Economics Bulletin

Volume 40, Issue 2

Comparing shadow rates in monetary policy shock identification

Daniel Groft
McNeese State Univeristy

Abstract

When the Federal Reserve's Federal Funds Rate target reached a range of 0% - 0.25% in 2009, the Federal Open Market Committee began taking unconventional monetary policy actions to stimulate the economy. In order to capture these actions in an empirical instrument, a number of measures, often referred to as shadow rates, have been derived by various researchers using alternative methods. These rates have been used in place of the federal funds rate to estimate the effects of monetary policy shocks on macroeconomic variables. This paper continues in this literature by using alternative shadow rates to derive a measure of monetary policy shocks using the methodology of Romer and Romer (AER, 2004). The estimation results of the policy equation and measures of monetary policy shocks are compared. While the shock measures at times show dramatic differences, the estimated effects on output and prices show no significant differences compared to using no change at all in the target rate. However, this may not be the case in the coming years as more Greenbook information becomes available.

Citation: Daniel Groft, (2020) "Comparing shadow rates in monetary policy shock identification", *Economics Bulletin*, Volume 40, Issue 2, pages 1781-1796
Contact: Daniel Groft - dgroft@mcneese.edu.
Submitted: February 17, 2020.   **Published:** June 18, 2020.

1. Introduction

During the last FOMC meeting of 2008, the Federal Reserve changed its target Federal Funds Rate (FFR) to a range of 0 – 0.25%. It remained at this range until the last meeting of 2015 when it was raised to a range of 0.25% – 0.50%. This time period is often viewed as the FFR hitting the zero-lower bound (ZLB). The FFR has often been used as the monetary policy instrument in a large work of empirical macroeconomic studies analyzing the effects of monetary policy. As the Fed effectively hit the ZLB, it began to undertake nontraditional monetary policy operations which included large scale asset purchases, new discount lending facilities, purchasing longer-term securities while selling shorter-term securities, among others to help the economy out of the 2008 financial crisis. The Fed has recently hit the ZLB once again in response to the economic downturn brought on by the COVID-19 pandemic and adopted more nontraditional monetary policies.

To capture these actions in a monetary policy instrument similar to the FFR, many studies constructed alternative measures, often referred to as shadow rates. These rates allow for negative values and illustrate the extreme expansionary monetary policy actions taken during the latest recession. After deriving these rates, they are often used in a familiar framework such as a VAR or factor-augmented VAR (FAVAR) to illustrate their usefulness in using these rates as a measure of monetary policy.

Krippner (2013), Lombardi and Zhu (2015), Xia and Wu (2016) and Doh and Choi (2016) all cite the work of Black (1995) and build factor models to approximate the short-term shadow rate. Christensen and Rudebusch (2015) estimate a three-factor shadow rate and conclude in their paper that shadow rate measures are sensitive to the number of factors in the estimation and cannot recommend them to measure the stance of monetary policy. Krippner (2015) states that shadow rate estimates from three-factor models are very sensitive while two-factor model estimates are very robust. Therefore, rates from these types of models may be suitable to use but should be subject to robustness checks. Keating et. al (2018) construct a model of monetary policy shocks using a broad monetary aggregate. In the course of their comparisons of their shock effects to shadow rate measures, they find the shadow rate measures often produce price and liquidity puzzles in a standard baseline VAR.

This paper does not look to answer whether or not shadow rates are an acceptable measure of monetary policy. This paper investigates the effects of using alternative shadow rates in constructing a measure of shocks through an alternative "quasi-narrative" approach of Romer and Romer (RR, 2004). RR derive a measure of monetary policy shocks by combining a narrative measure of the intended federal funds rate with the forecasts from the FOMC Greenbooks. The RR policy shocks in this approach represent changes in monetary policy that are exogenous to Greenbook forecasts of lagged, current, and anticipated macroeconomic changes. Until the FOMC began announcing its target FFR, a narrative measure of the change in the intended funds rate was constructed for each FOMC meeting. After the FOMC began announcing its target FFR after every meeting, the RR measure of monetary policy shocks could be updated using the announcement. Once the ZLB was hit, there were no more changes in the target FFR and using this approach to measure monetary policy shocks became difficult. However, using changes in an intended shadow rate within the RR framework may provide a solution the ZLB target rate problem. This paper seeks to investigate the effects of utilizing different shadow rates on the RR monetary policy shock measure.

This paper first updates the RR dataset and analysis until 2013 using no change in the intended funds rate target once the FFR effectively hit the ZLB. Next, alternative shadow rates are used in place of the intended target rate during the time period of the ZLB and policy equations are estimated. The results are compared and new measures of monetary policy shocks are obtained and examined. Finally, the effects of changes in the shock measure on output, prices, and the monetary policy instrument are estimated and compared for significant differences using both single equation and vector autoregression methods.

2. Data and Interest Rates

To obtain a measure of exogenous changes in monetary policy, RR utilize their narrative measure of the intended funds rate as the dependent variable in the following regression:

$$\Delta ff_m = \alpha + \beta ffb_m + \sum_{i=1}^{2} \gamma_i \Delta\tilde{y}_{mi} + \sum_{i=1}^{2} \delta_i \left(\Delta\tilde{y}_{mi} - \Delta\tilde{y}_{m-1,i}\right) + \sum_{i=1}^{2} \varphi_i \Delta\tilde{\pi}_{mi} + \sum_{i=1}^{2} \varphi_i \left(\Delta\tilde{\pi}_{mi} - \Delta\tilde{\pi}_{m-1,i}\right) + \theta_i \tilde{\mu}_{m0} + \varepsilon_m \quad (1)$$

where Δff_m is the change in the intended federal funds rate that occurred at meeting m and ffb_m is the level of the intended federal funds rate prior to the meeting. $\Delta\tilde{y}$ is the forecast of the rate of growth of output, and $\tilde{\pi}$ is the forecast of the inflation rate. Greenbook forecasts for the quarter before the FOMC meeting (i = -1), the quarter of the meeting (i=0), and one and two quarters ahead (i = 1,2) are considered.[1] For the total unemployment rate ($\tilde{\mu}$), only the forecast for the quarter of the FOMC meeting is used.

The current quarter forecast for the unemployment rate is used as another measure of the current state of the economy that is considered by the FOMC. Only the forecast of the current quarter unemployment rate is used by RR because Okun's Law predicts a strong relationship between the unemployment rate and output. Consequently, there is likely to be a high degree of co-linearity between the forecasts of the unemployment rate and the growth rate of output.

$\left(\Delta\tilde{y}_{mi} - \Delta\tilde{y}_{m-1,i}\right)$ and $\left(\Delta\tilde{\pi}_{mi} - \Delta\tilde{\pi}_{m-1,i}\right)$ are changes in the forecasts for output growth and inflation, respectively. These measures are included because a forecast for a particular quarter may change from one meeting to another, and the FOMC may respond to the change in the forecast as well as the forecast itself. Quarterly Greenbook forecasts of the annualized percentage change in real GNP/GDP, the annualized percentage change in the GNP/GDP deflator[2], and the level of the unemployment rate are used for Δy, π, and μ, respectively. The error term, ε_m , is the measure of exogenous policy shocks. These shocks represent changes in monetary policy that are external to lagged, current, and anticipated actions in key macroeconomic variables.

Since the release of the RR paper, further Greenbooks have been released on the Philadelphia Federal Reserve's website. As of this writing the latest available Greenbooks are for all FOMC meetings in 2013. To analyze the differential responses among shadow rate variables and the effects on monetary policy shocks, the RR dataset was updated until 2013 using the same variables.

To update the intended funds rate and previous meeting target measures, values were taken from FOMC press releases after each meeting. However, beginning with the December 2008 meeting, the FOMC lowered its target federal funds rate to a range of 0 and ¼ percent. This effectively meant the rate hit a ZLB and all further meetings after that time had no change in the announced federal funds rate.

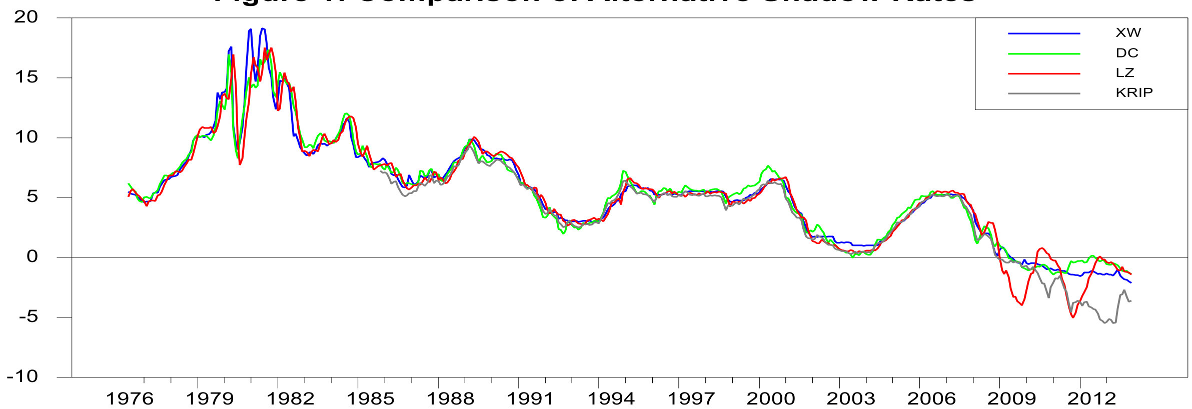
---

[1] Data from the Greenbook are used for every observation. For the lagged forecast (i = -1), the value from the Greenbook is often actual real-time data rather than the forecast of the quarter before the one the FOMC meeting is taking place in. Investigation of the actual Greenbooks shows that there is often an indicator as to whether the previous quarter's value is a forecast or preliminary data; however, RR make no distinction as the data always come from the Greenbook.

[2] GDP replaced GNP as the measure for output beginning with the Greenbook prepared for the December 17, 1991 FOMC meeting. This replacement was incorporated into the update.

In order to compute the changes in the intended funds rate, four shadow rates were chosen. Monthly averages of the Xia-Wu (XW) rate, the Doh-Choi (DC) rate, the Lombardi-Zhu (LZ) rate, and the Krippner (Kripp) rate were used in the analysis. Figure 1 illustrates the shadow rate measures from June 1976, the first month most measures were available, until the end of 2013, the end of Greenbook availability.

Figure 1: Comparison of Alternative Shadow Rates



The measures all have a very high correlation for the entire time period. Table I shows the correlations among all measures for the entire sample period beginning in June 1976 (with the Krippner measure beginning in November 1985).

Table I – Shadow Rate Correlations: 1976:1 – 2013:12

	Xia-Wu Rate	Doh-Choi Rate	Lombardi-Zhu Rate	Krippner Rate
Xia-Wu Rate	1.00	0.98	0.97	0.98
Doh-Choi Rate	0.98	1.00	0.95	0.96
Lombardi-Zhu Rate	0.97	0.95	1.00	0.94
Krippner Rate	0.98	0.96	0.94	1.00

However, the results become drastically different when comparing correlations for the period at which the Federal Funds Rate effectively hit the ZLB, January 2009, until the end of the sample for the RR comparison, December 2013. Table 2 below shows the correlations over this time period.

Table II – Shadow Rate Correlations: 2009:1 – 2013:12

	Xia-Wu Rate	Doh-Choi Rate	Lombardi-Zhu Rate	Krippner Rate
Xia-Wu Rate	1.00	0.51	0.02	0.80
Doh-Choi Rate	0.51	1.00	-0.06	0.05
Lombardi-Zhu Rate	0.02	-0.06	1.00	-0.14
Krippner Rate	0.80	0.05	-0.14	1.00

The Krippner and Xia-Wu rates have the highest correlation of 0.80. The lowest correlation is between the Krippner rate and the Lombardi-Zhu rate of -0.14.

3. Results

3.1 Policy Equation Regressions

In order to estimate equation 1, data from Greenbooks were used to update the forecast variables. For the intended funds rate and previous meeting's target measures, the original RR intended rate was used until the end of their original sample, December 1996. For meetings from January 1997 to December 2008, the change in intended funds rate and previous meeting's rate were taken from FOMC press releases after each meeting. For meetings after this time, the change in the intended funds rate and previous meeting's rate were constructed for each of the four shadow rate measures.

While the original RR data set consisted of data at a frequency of FOMC meetings, most of the shadow rate measures were only available at a monthly frequency. In order to account for this and create a change in the intended funds rate, the change between the rate in the month after the meeting was subtracted from the rate in the month before the meeting[3]. This was done because a meeting in the middle of the month would contain a shadow rate average which contained values before and after any changes decided on by the FOMC. Any change in the intended rate would contain within month movements that cannot be parsed out. Therefore, it was assumed that the target would be hit in the month following the meeting. The previous meeting's target rate, ffb_m, was calculated as the previous meeting's change in the intended rate plus the previous meeting's ffb_m. For a particular meeting, $ffb_m = \Delta ff_{m-1} + ffb_{m-1}$ shows the general target rate coming into an FOMC meeting[4].

Equation 1 was estimated using no change in the intended funds rate (with the previous meeting's target rate constant at 0.125%, which is an average of 0 – 0.25%) as well as each of the four intended target rates and previous meeting's rates constructed from the shadow rate measures. Initial estimations showed that each regression produced low Durbin-Watson statistics providing evidence of serial correlation in the residuals. Breusch-Godfrey tests for each regression showed each measure produced first order serial correlation. Table III shows the results of each estimation with Newey-West (NW) standard errors with one lag.

[3] There are a few instances when the meeting took place very early in the month. Therefore, the current monthly average was used.

[4] This results in the assumption there were no intermeeting changes as occurred frequently in the early FOMC meetings of the RR sample and less frequently as FOMC press releases were created and made public.

Table III - Determinants of the Change in the Intended Federal Funds Rate

	No Change		**Xia-Wu Rate**		**Doh-Choi Rate**		**Lombardi-Zhu Rate**		**Krippner Rate**	
	Coefficient	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Constant	0.055	0.089	0.064	0.089	0.055	0.089	-0.005	0.102	0.102	0.095
Initial level of intended funds rate	-0.024	0.009	-0.020	0.008	-0.023	0.009	-0.024	0.011	-0.021	0.010
Forecasted output growth, Quarters ahead:										
-1	0.007	0.009	0.008	0.009	0.007	0.009	0.019	0.011	0.011	0.010
0	0.008	0.015	0.007	0.015	0.013	0.015	0.006	0.016	-0.002	0.015
1	0.013	0.022	0.010	0.021	0.016	0.021	0.015	0.021	0.015	0.022
2	0.013	0.023	0.021	0.023	0.014	0.024	0.016	0.026	0.025	0.024
Change in forecasted output growth since last meeting, Quarters ahead:										
-1	0.026	0.026	0.029	0.026	0.023	0.026	0.020	0.029	0.031	0.029
0	0.123	0.034	0.121	0.033	0.119	0.034	0.138	0.036	0.144	0.035
1	0.038	0.035	0.037	0.034	0.030	0.035	0.023	0.035	0.027	0.036
2	-0.001	0.041	0.006	0.039	-0.015	0.041	0.001	0.047	0.020	0.043
Forecasted inflation, Quarters ahead:										
-1	0.023	0.019	0.022	0.019	0.020	0.019	0.022	0.022	0.026	0.020
0	-0.024	0.024	-0.021	0.024	-0.014	0.025	-0.035	0.029	-0.043	0.026
1	0.000	0.049	-0.001	0.049	-0.005	0.049	-0.008	0.051	0.007	0.049
2	0.040	0.057	0.040	0.057	0.045	0.057	0.068	0.059	0.053	0.058
Change in forecasted inflation since last meeting, Quarters ahead:										
-1	0.046	0.037	0.040	0.037	0.056	0.037	0.054	0.042	0.028	0.039
0	0.011	0.035	-0.001	0.034	-0.009	0.039	0.074	0.050	0.037	0.045
1	0.046	0.062	0.073	0.062	0.036	0.063	-0.020	0.082	0.058	0.070
2	-0.081	0.063	-0.078	0.063	-0.135	0.075	-0.068	0.095	-0.054	0.085
Forecasted unemployment rate (current quarter)	-0.027	0.011	-0.037	0.012	-0.036	0.012	-0.029	0.018	-0.046	0.014
R^2	0.26		0.26		0.27		0.24		0.25	
S.E.E.	0.34		0.34		0.34		0.40		0.38	
D-W	1.70		1.72		1.71		1.52		1.81	
N	399		399		399		399		399	

The results show similar results across all the regressions. The R^2 statistics range from a low of 0.24 in the LZ regression to a high of 0.27 in the regression using the DC rate. The Kripp regression has an R^2 statistic of 0.25. All results have positive and insignificant coefficients on the constant, with the exception of LZ which has a negative constant. The coefficient on the previous meeting's target rate is negative and significant in all regressions. In terms of the unemployment rate, the coefficient is negative and significant with the exception of the LZ regression which produces an insignificant coefficient. To investigate the responses in the intended funds rate to forecasted changes in output and prices, the coefficients for each of the respective groups are summed and tested for significance. Table IV shows the summed results for each of the regressions.

Table IV - Sums of Coefficients

	No Change			**Xia-Wu Rate**			**Doh-Choi Rate**		
	Sums of Coefficients	**t-statistic**	**p-value**	**Sums of Coefficients**	**t-statistic**	**p-value**	**Sums of Coefficients**	**t-statistic**	**p-value**
Forecasted output growth	0.042	2.21	0.03	0.047	2.47	0.01	0.050	2.63	0.01
Change in forecasted output growth since last meeting	0.187	4.46	0.00	0.193	4.72	0.00	0.157	3.47	0.00
Forecasted inflation	0.039	2.43	0.01	0.040	2.49	0.01	0.046	2.74	0.01
Change in forecasted inflation since last meeting	0.022	0.35	0.73	0.034	0.55	0.58	-0.052	-0.592	0.55

Table IV (continued) - Sums of Coefficients

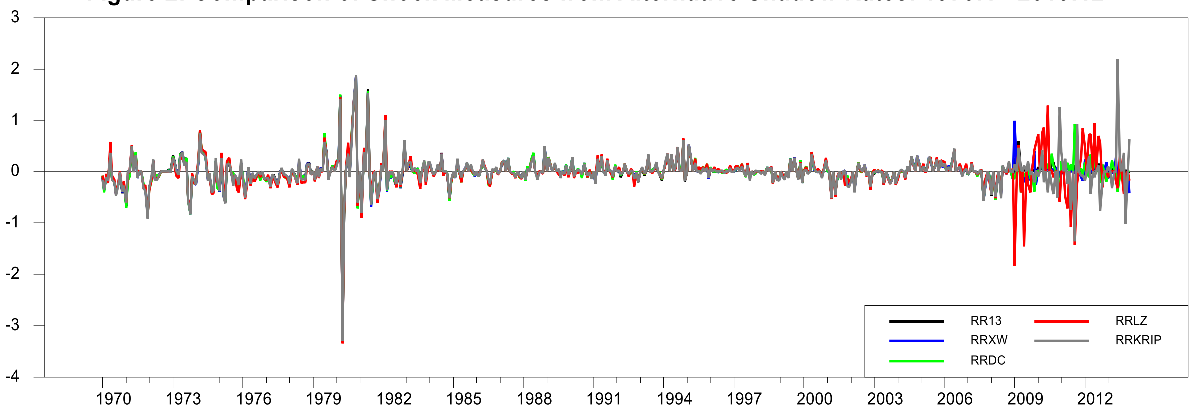
	Lombardi-Zhu Rate			**Krippner Rate**		
	Sums of Coefficients	**t-statistic**	**p-value**	**Sums of Coefficients**	**t-statistic**	**p-value**
Forecasted output growth	0.055	2.60	0.01	0.049	2.62	0.01
Change in forecasted output growth since last meeting	0.182	3.37	0.00	0.222	4.60	0.00
Forecasted inflation	0.048	2.61	0.01	0.043	2.51	0.01
Change in forecasted inflation since last meeting	0.040	0.36	0.72	0.070	0.65	0.51

Table IV shows the sums of coefficients on forecasted output growth are positive and significant across all regressions. The magnitudes are similar with the largest responses from the LZ regression (0.055) while the lowest is when using no change in the intended funds rate (0.042). The same applies to forecasted inflation in that all sums of coefficients are positive, significant, and similar in magnitudes. The largest response to inflation occurs in the LZ regression (0.048) while the smallest is in the regression which has no change in the intended funds rate (0.039). The change in forecasted output coefficient sums are positive and significant in all regressions while the change in forecast inflation coefficients sums are insignificant.

3.2 Investigation of Monetary Policy Shocks

The residuals from each regression are interpreted as measures of changes in monetary policy that are free of endogenous and anticipatory movements. The residuals are converted to a monthly measure by using the month of the meeting associated with each residual. For months in which there was more than one meeting, the residual is summed and is equal to zero in months with no FOMC meetings. Figure 2 shows the different shock measures for the full sample[5]. Table V shows the correlations for each of the shock measures.

Figure 2: Comparison of Shock Measures from Alternative Shadow Rates: 1970:1 - 2013:12



---

[5] The residual measures in this graph, along with the following graphs throughout the paper, are named via the shadow rate intended funds rate measure. For example, "RRXW" represents the shocks constructed using the Xia-Wu shadow rate. When using no change in the intended rate the measure label will just end "13" to signify the end year of the sample.

Table V – Shadow Rate Monetary Policy Shock Correlations: 1970:1 – 2013:12

	No Change in Intended Rate	Xia-Wu Rate	Doh-Choi Rate	Lombardi-Zhu Rate	Krippner Rate
No Change in Intended Rate	1.00	0.98	0.97	0.81	0.85
Xia-Wu Rate	0.98	1.00	0.95	0.79	0.83
Doh-Choi Rate	0.97	0.95	1.00	0.81	0.78
Lombardi-Zhu Rate	0.81	0.79	0.81	1.00	0.70
Krippner Rate	0.85	0.83	0.78	0.70	1.00

As with the shadow rate measures themselves, the shock measures show high correlations when looking at the entire sample. Using no change in the intended funds rate produces shock measures that have the highest correlations with the shocks constructed from the Xia-Wu (0.98) and Doh-Choi (0.97) rates. The lowest correlation with the no change measures is with the Lombardi-Zhu rate shocks (0.81). The lowest overall correlation is between shocks obtained from using the Krippner and Lombardi-Zhu rates (0.70).

As before, when looking just at when the zero lower bound was effectively in place, the correlations drop dramatically. Figure 3 illustrates every measure over this time period while Table VI shows the correlations.

Figure 3: Comparison of Shock Measures from Alternative Shadow Rates: 2009:1 - 2013:12

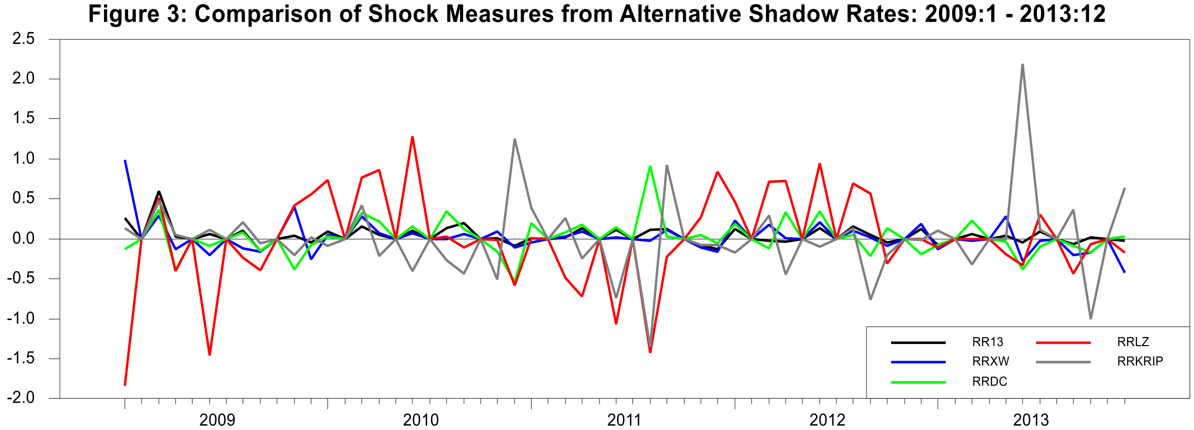


Table VI – Shadow Rate Monetary Policy Shock Correlations: 2009:1 – 2013:12

	No Change in Intended Rate	Xia-Wu Rate	Doh-Choi Rate	Lombardi-Zhu Rate	Krippner Rate
No Change in Intended Rate	1.00	0.58	0.41	-0.01	-0.08
Xia-Wu Rate	0.58	1.00	0.11	-0.04	-0.12
Doh-Choi Rate	0.41	0.11	1.00	0.06	-0.43
Lombardi-Zhu Rate	-0.01	-0.04	0.06	1.00	-0.03
Krippner Rate	-0.08	-0.12	-0.43	-0.03	1.00

The shocks obtained from using the Krippner rate have a negative correlation with all other measures. The highest overall correlation between two different shock measures is only 0.58 between the shocks obtained from using the Xia-Wu rate and using no change at all.

RR also accumulate the residuals from their regression to obtain a level measure to be used in place of the Federal Funds rate in VAR's. The accumulated measures from each separate regression for the full sample are shown in Figure 4 while Table VII shows the correlations over this time period.

Figure 4: Comparison of Accumulated Shock Measures from Alternative Shadow Rates: 1970:1 - 2013:12

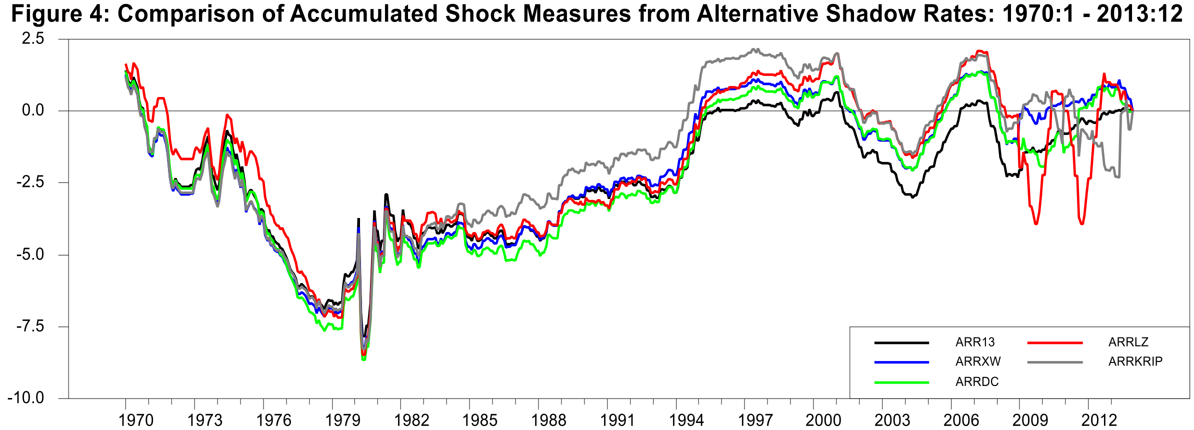


Table VII – Shadow Rate Accumulated Monetary Policy Shock Correlations: 1970:1 – 2013:12

	No Change in Intended Rate	Xia-Wu Rate	Doh-Choi Rate	Lombardi-Zhu Rate	Krippner Rate
No Change in Intended Rate	1.00	0.98	0.98	0.95	0.94
Xia-Wu Rate	0.98	1.00	0.99	0.94	0.96
Doh-Choi Rate	0.98	0.99	1.00	0.96	0.94
Lombardi-Zhu Rate	0.95	0.94	0.96	1.00	0.91
Krippner Rate	0.94	0.96	0.94	0.91	1.00

The graphs show that the accumulated measures are very similar until 2009. For the full sample the measures all exhibit fairly high correlations. However, when looking at just the last years of the sample from 2009 – 2013, the shocks begin to vary dramatically. This is illustrated in Figure 5 which shows each shock measure from January 2009 – December 2013. Table VIII shows the correlations over this time period only.

Figure 5: Comparison of Accumulated Shock Measures from Alternative Shadow Rates: 2009:1 - 2013:12

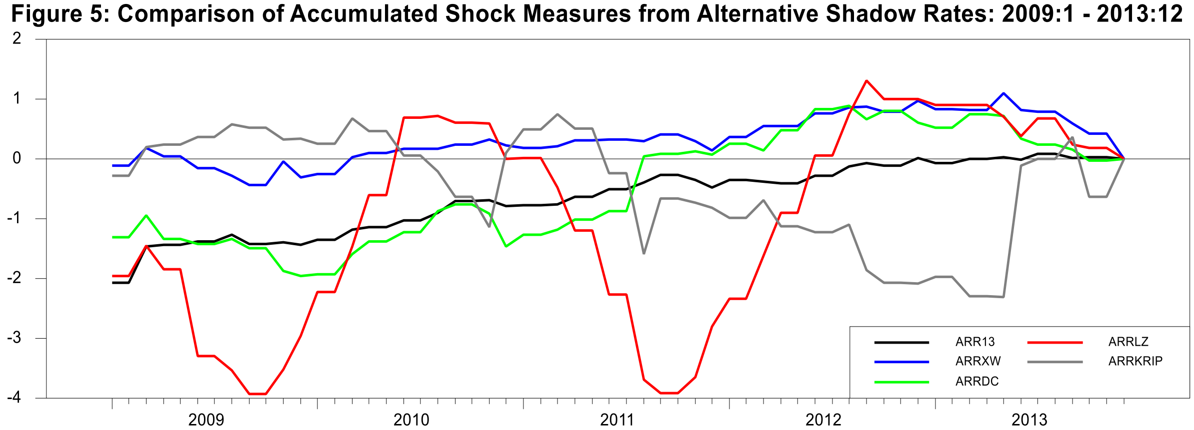


Table VIII – Shadow Rate Accumulated Monetary Policy Shock Correlations: 2009:1 – 2013:12

	No Change in Intended Rate	Xia-Wu Rate	Doh-Choi Rate	Lombardi-Zhu Rate	Krippner Rate
No Change in Intended Rate	1.00	0.85	0.87	0.52	-0.63
Xia-Wu Rate	0.85	1.00	0.88	0.67	-0.75
Doh-Choi Rate	0.87	0.88	1.00	0.45	-0.82
Lombardi-Zhu Rate	0.52	0.67	0.45	1.00	-0.42
Krippner Rate	-0.63	-0.75	-0.82	-0.42	1.00

The Krippner rate shocks now have negative correlations with every other measure, the lowest being the correlation with the Doh-Choi measure of -0.82. The Lombardi-Zhu rate also has very low correlations reaching only 0.67 with the Xia-Wu Shocks. The highest overall correlation of 0.88 is between the Xia-Wu shocks and shocks derived with the Doh-Choi shadow rate.

3.3 Effects on Output and Price

Following RR, the effects of shocks to monetary policy on the levels of output and price are first estimated by computing cumulative impulse response functions (IRFs) from the following regressions which are estimated using monthly data:

$$\Delta y_t = \alpha_0 + \sum_{k=1}^{11} a_k D_{kt} + \sum_{i=1}^{24} b_i \Delta y_{t-i} + \sum_{j=1}^{36} c_j S_{t-j} + e_t \quad (2)$$

$$\Delta p_t = \alpha_0 + \sum_{k=1}^{11} a_k D_{kt} + \sum_{i=1}^{24} b_i \Delta p_{t-i} + \sum_{j=1}^{48} c_j S_{t-j} + e_t \quad (3)$$

where Δy is output growth (measured by the change in the log of non-seasonally adjusted industrial production index), Δp is the inflation rate (measured by the change in the log of the non-seasonally adjusted producer price index for finished goods[6]), D is a monthly dummy, and S is the monetary policy shock measure. The specification of the equations is the same as that used by RR. Note that twenty-four lags of the dependent variable are included in each equation, but thirty-six lags of the policy shock are included in the output growth equation whereas forty-eight lags of the policy shock are included in the inflation equation. RR state "there appear to be longer lags in the impact of policy on prices" (p. 1073) and hence use longer lags in the price equation.

Alternatively, the same results can be generated using polynomial division and summation to obtain a cumulative impulse response function. In this paper, both the price and output cumulative impulse response functions are obtained using polynomial division.[7] Confidence interval bands are obtained in a similar manner to RR[8].

In order to test for significant differences, this paper compares the responses of output and price for each of the shock measures obtained from alternative shadow rates to the confidence interval bands obtained from the shocks obtained using no change in the intended funds rate. If the responses lie outside the CI bands, this implies significant differences in the responses. Figures 6 and 7 illustrate the responses of output and prices, respectively, 48 months out from a 1 percentage point increase in the shock measures obtained from using shadow rates (as well as no change in the intended rate). The CI bands are obtained from responses from shocks using no change in the intended funds rate.

[6] Since the writing of the RR paper, both indexes have been revised and analysis utilizes the latest indexes available. The discontinued PPI that was used in the original RR paper was investigated and did not provide significantly different results.
[7] The method of adding forty-eight lags to the shock variable is shown in the appendix available from the author. The procedure is the same when adding thirty-six lags, as in the output equation.
[8] Detailed description of the polynomial division technique and further description of the CI bands are available in an appendix from the author.

Figure 6: Single Equation Output Responses in No Change Error Bands

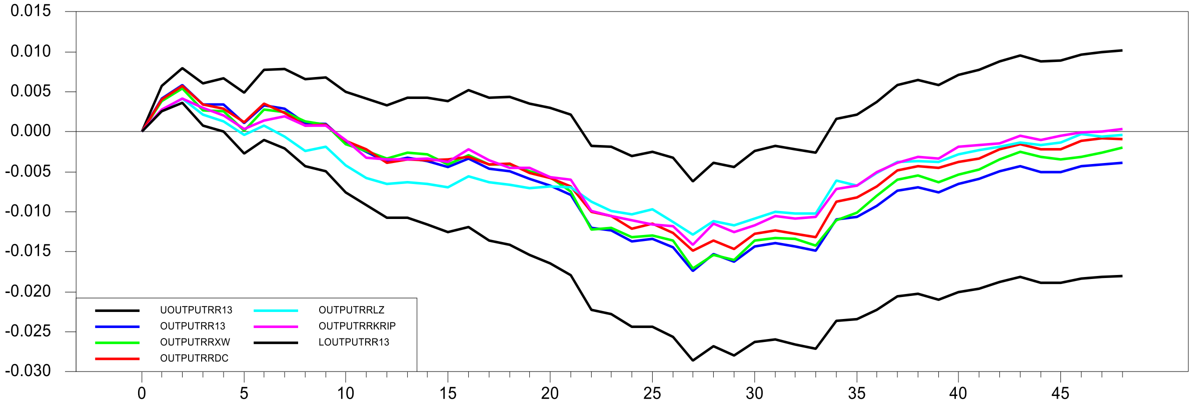
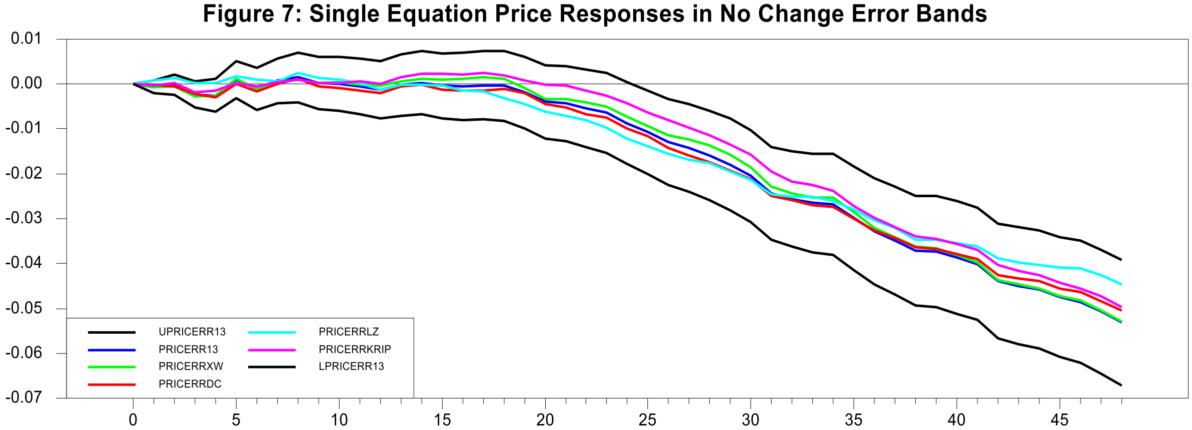


Figure 7: Single Equation Price Responses in No Change Error Bands



The responses show no significant differences among the measures. All responses lie within the confidence bands at almost all horizons (with the exception of negligible and transitory differences in the early months). The output response follows the expected hump shaped pattern while prices are permanently lower at longer horizons. Although the time to significance in price is fairly long at approximately two years, this is similar to the original RR results. One striking difference between the 2013 update and the original paper is that the response of output has become much weaker and the time of a significant output response is much shorter.

RR also use their accumulated measure in a simple VAR that includes thirty-six lags of the log of the industrial production index, the log of the producer price index, and the accumulated monetary policy instrument[9]. The VAR utilizes a standard Choleski decomposition with the monetary policy measure ordered last so that output and prices do not respond contemporaneously to monetary policy shocks. To test these results for significant differences, the impulse response functions (IRFs) of output, price, and the own response of the monetary policy instrument were calculated for each shock measure. These responses were placed in the CI bands obtained from the VAR IRF's from the shock measures using no change in the intended funds rate. Figures 8 through 10 show these responses in the CI bands.

[9] The VAR also includes a constant and seasonal dummies as exogenous variables as the IP index and PPI measures used are not seasonally adjusted.

Figure 8: VAR Output Responses in No Change Error Bands

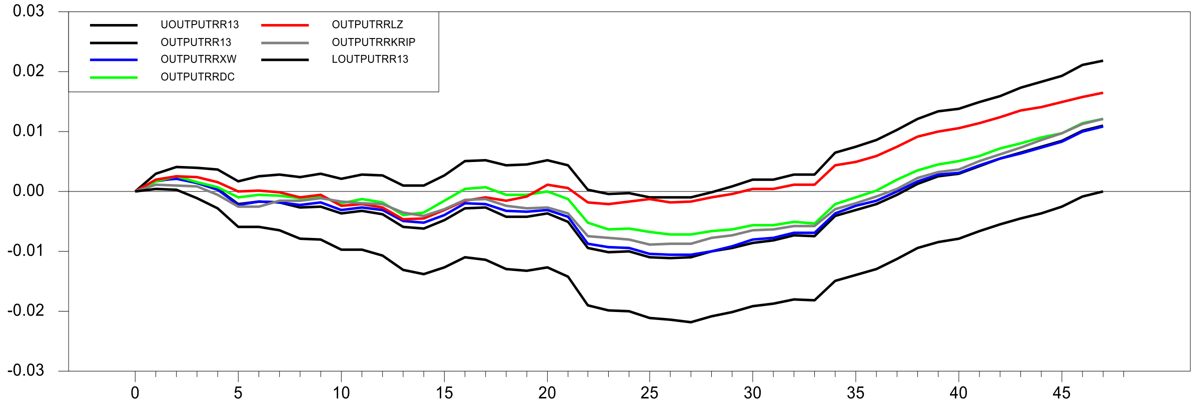


Figure 9: VAR Price Responses in No Change Error Bands

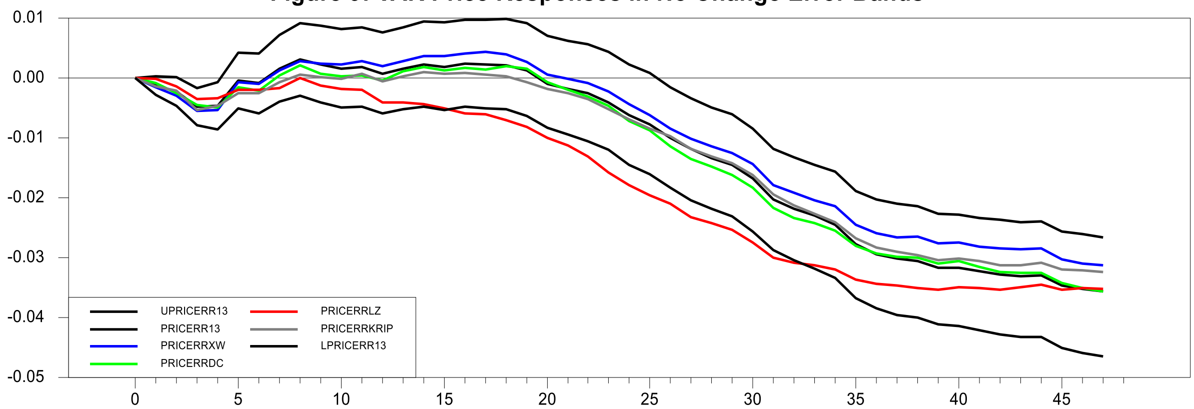
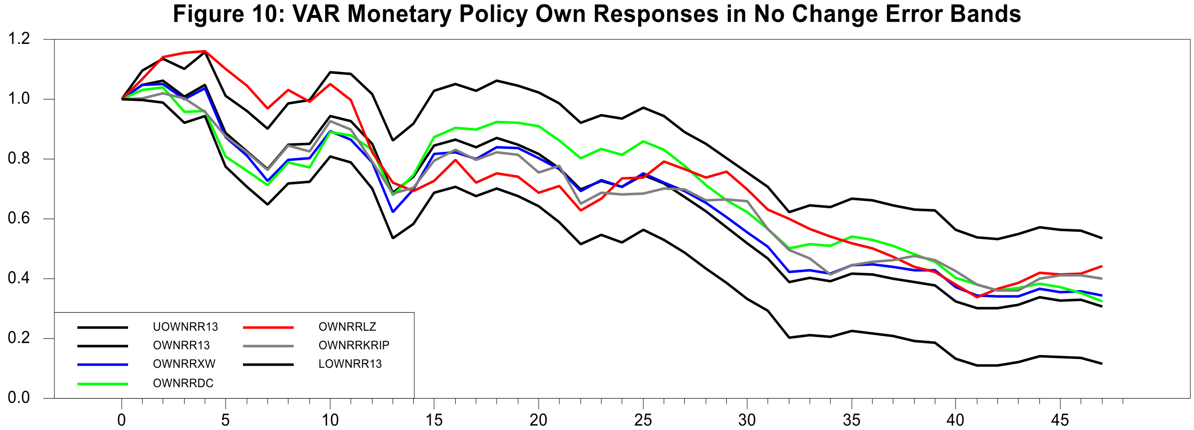


Figure 10: VAR Monetary Policy Own Responses in No Change Error Bands

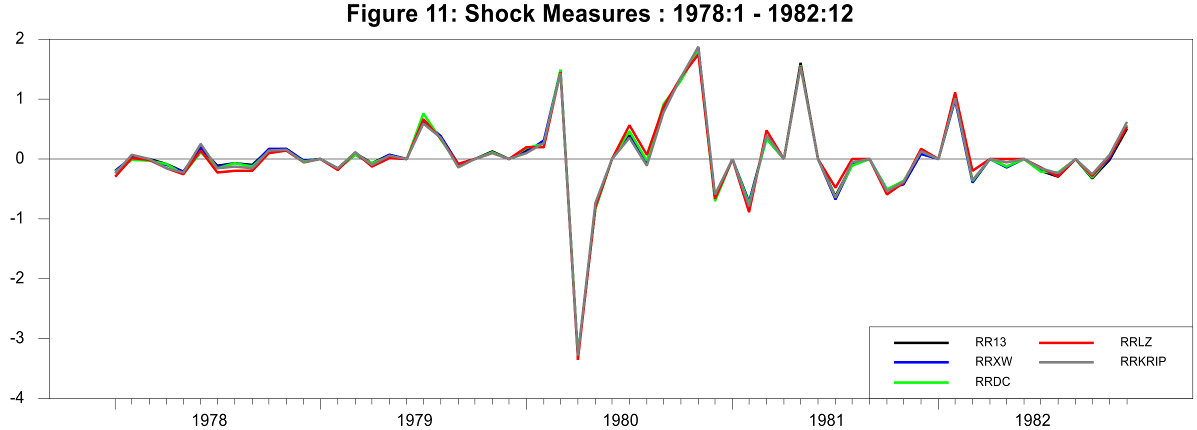


As with the single equation estimates, there are no significant differences in the responses of output. All responses lie within the CI bands at all horizons. Once again, extending the sample to 2013 produces much weaker output responses and a less significant response compared to the original paper. In terms of price responses, all responses lie within the CI bands with the exception of the responses from the LZ shocks. After approximately 15 months, the response of prices becomes significantly lower until 33 months after the shock. At this time, the response goes back within the CI bands, indicating only a transitory difference in the price response. The LZ IRF is once again the only response outside CI bands for the own response of monetary policy. At early horizons, the LZ response shows monetary policy becoming more contractionary. The differences are small at this time, and the response quickly goes back within the bands.

3.4 Discussion of Results

These results can lead to a number of conclusions. One is that using alternative shadow rates is acceptable in the RR framework for identifying monetary policy shocks because the differences in IRF's are insignificant from the original RR results. However, one could also say they are not useful as the results are not significantly different from using no change at all. What using shadow rates will be useful for is further investigation of updating the measure over time. The RR measure has been studied extensively and one conclusion is that a driving force of the responses in output and prices from the monetary policy shocks is the period of nonborrowed reserve targeting (NBR). This period produced the greatest amount of volatility in the RR shock measure. Figure 11 illustrates the shock measures calculated in this paper from 1978 to 1982.

Figure 11: Shock Measures : 1978:1 - 1982:12



This period produced the largest shock measure in the sample reaching below -3. This amount of volatility and the magnitudes in the shocks was not seen before or after. When updating the sample to various time periods the responses in output became weaker and weaker, as the sample was extended.

Using the shadow rates produces shock measures that result in a similar level of volatility, especially for the LZ and Kripp shadow rates. Figures 2 and 3 earlier in the paper illustrated the shock measures from 2009 until the end of 2013. During this time period the shock measures show more volatility and have larger magnitudes than at any time since the NBR targeting period. These shocks could produce very different responses in macroeconomic variables as the measures are updated with the future release of new Greenbooks. This work can conclude that using shadow rates will not cause significant differences and are a possibility for updating the RR dataset at the current moment. Future research should continue to update these measures and test the results as new Greenbooks become available. The increased volatility of monetary policy shock measures during the ZLB could produce much stronger estimated responses in macroeconomic variables as more time passes.

These measures can also be used in robustness tests. During the period of the ZLB, the correlations among the rates themselves, as well as the shock measures, fell drastically. This would lead one to conclude that future results could differ greatly as the measure is updated. Changing the sample for analysis may lead to drastically different conclusions depending on the measure of monetary policy chosen. Using alternative measures may illustrate the robustness of the results.

The Federal Reserve came out of the ZLB after the 2008 crisis and began announcing changes in the target federal funds rate. Bridging this gap during the ZLB will be crucial to identifying shocks if one would use the FFR target at later meetings. These shadow rates provide a way to update the RR measure during this time and then begin using the press release announcements for changes in the intended rate. As the Fed has once again hit the ZLB, these shadow rate measures provide a way to estimate monetary policy shocks in the future and alternative rates can be used for robustness checks.

4. Conclusion

This paper has investigated the effects of using alternative shadow rates in place of an intended funds rate target measure to construct monetary policy shocks. While the shadow rates themselves show low correlations over the period of the ZLB, using alternative shadow rates in the RR framework produces policy equation estimations that are not drastically different from each other, or from using no change in the intended FFR target. However, the estimated monetary policy shocks from each approach show low correlations that could lead to differing results when testing the effects of monetary policy in the future.

Estimations through single equation and VAR methods show there are no significant differences in the responses of macroeconomic variables when using shocks obtained from shadow rates or from using no change in the intended funds rate. This implies that shadow rates could be used as a bridge mechanism in this technique from when the FFR target reached above the ZLB. These shadow rates can also be used in the future to cover the current period in which the Fed has once again gone back to the ZLB. This facilitates research opportunities to keep up with this technique as further Greenbooks become available from the FOMC. The dataset and shock measures can be continuously updated to analyze how the increased volatility during the financial crisis and pandemic affected monetary policy shocks and their effects. The drastic differences in the shock measures could perhaps lead to differing macroeconomic variable responses that should be explained.

Literature Cited

Christensen, J. and Rudebusch, G. (2014) "Estimating shadow-rate term structure models with near-zero yields," *Journal of Financial Econometrics*, 13(2), 226-259.

Doh, T. and Choi, J. (2016) "Measuring the Stance of Monetary Policy On and Off the Zero Lower Bound," Economic Review-Federal Reserve Bank of Kansas City, 103 (1), 31-58.

Keating, J., Kelly, L., Smith, A.L., and Valcarecel, V. (2018) "A Model of Monetary Policy Shocks for Financial Crises and Normal Conditions," Federal Reserve Bank of Kansas City, working paper no.14-11, February available at https://doi.org/10.18651/RWP2014-11.

Krippner, L. (2013) "Measuring the Stance of Monetary Policy in Zero Lower Bound Environments," *Economics Letters*, vol. 118, no. 1, pp. 135–138.

Krippner, L. (2015) "A comment on Wu and Xia (2015), and the case for two-factor Shadow Short Rates," CAMA Working Paper 48/2015, December 2015.

Lombardi, M. and Zhu, F. (2014) "A Shadow Policy Rate to Calibrate U.S. Monetary Policy at the Zero Lower Bound," Bank for International Settlements, working paper no. 452-2014, June.

Romer, C. and Romer, D. (2004) "A New Measure of Monetary Policy Shocks: Derivations and Implications." *The American Economic Review,* Vol. 94 (4), 1055 - 1084.

Wu, J.C. and Xia, F.D. "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound", *Journal of Money, Credit, and Banking*, 2016, 48(2-3), 253-291.