequency in the same was as with our version of Krippner’s shadow rate.

Figure 3 shows a sub-sample from 2006:I-2013:III of the quarterly policy instruments used for estimation in the VAR. Prior to 2009:I, all policy instruments use observed values of the nominal FFR. From 2009:I through the end of the sample, we substitute the two shadow rate measures for the effective fed funds rate in separate VARs. By construction, when the nominal FFR is sufficiently far from zero, it and the shadow rate move consistently together. The shadow rate should be equal to the nominal short rate when the nominal short rate is positive and the model preserves this relationship up to a small measurement error. However, once the FFR effectively reaches the ZLB in 2008:IV, the shadow rate becomes increasingly more negative as the Fed took action to jump-start the economy.

Therefore, as a third alternative treatment option for the ZLB period, we estimate the same VAR(4) as above with this new hybrid policy measurement. Lines 3 and 4 of Table 1 show results of
the Bayes Factor model comparisons using both the Krippner [2012] and Wu and Xia [2014] shadow rates as the policy instrument, respectively. Similar to the case with using the FFR, the linear VAR using the Wu and Xia [2014] shadow rate still favors the model incorporating parameter instability around 2008:I, after the onset of the financial crisis. There is very strong evidence in favor of the model allowing for a shift in the macro responses over the entire post-war sample. The evidence is still positive, but much less strong for the post-Great Moderation subsample. Conversely, when using the Krippner [2012] shadow rate, the results favor the constant parameter model for both the full post-war or the post-Great Moderation samples. This shadow rate exhibits much richer dynamics over the crisis and ZLB periods, taking on greater negative values. It appears that this variation, in contrast to the FFR or the smoother path of the Wu and Xia [2014] shadow rate, allows the Krippner [2012] shadow rate to provide a better proxy for the policy instrument in the VAR setting.

These results elicit the question: is the shadow rate a sufficient proxy for the stance of policy to preserve the linearity in the monetary models? Figure 4 shows the impulse responses of the VAR using the shadow rates substituted for the effective funds rate at the ZLB. The first column repeats the benchmark using the FFR from 1960:1-2007:IV from Figure 1. The center column estimates the VAR with the Krippner [2012] shadow rate as the policy instrument from 2009:I-2013:III and the right column estimates the VAR with the Wu and Xia [2014] shadow rate as the policy instrument. Using either shadow rate to represent policy generates posterior coverages for the responses of all macro variables similar to the benchmark. The median benchmark responses fall within the posterior coverage for the full-sample analyses in all cases except for a small bias on the persistence of the policy shock’s effect on the policy rate itself. Again, the ZLB period itself is very short compared to the entire sample and the lack of significant differences in responses may be due to the stronger influence of pre-ZLB data. Even with the subtle differences noted here, the shadow rates seem to preserve the qualitative (and much of the quantitative) relationships between our macroeconomic indicators and the effects of monetary policy actions.

Figure 4 here

We are interested in whether the shadow rate provides a sufficient proxy for monetary policy
in the ZLB environment, in particular to explain the effects of policy throughout the economic contraction of the recent recession. The objective is to use the shadow rate to represent the significant policy stimulus associated with unconventional policies when the FFR does not deviate from the ZLB. The substantial downward movement of the shadow rate occurs in the early stages of the Great Recession, with increasingly negative shadow rates while the FFR is near zero.

Wu and Xia [2014] treat this period differently than the subsequent ZLB period once the economy is no longer in recession but the FFR is still near zero and unconventional policies are still in use. They argue for using the shadow rate to model policy action only after the recessionary conditions subside. We would like to construct a comprehensive measure of policy even during the recessionary period. The large negative shocks that pushed the economy into recession and drove the FFR towards zero are important for determining the validity of the shadow rate approach to modeling policy in these abnormal environments.

We re-estimate the VAR and include only the period after the onset of the ZLB to look specifically at economic conditions when the shadow rate should provide more information than the FFR alone. Figure 5 shows the impulse responses of the benchmark VAR(4) and then using the shadow rates over the period from 2008:I through 2013:III, isolating the period during which we model the ZLB as binding. During this time the nominal FFR hardly fluctuated from zero and thus could not effect much change itself on the overall economy. The shadow rates incorporate other external influences on both current policy as well as market expectations of future policy and future economic conditions. Thus, the responses of macro aggregates to shocks to this alternative policy measurement illustrate more comprehensive policy action during the severe economic contraction.

The impulse responses are estimated with much less precision and the posterior coverage is considerably wider for the VAR shadow rate estimation using only ZLB data than for the benchmark. As a result, the median benchmark responses tend to fall within the considerably wide posterior coverage. The median point estimate of the response of output is comparable when examining the benchmark and using the Wu-Xia shadow rate over the ZLB period. The Krippner shadow

\[ ^{11} \text{Of course, given the data limitations for this period, error bands are expected to be large and results will be only suggestive.} \]
rate does not induce a contractionary response until after one period but then moves in a similar fashion to the benchmark. Not surprisingly, the median responses of inflation and commodity prices still fluctuate from the benchmark. The response of inflation implies a price puzzle in the benchmark but neither of the shadow rates replicate this type of response during the ZLB period. Contractionary policy shocks are associated with falling inflation using either shadow rate. As we previously discussed, the shadow rate may incorporate future expectations as it extracts data from interest rates and investment decisions. Finally, while the response of the policy rate to its own shocks dissipates more quickly with the shadow rates than the benchmark, the qualitative nature of the response matches that of the FFR in normal times.  

3.3 Model Performance

Finally, we test whether there are appreciable differences in the impulse responses to a shock to the shadow short rate estimated over the full sample versus the responses to a shock to the FFR in our benchmark pre-ZLB sample. In order to do this, we construct the Kullback-Leibler Divergence (KLD) between the posterior distribution of the benchmark VAR parameters and the posterior distribution of the VAR parameters estimated using the alternative policy instruments. We can think of the KLD as a type of loss function that measures deviations between distributions. We take the benchmark, pre-ZLB posterior parameter distributions as the truth and measure the extent to which the posterior distributions differ from this when using the shadow rate proxies. Ideally, we want to look at the difference in the distributions of the impulse responses themselves. However, since there is a one-to-one mapping between the impulse responses functions and the VAR coefficient and covariance matrices, we can use the output of the Gibbs sampler to analyze the posterior distribution of the parameter estimates directly.

Table 2 gives the values of the KLD between the post-war, pre-ZLB benchmark (1960:I-2007:IV) and the full-sample (1960:I-2013:III) when using the FFR and each of the two shadow rates. When including both the pre-ZLB and ZLB periods within the sample, the model in which the FFR is used

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12 For robustness, we repeat these impulse response comparisons after adjusting the benchmark to begin after the end of the Great Moderation (1984:1-2007:IV) rather than using the entire post-war sample. We reach the same qualitative conclusions regarding the deviation from the benchmark for full-sample and ZLB sub-sample responses using the FFR and the shadow rates.

13 The Kullback-Leibler Distance is a metric to assess the deviation of one distribution from another. See Kullback and Leibler [1951] for more details regarding how to construct this distance.
to represent policy the entire time produces the smallest KLD, thus showing the smallest deviation from the benchmark. This is in agreement with our previous results using the full-sample with a majority of non-ZLB data. However, when looking specifically at the ZLB period, the posterior distribution of VAR parameters estimated with the shadow rate of Krippner [2012] has the smallest KLD, thus exhibiting less variation than the distributions using the FFR or the shadow rate of Wu and Xia [2014]. The results are the same if we adjust the benchmark to only consider data after the end of the Great Moderation, therefore estimating the VAR using data from 1984:I-2007:IV to establish our basis for comparison. Again, the KLD produced from the FFR is smaller than those of the other two models for both the full, post-Great Moderation (1984:I-2013:III) sample. Furthermore, the KLD using the Krippner [2012] shadow rate is smallest for the ZLB sub-sample. Removing the influence of pre-ZLB data in the dataset by excluding the first 24 years of data allows for the shadow rate modifications at the ZLB to achieve greater success at merging a comprehensive, continuous representation of policy between these two periods.

We cannot compute the impulse responses of macroeconomic variables to the FFR during the ZLB period alone as the policy instrument did not exhibit meaningful variation over this time. When at the ZLB, the shadow rate of Krippner [2012] more closely recovers some of the benchmark macro dynamics of the pre-ZLB period and these are further preserved if we employ a full dataset over the entire post-war period, including the years at the ZLB. We have also found that controlling for the size of the Fed’s balance sheet and significant policy announcements regarding alternative policy programs allows for recovering our baseline dynamics and provides options to researchers seeking to model economies in which the central bank is constrained by the ZLB. Having these anomalous years of data between extended episodes of normal economic activity does not seem to prohibit the use of standard VAR analyses for the effects of monetary policy.

3.4 The Bottom Line

The ZLB period poses an interesting dilemma for empirical researchers. At the outset, we posed a series of questions for the future empirical study of monetary policy, assuming that the FFR is the policy instrument when normalcy returns. First, how large are the biases in the estimated IRF’s if one uses the FFR for the full sample? When estimating the linear VAR model over a long time span, inclusive of a period at the ZLB, we find that it is sufficient to simply use the FFR as the
policy instrument. While the results will be slightly biased, the biases appear to be small. Once the economy lifts-off from the ZLB and returns to normal conditions, this bias should be mitigated and the majority of non-ZLB data should dominate the results.

Second, does adding policy dummies and the balance sheet of the Fed mitigate these biases? Representing the policy instrument with a combination of measurements of the FFR, changes in the size of the Fed’s balance sheet, and indicator variables for significant policy events within the VAR over the full post-war period still produces similar, if not larger, biases to those produced by the model using only the FFR. This exercise requires estimation of additional parameters associated with policies unique to the ZLB environment and thus may introduce inefficiencies when using a dataset consisting of predominantly non-ZLB data.

Third, does exchanging either shadow short rate mitigate these biases? We find that should one wish to substitute a shadow rate proxy for the policy instrument during the ZLB period, hoping to maintain consistent model dynamics throughout the time series, one must recognize that the shadow rate methodology does not achieve a consistent model in all circumstances. The choice over which shadow rate to incorporate will dictate whether or not accounting for structural change is required.

Finally, which shadow short rate does a better job at mitigating these biases? Interestingly, should one attempt to examine particular ZLB periods in isolation, neither the FFR nor the shadow rate serve as an adequate representation of policy and do not produce the expected relationship between effective monetary policy and macroeconomic fluctuations. Therefore, modeling this unique period requires further adjustments and a linear model may not suffice.

4 Conclusions

Researchers attempting to measure the effects of monetary policy during the financial crisis and subsequent recession beginning in 2008 have encountered difficulties when trying to use the FFR which essentially flatlines at zero for much of the period under consideration. We have proposed using the shadow rate as a measurement of policy which is able to fluctuate to negative values when the effective central bank policy rate faces a binding constraint at zero. Our results suggest that the shadow rate acts as a good proxy for monetary policy throughout the ZLB environment only
if using a dataset that spans the pre-ZLB period throughout the ZLB environment. However, the shadow rate is and insufficient proxy for a comprehensive measurement of monetary policy when examining the ZLB period in isolation.

Examining the FFR alone may suggest that policy has become inactive or ineffective but the monetary authority has indeed been successful at implementing expansionary policy albeit through alternative mechanisms. An important point to note is that the economy has witnessed a break in the instrument used to enact policy but not a break in the effects of monetary policy on the macroeconomy. Economic researchers use the FFR as a measurement of the policy instrument for the post-WWII era even though the Fed targeted non-borrowed reserves from 1979-1982 and borrowed reserves from late 1982 through the mid-1980’s. It did not stop targeting M1 until 1987 and M2 until 1993 and began announcing formal targets for the FFR only in 1994. Similarly to that change in the behavior of central bankers, the ZLB period beginning in December 2008 has rendered the traditional policy tool impotent for stimulating economic activity. The Fed has successfully utilized balance sheet items as instruments and introduced a much more expansive period of alternative policy measures than the time spent targeting non-borrowed/borrowed reserves. In order to accurately represent monetary policy during this period, we need a surrogate measurement such as the shadow rate.
References


Jing Cynthia Wu and Fan Dora Xia. Measuring the macroeconomic impact of monetary policy at the zero lower bound. Manuscript, November 2013.

Table 1: Bayes Factor Test for Parameter Instability in U.S. Monetary Policy

Je¡rey’s scale for evidence in favor of parameter instability in VAR(4) coefficients

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<tr>
<td>1. Federal Funds Rate</td>
<td>7.78**</td>
<td>14.15***</td>
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<tr>
<td>2. FFR w/ Lagged Changes in Balance Sheet and Policy Announcement Effects</td>
<td>56.58***</td>
<td>27.35***</td>
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<tr>
<td>3. Krippner Shadow Rate</td>
<td>-46.00</td>
<td>-15.96</td>
</tr>
<tr>
<td>4. Wu-Xia Shadow Rate</td>
<td>14.34***</td>
<td>3.77*</td>
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Table 1: Bayes Factor Comparison for Parameter Instability. Comparison of log marginal likelihoods of models allowing for parameter instability in the set of VAR coefficients describing the response of macro variables to various measures of the policy rate: 1. the effective nominal FFR, 2. the FFR and also controls for changes in the size of the Fed balance sheet and policy announcement effects within the VAR, 3. the shadow rate of Krippner (2012), and 4. the shadow rate of Wu and Xia (2014). We compare one model assuming constant parameters in the pre-ZLB and ZLB periods with another allowing for shifts in the response of all variables to lags of the policy rate. We compute an adjusted Bayes Factor, as described in the text, to convert it to a scale similar to that used in the well-known Likelihood Ratio tests. Interpretation of the Bayes Factors is as follows: * indicates positive evidence in favor of the model with parameter instability, ** indicates strong evidence, and *** indicates very strong evidence.
Table 2: Kullback-Leibler Divergence between the posterior distributions of the VAR parameters estimated with the benchmark data, using the FFR, and the posterior distributions when estimating the model using full-sample instrument combining the FFR and shadow rate policy measurements. We compare the distributions to either the full pre-ZLB benchmark (1960:I-2007:IV) or the Post-Great Moderation benchmark (1984:I-2007:IV).

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<tr>
<td>Alternative:</td>
<td>Full-Sample</td>
<td>ZLB</td>
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<td>Federal Funds Rate</td>
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<td>Wu-Xia Shadow Rate</td>
<td>30.20</td>
<td>187.49</td>
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<tr>
<td>Alternative:</td>
<td>Post-Great Moderation</td>
<td>ZLB</td>
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<td>Federal Funds Rate</td>
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<td>Krippner Shadow Rate</td>
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<td>Wu-Xia Shadow Rate</td>
<td>63.64</td>
<td>121.15</td>
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Figure 1: Impulse Responses Over the Full Sample with the FFR - Left panel: Benchmark IRF with FFR 1960:I-2007:IV: VAR(4) with GDP, CPI, Commodity Prices, and FFR as the policy instrument. This column gives the VAR results using data from 1960:I-2007:IV and serves as our baseline "truth" during normal, non-ZLB environments. The thick blue line and the blue shaded area show the median point estimate and the 68% posterior coverage, respectively, for the impulse responses to a 25 basis point shock to the policy instrument. Right panel: IRF of full-sample VAR which extends the dataset from 1960:I-2013:III and continues using the FFR as the policy instrument through the ZLB period. The thick green line and the green shaded area give the median IRF point estimates and 68% posterior coverage, respectively, incorporating data through the ZLB period without accounting for any potential changing macroeconomic dynamics. The thick blue line and the blue shaded region replicate the plots from the benchmark model.
Figure 2: Impulse Responses Over the Full Sample with the FFR and Balance Sheet and Policy Announcement Effects - Left panel: Benchmark IRF with FFR 1960:I-2007:IV: VAR(4) with GDP, CPI, Commodity Prices, and FFR as the policy instrument. This column gives the VAR results using data from 1960:I-2007:IV and serves as our baseline "truth" during normal, non-ZLB environments. The thick blue line and the blue shaded area show the median point estimate and the 68% posterior coverage, respectively, for the impulse responses to a 25 basis point shock to the policy instrument. Right panel: IRF of full-sample VAR which extends the dataset from 1960:I-2013:III and uses the FFR to represent the policy instrument during the ZLB period but also includes controls for changes in the size of the Fed’s balance sheet as well as policy announcement effects over this time. The thick green line and the green shaded area give the median IRF point estimates and 68% posterior coverage, respectively, incorporating data through the ZLB period without accounting for any potential changing macroeconomic dynamics. The thick blue line and the blue shaded region replicate the plots from the benchmark model.
Figure 3: Plot of quarterly nominal FFR and estimated shadow rates over the period from 2006:I - 2013:III. The shaded columns indicated US recessions.
Figure 4: Impulse Responses Over the Full Sample with Shadow Rates - Left panel: Benchmark IRF with FFR 1960:I-2007:IV: VAR(4) with GDP, CPI, Commodity Prices, and FFR as the policy instrument. This column gives the VAR results using data from 1960:I-2007:IV and serves as our baseline "truth" during normal, non-ZLB environments. The thick blue line and the blue shaded area show the median point estimate and the 68% posterior coverage, respectively, for the impulse responses to a 25 basis point shock to the policy instrument. Center panel: IRF of full-sample VAR which extends the dataset from 1960:I-2013:III and uses the Krippner (2012) shadow rate as the policy instrument through the ZLB period. The thick green line and the green shaded area give the median IRF point estimates and 68% posterior coverage, respectively, incorporating data through the ZLB period. The thick blue line and the blue shaded region replicate the plots from the benchmark model. Right panel: IRF of full-sample VAR which uses the Wu and Xia (2014) shadow rate as the policy instrument through the ZLB period.
Figure 5: Impulse Responses in the ZLB Environment with Shadow Rates- Left panel: Benchmark IRF with FFR 1960:I-2007:IV: VAR(4) with GDP, CPI, Commodity Prices, and FFR as the policy instrument. This column gives the VAR results using data from 1960:I-2007:IV and serves as our baseline "truth" during normal, non-ZLB environments. The thick blue line and the blue shaded area show the median point estimate and the 68% posterior coverage, respectively, for the impulse responses to a 25 basis point shock to the policy instrument. Center panel: IRF of VAR(4) using data from the ZLB period only, 2008:I-2013:III, and using the Krippner (2012) shadow rate as the policy instrument. The thick green line and the green shaded area give the median IRF point estimates and 68% posterior coverage, respectively, using only data from the ZLB period. The thick blue line and the blue shaded region replicate the plots from the benchmark model. Right panel: IRF of VAR(4) using data from the ZLB period only, 2008:I-2013:III, and using the Wu and Xia (2014) shadow rate as the policy instrument.