Documentation for United States measures of monetary policy

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1 Introduction

In this note, I provide the essential background information on how to interpret the results provided on the website, and how they are obtained. The model used to produce the estimates on the website is the K-ANSM(2), which is a two state-variable shadow yield curve model within the Krippner (2011, 2012b,c, 2013d,e, 2015) shadow/ZLB framework. It is estimated using the iterated extended Kalman filter on month-end US yield curve data from 1985 with times to maturity spanning 0.25 to 30 years.

Section 2 discusses the concepts of the Shadow Short Rate, the Expected Time to Zero, and the Effective Monetary Stimulus obtained from the K-ANSM(2). Sections 3, 4, and 5 contain further details on the K-ANSM(2) specification, estimation method, and yield curve data set used for estimation.

I note up front that, being estimated, the results from shadow/ZLB term structure models differ depending on the specification, estimation method, and data used for the estimation. I therefore include brief explanations in this note on my particular choices. In particular, section 6 provides extended empirical evidence (mainly graphical) on why I prefer Shadow Short Rate estimates from the K-ANSM(2), rather than the very sensitive and often counterintuitive results from K-ANSM(3) specifications. However, I consider the Effective Monetary Stimulus to be the best indicator of the stance of monetary policy, based on the empirical results provided in section 6 and the principals discussed in section 2.

I welcome questions and comments regarding the information on the website, this note, and my related work. Please contact me at leo.krippner@rbnz.govt.nz.

2 Overview of three monetary policy measures

The K-ANSM(2) readily provides three quantitative measures that can potentially be used to gauge the stance of monetary policy. As illustrated in figure 1, these are:

- The **Shadow Short Rate (SSR)**. The SSR is the shortest maturity rate from the estimated shadow yield curve. The SSR is essentially equal to the policy interest

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rate in non-ZLB/conventional monetary policy environments (e.g. August 2008), but it can take on negatives values in ZLB/unconventional environments (e.g. July 2011). Krippner (2011, 2012b,c, 2013b, 2015), and Bullard (2012, 2013) provide discussion on the SSR as an indicator of the stance of monetary policy. However, as discussed in Krippner (2014b,c and 2015), the theoretical issue with SSRs as a quantitative measure of monetary policy, is that negative values do not represent interest rates at which economic agents can transact. Therefore, the levels and changes in SSRs when they are negative will, in principal, influence the economy differently than the Federal Funds Rate levels and changes in the past.

- The **Expected Time to Zero (ETZ)**. If the SSR is negative, as in the July 2011 example, the ETZ indicates the future time horizon when the expected path of the SSR will reach zero. The expected path of the SSR is a simple function of the estimated state variables and parameters for the shadow/ZLB yield curve model, and so the ETZ may be readily calculated using those estimates. Krippner (2015) discusses the ETZ in more detail, including its drawbacks. One practical drawback is that the ETZ does not provide a quantitative measure of monetary policy when the SSR is non-negative, such as for the August 2008 example in figure 1. Even when the SSR is negative, a theoretical drawback is that the ETZ doesn't account for the profile of the policy rate after it evolves above zero. Nevertheless, the ETZ does provide a useful cross-check against market expectations for when the Federal Funds Target Rate will likely be raised from the prevailing 0 to 0.25% range.

- The **Effective Monetary Stimulus (EMS)**. The EMS summarizes the current and expected path of the actual or ZLB-constrained short rate relative to an estimate of the neutral interest rate. As discussed in Krippner (2014b,c and 2015), EMS measures are theoretically appealing because they are based on expected actual or ZLB-constrained policy rates, and they are consistent and comparable across both non-ZLB and ZLB environments. Mechanically, the EMS is the total area between the expected path of the SSR truncated at zero and the estimated neutral rate proxied by the Level state variable $L(t)$ estimated from the model. A higher value indicates more stimulus (i.e. a larger and/or longer time of the expected policy rate below the neutral rate). For the August 2008 example in figure 1, the SSR and its expected path were all positive, so no truncation at zero is required to calculate the EMS. For the July 2011 example, the SSR and its expected path are negative out to the ETZ horizon, and those values are truncated to zero to calculate the EMS. The truncation represents that only the positive part of the SSR relative to the neutral rate is effective for monetary stimulus, because the actual interest rates faced by economic agents cannot fall below zero.

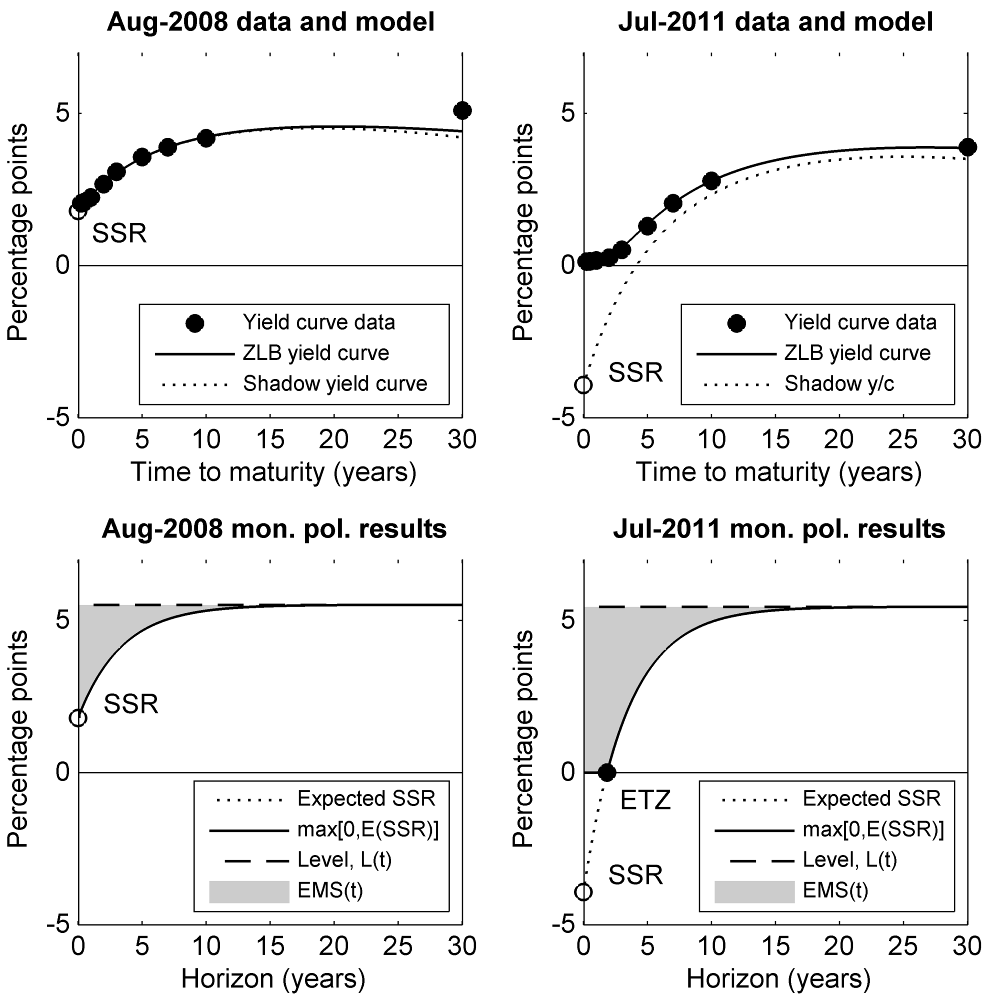


Figure 1: Examples of yield curve data and shadow/ZLB yield curve model estimates, and the associated SSR, the ETZ, and the EMS estimates. The August 2008 data and results are an example of a non-ZLB/conventional monetary policy environment, and July 2011 is a ZLB/unconventional monetary policy environment.

The results shown on the website are the SSR, ETZ, and EMS measures calculated for each K-ANMS(2) estimate from the month-end data. I discuss the model specification, the estimation method, and the data set used for estimation in the following three sections.

3 Model specification

The Krippner (2011, 2012b,c, 2013d,e, 2015) shadow/ZLB framework uses a continuous-time Gaussian affine term structure model (GATSM) to represent the shadow term structure, and the ZLB is imposed using a call option on shadow bonds with a strike price based on the lower bound for interest rates r_L (e.g. $\mathrm{r}_L = 0$ gives a strike price of 1 for the shadow bond). The options reproduce the Black (1995) lower bound mechanism:

$$\underline{\mathrm{r}}(t) = \max\{\mathrm{r}_L, \mathrm{r}(t)\} \tag{1}$$

where $\underline{\mathrm{r}}(t)$ is the ZLB short rate, $\mathrm{r}(t)$ is the shadow short rate, and $\max\{\mathrm{r}_L, \mathrm{r}(t)\}$ imposes the lower bound.

The model used to produce the estimates on the website uses an arbitrage-free Nelson and Siegel (1987) model with two state-variables (Level and Slope), or ANSM(2), to represent the shadow yield curve. I therefore call the associated shadow/ZLB model the Krippner ANSM(2), or K-ANSM(2). The reason for choosing an ANSM to represent the shadow yield curve is theoretical; Krippner (2012d, 2014a, 2014e, 2015) shows that ANSMs provide a parsimonious approximation to any GATSM that could be used regardless of its particular specification. The reason for choosing two factors is empirical; as I will outline in section 6, the shadow short rates obtained from K-ANSM(3) models are very sensitive to the specification to the lower bound, and the movements are often counterintuitive with respect to known monetary policy events.

K-ANSM(2) shadow short rates are:

$$\mathrm{r}\,(t) = L\,(t) + S\,(t) \tag{2}$$

where $L\,(t)$ and $S\,(t)$ are the Level and Slope state variables, respectively. The state variables under the physical $\mathbb{P}$ measure evolve as a correlated vector Ornstein-Uhlenbeck process:

$$\mathrm{d}x\,(t) = \kappa\,[\theta - x\,(t)]\,\mathrm{d}t + \sigma \mathrm{d}W\,(t) \tag{3}$$

where:

$$\begin{aligned} x_t &= \begin{bmatrix} L_t \\ S_t \end{bmatrix} ; \kappa = \begin{bmatrix} \kappa_{11} & \kappa_{12} \\ \kappa_{21} & \kappa_{22} \end{bmatrix} ; \theta = \begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix} \\ \sigma &= \begin{bmatrix} \sigma_1 & 0 \\ \rho_{12}\sigma_2 & \sigma_2\sqrt{1-\rho_{12}^2} \end{bmatrix} \end{aligned} \tag{4}$$

and $\mathrm{d}W\,(t)$ is a 2×1 vector of independent Wiener increments.

K-ANSM(2) shadow forward rates are:

$$\begin{aligned} \mathrm{f}\,(t,u) &= L\,(t) + S\,(t) \cdot \exp\,(-\phi u) \\ &\quad -\sigma_1^2 \cdot \frac{1}{2}u^2 - \sigma_2^2 \cdot \frac{1}{2}\,[G\,(\phi,u)]^2 - \rho_{12}\sigma_1\sigma_2 \cdot uG\,(\phi,u) \end{aligned} \tag{5}$$

where:

$$G\,(\phi,u) = \frac{1}{\phi}\,[1 - \exp\,(-\phi u)] \tag{6}$$

K-ANSM(2) ZLB forward rates are:

$$\begin{aligned} \underline{\mathrm{f}}\,(t,u) &= \mathrm{r}_L + [\mathrm{f}\,(t,u) - \mathrm{r}_L] \cdot \Phi \left[\frac{\mathrm{f}\,(t,u) - \mathrm{r}_L}{\omega\,(u)}\right] \\ &\quad + \omega\,(u) \cdot \phi \left[\frac{\mathrm{f}\,(t,u) - \mathrm{r}_L}{\omega\,(u)}\right] \end{aligned} \tag{7}$$

where $\Phi\,[\cdot]$ is the cumulative unit normal probability density function, $\phi\,[\cdot]$ is the unit normal probability density function:[1]

$$\phi\,[\cdot] = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left[\frac{\mathrm{f}\,(t,u) - \mathrm{r}_L}{\omega\,(u)}\right]^2\right) \tag{8}$$

[1] ϕ as a parameter is completely unrelated to $\phi\,[\cdot]$ as a function. This is a coincidental collision of two standard notations.

and $\omega(\tau)$ is:

$$\omega(u) = \sqrt{\sigma_1^2 \cdot u + \sigma_2^2 \cdot G(2\phi, u) + 2\rho_{12}\sigma_1\sigma_2 G(\phi, u)} \tag{9}$$

K-ANSM(2) interest rates, $\underline{\mathrm{R}}(t,\tau)$, are calculated from K-ANSM(2) forward rates using the standard term structure relationship:

$$\underline{\mathrm{R}}(t,\tau) = \frac{1}{\tau}\int_0^\tau \underline{\mathrm{f}}(t,u)\,\mathrm{d}u \tag{10}$$

which I evaluate by univariate numerical integration with rectangular increments.[2]

4 Estimation method

The K-ANSM(2) with an estimated lower bound has 11 free parameters to estimate, that is, $\mathbb{B} = \{\mathrm{r}_L,\ \phi,\ \kappa_{11},\ \kappa_{12},\ \kappa_{21},\ \kappa_{22},\ \theta_1,\ \theta_2,\ \sigma_1,\ \sigma_2,\ \rho_{12}\}$. I estimate the model using the iterated extended Kalman filter, which allows for the non-linearity of $\underline{\mathrm{R}}(t,\tau)$ with respect to the state variables. I prefer to use the iterated extended Kalman filter because it is acknowledged to be more reliable than the extended Kalman filter in general,[3] and I also found it to be more reliable when applied to estimating K-ANSMs; see Krippner (2013d,e).

The state equation for the K-ANSM(2) is a first-order vector autoregression:

$$x_t = \theta + \exp(-\kappa\Delta t)(x_{t-1} - \theta) + \varepsilon_t \tag{11}$$

where the subscripts t are an integer index to represent the progression of time in steps of Δt between observations (e.g. 1/12 for month-end data), $\exp(-\kappa\Delta t)$ is the matrix exponential of $-\kappa\Delta t$, and ε_t is the vector of innovations to the state variables. The variance of ε_t is:

$$\mathrm{var}[\varepsilon_t] = \int_0^{\Delta t} \exp(-\kappa u)\,\sigma\sigma'\exp(-\kappa' u)\,\mathrm{d}u \tag{12}$$

which is a 2×2 matrix.

The measurement equation for the K-ANSM(2) is:

$$\begin{bmatrix} \mathrm{R}_t(\tau_1) \\ \vdots \\ \mathrm{R}_t(\tau_K) \end{bmatrix} = \begin{bmatrix} \underline{\mathrm{R}}(x_t, \tau_1, \mathbb{B}) \\ \vdots \\ \underline{\mathrm{R}}(x_t, \tau_K, \mathbb{B}) \end{bmatrix} + \begin{bmatrix} \eta_t(\tau_1) \\ \vdots \\ \eta_t(\tau_K) \end{bmatrix} \tag{13}$$

where k is the index for the yield curve data of difference times to maturity τ_k, $\mathrm{R}_t(\tau_k)$ is the observed interest rate at time index t for the time to maturity τ_k, $\underline{\mathrm{R}}(x_t,\tau_k,\mathbb{B})$ are the K-ANSM(2) interest rate functions evaluated at τ_k, and $\eta_t(\tau_k)$ is the component of $\mathrm{R}_t(\tau_k)$ that is unexplained by the K-ANSM(2).

The measurement equation in vector form is:

$$\underline{\mathrm{R}}_t = \underline{\mathrm{R}}(x_t, \mathbb{B}) + \eta_t \tag{14}$$

[2] The integral therefore becomes a simple average of the sequence of $\underline{\mathrm{f}}(t,u)$ up to τ.

[3] For example, Grewal and Andrews (2008) p. 312 cites Lefebvre, Bruyninckx, and De Schutter (2004) to note that the iterated extended Kalman filter outperforms the extended Kalman filter (and the unscented Kalman filter).

where $\underset{\sim}{R}_t$, $\underset{\sim}{R}(x_t, \mathbb{B})$, and η_t are all $K \times 1$ vectors. I specify the variance of η_t to be a diagonal matrix:

$$\Omega_\eta = \text{diag}\left[\left\{[\sigma_\eta(\tau_1)]^2, \ldots, [\sigma_\eta(\tau_K)]^2\right\}\right] \tag{15}$$

where Ω_η is a $K \times K$ matrix with entries $[\sigma_\eta(\tau_k)]^2$, and $\sigma_\eta(\tau_k)$ are standard deviations of $\eta_t(\tau_k)$. As also standard in the literature, I assume that the vectors η_t and ε_t are uncorrelated over time, and the covariances between η_t and ε_t are zero.

5 Yield curve data

I use month-end US yield curve data to estimate the K-ANSM(2). The following three points provide the essential description of the data set:

- The sample period is November 1985 to the latest available month-end data at the time of estimation. The start of the sample is determined by the availability of 30-year interest rate data from the Gürkaynak, Sack, and Wright (2007) data set noted below, but it also coincides with a consistent macroeconomic and policy period. Specifically, the disinflation period under Chairman Volker was completed so inflation was already relatively low and stable, the banking sector deregulation from the early 1980s had also been completed, and the primary monetary policy lever was the Federal Funds Target Rate (FFTR) over the entire period.[4]

- The maturities are 0.25, 0.5, 1, 2, 3, 5, 10, and 30 years. These maturities are the standard benchmarks for Treasury notes and bonds from when the 30-year bond was first issued. I prefer to use the full maturity span of yield curve data, because the 30-year data should help to provide a better estimate of the Level component of the term structure than shorter maturity interest rates, which are subject to larger cyclical fluctuations.

- The data are month-end government interest rates spliced with overnight indexed swap (OIS) rates. The government interest rates are from the Gürkaynak, Sack, and Wright (2007) data set, up to December 2005. I have spliced those with Bloomberg overnight indexed swap (OIS) rate data from January 2006, which is when the data set out to 30-years' time to maturity first became available. I prefer to use OIS rates because they are directly relevant to expectations of the Federal Funds Rate. My pragmatic choice therefore obtains a long time series of data with the more-relevant OIS rates over the sample period within the ZLB environment.

6 Empirical results for monetary policy measures

In this section, I provide empirical results to show why I have chosen the K-ANSM(2) with an estimated lower bound as the model to produce the measures of monetary policy on the website. The reason is essentially that different K-ANSM(2) specifications produce SSR estimates that are empirically robust, i.e. similar in profile and magnitude across different specifications (particularly when standardized as z scores, which is relevant to their use

[4] The Federal Open Market Committee only began making official FFTR announcements after meetings from 1992, but market participants could infer policy changes by open market operations prior to then.

as data in econometric applications), and consistent with unconventional monetary policy announcements.

As discussed in section 2 from a theoretical perspective, I prefer the concept of the EMS as an indicator of the stance of monetary policy stance. Empirically, EMS estimates also turn out to be robust across all of the specifications I have tested. Therefore, while any of the EMS estimates could be used as data in econometric applications, for consistency I have reported the K-ANSM(2) results for all three monetary policy measures (i.e. the SSR, ETZ, and EMS). However, any or all of the measures mentioned below (along with supplementary results for the analysis) are available by request.

6.1 Overview

For my book, Krippner (2015), I have estimated six different K-ANSMs to assess their performance when estimating the measures of monetary policy outlined in section 2. These are K-ANSMs with two or three state variables (i.e. respectively, Level and Slope, or Level, Slope, and Bow), and for each I use the following specifications for the lower bound:

- An imposed lower bound of zero. I will refer to this as $r_L = 0$ percent, or 0 basis points (where 1 basis point equals 0.01 percentage points).
- An estimated lower bound. I will refer to the estimated value of r_L, respectively, $r_L = 0.14\%$ (or 14 basis points) for the K-ANSM(2) and $r_L = 0.12\%$ (or 12 basis points) for the K-ANSM(3).
- An imposed lower bound of 0.25%. This is a lower bound value proposed and used in Wu and Xia (2013, 2014). I will refer to this as $r_L = 0.25\%$, or 25 basis points.

As an initial indication of how the monetary policy estimates can differ according to the number of state variables, figure 2 provides the full-sample results for the K-ANSM(2) and K-ANSM(3) with estimated lower bounds r_L. Figure 3 provides the same results, but from the end of 2007 to highlight the onset of the ZLB/unconventional monetary policy period (the FFTR was set to a 0 to 0.25% target in December 2008). The down and up arrows respectively indicate major unconventional monetary policy easing and tightening events, which I have listed in appendix A.

The SSR results differ materially between the two models. The ETZ results are similar, but are only available in ZLB/unconventional monetary policy environments. The EMS results are similar, and are available for the entire sample.

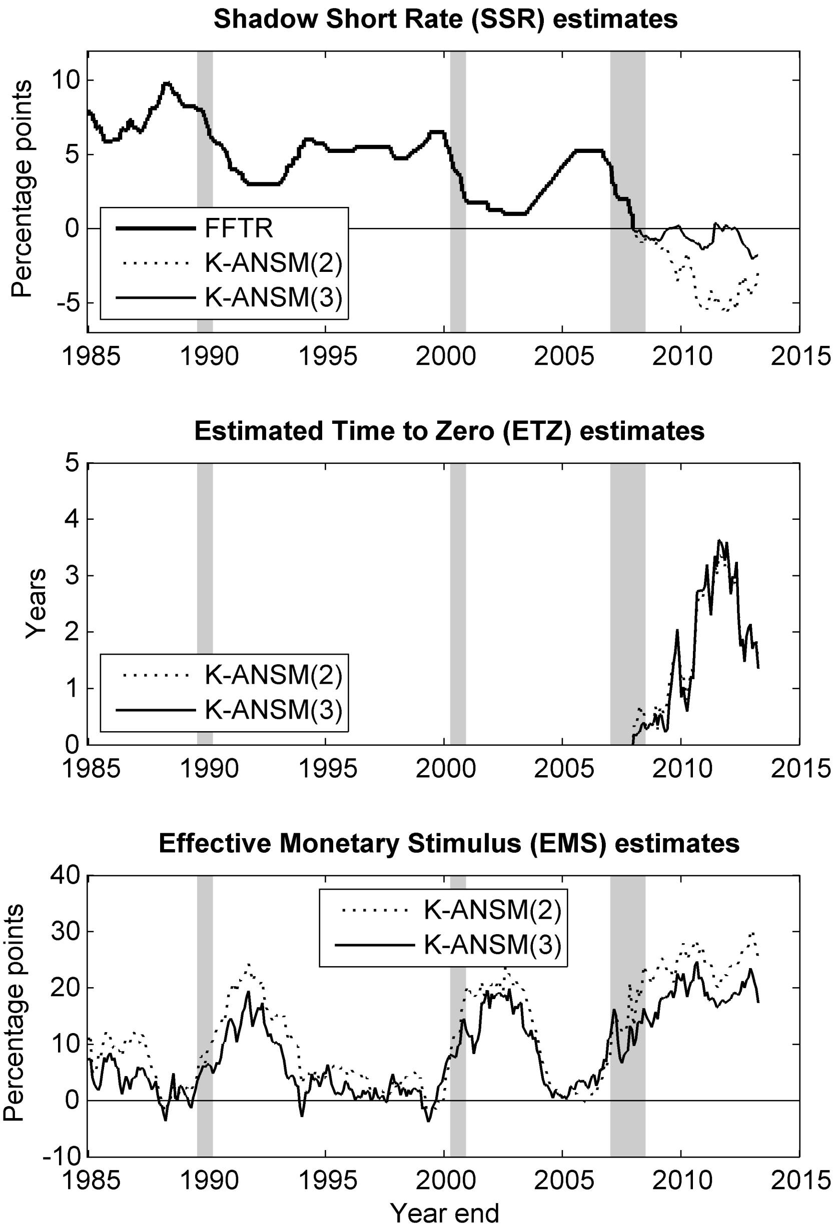


Figure 2. The full-sample time series of the three alternative measures of the monetary policy stance obtained from the K-ANSM(2) and K-ANSM(3) with estimated lower bounds.

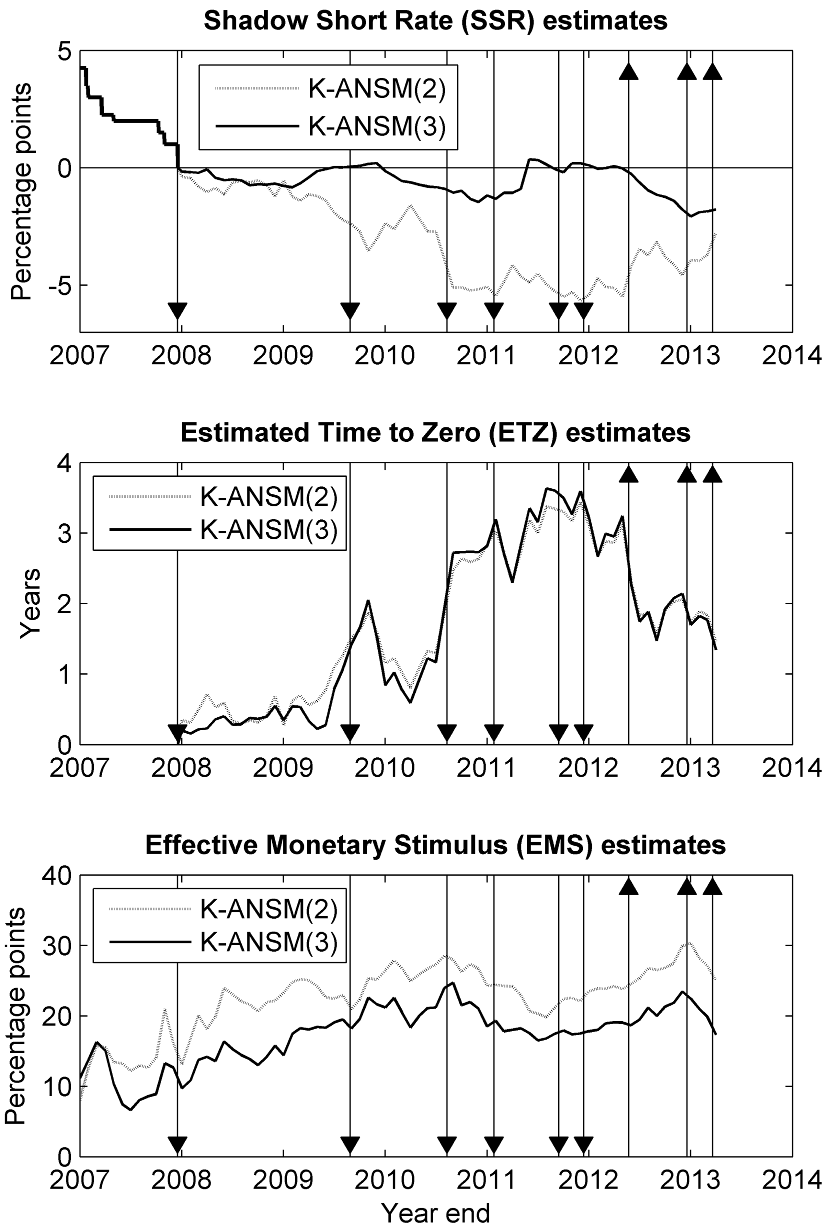


Figure 3. The ZLB-period time series of the three alternative measures of the monetary policy stance obtained from the K-ANSM(2) and K-ANSM(3) shadow term structures. Note that down (up) arrows represent monetary policy easing (tightening) events as detailed in appendix A.

6.2 Shadow Short Rates

Figure 4 plots the SSR estimates from all six models, focussing on the ZLB period (all results prior to December 2008 are set equal to the FFTR, as illustrated in figure 2, so they are identical for each series).

The K-ANSM(2) SSR estimates are relatively robust, and generally consistent with the monetary policy events. That is, the SSRs fall on easing events and rise on tightening events. Conversely, the K-ANSM(3) SSR estimates are very sensitive to how the ZLB is specified, which concurs with results from Bauer and Rudebusch (2013). The movements in the K-ANSM(3) SSRs are also often counterintuitive with respect to monetary policy events. Another item of evidence in favor of K-ANSM(2) SSRs is that Francis, Jackson, and Owyang (2014) finds better results for macroeconomic models estimated with a K-ANSM(2) SSR series, rather than with the Wu and Xia (2013, 2014) SSR series (which are obtained from a model with three state variables).

Therefore, if one prefers an SSR measure of monetary policy, the empirical results suggest using SSR estimates from the K-ANSM(2) specification. I have chosen the results with an estimated lower bound because they represent the central set of results from the three estimates, as indicated in panel 1 of figure 4.

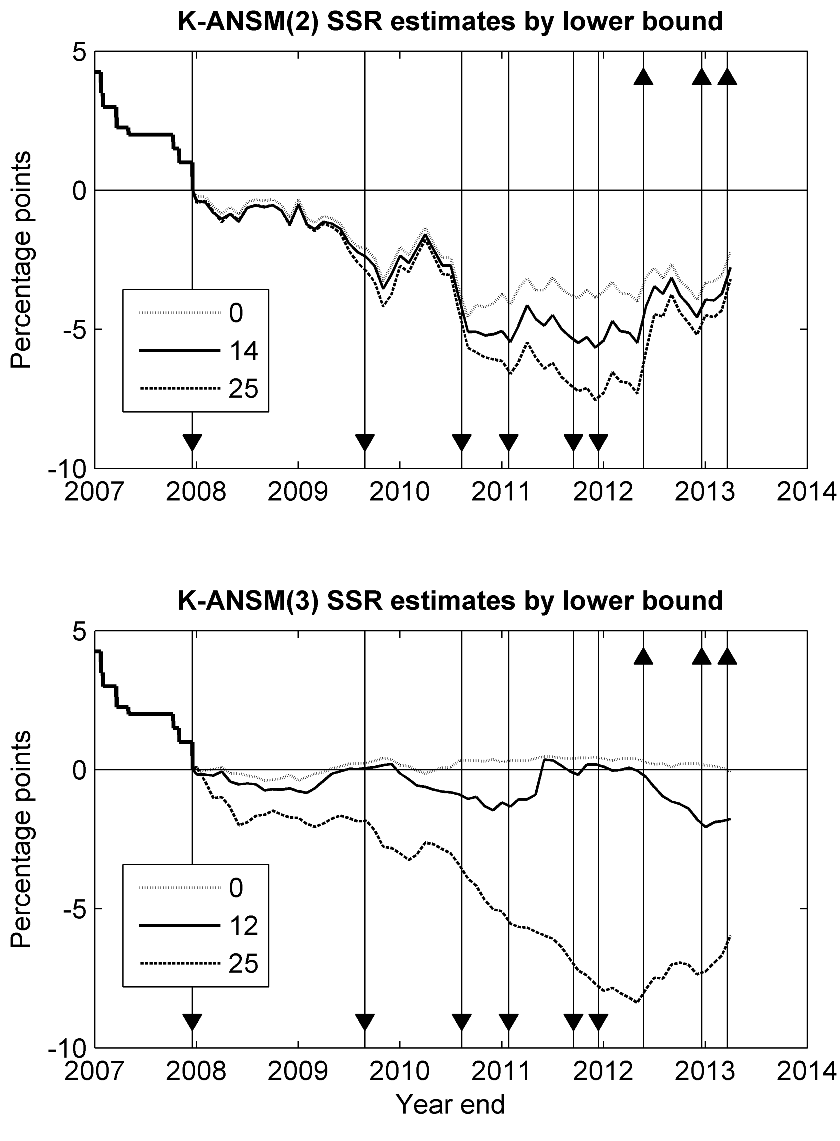


Figure 4. ZLB-period SSR estimates from K-ANSM(2) and K-ANSM(3) specifications with lower bounds as indicated. The flexibility of the K-ANSM(3) makes the estimated SSRs very sensitive to minor parameter differences. Note that down (up) arrows represent monetary policy easing (tightening) events as detailed in appendix A.

Krippner (2015) provides a detailed discussion of the results above. Essentially, the Bow component of the K-ANSM(3) allows too much flexibility for short times to maturity, which leads to counterintuitive results and material changes in K-ANSM(3) SSR results with only minor changes to its specification. This is particularly the case when the lower bound is set well above the majority of the short-maturity yield curve data, as with the specification with a lower bound of 0.25%. The relative robustness of the K-ANSM(2) is due to the absence of the Bow component, but the trade-off is a poorer fit to the yield curve data. The poorer fit seems necessary to obtain robust SSRs for monetary policy purposes.[5]

6.3 Estimated Time to Zero

Figure 5 plots the ETZ estimates from all six models. ETZ estimates are robust empirically, as evidenced by the similar results regardless of the number of state variables and the specification of the lower bound. However, ETZ estimates are not defined in non-ZLB environments (which is why there are no results to plot prior to December 2008). Therefore, ETZ estimates cannot provide a quantitative measure of monetary policy over the entire sample.

[5] As a related point for the K-ANSM(3) and higher-order K-ANSMs, one could add more state variables to produce an increasingly better fit to the data, and the result would be to eventually replicate the short-maturity yield curve data with an SSR result close to zero. However, the replicated short-maturity interest rates and the associated SSR would lack any useful information for monetary policy.

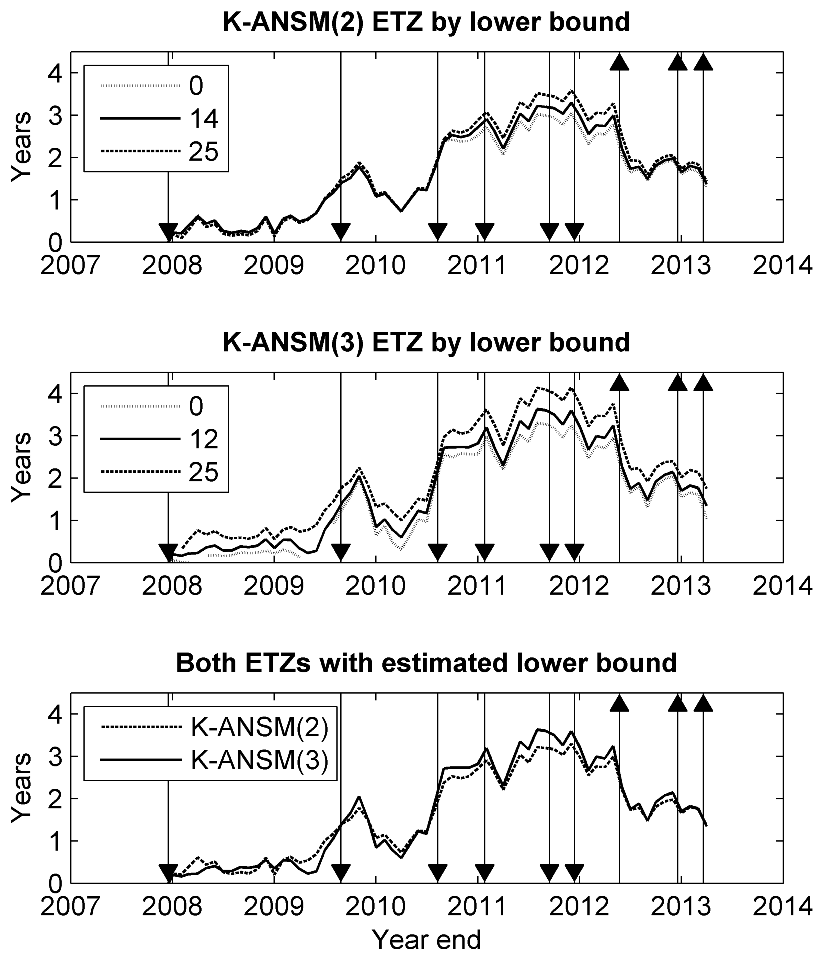


Figure 5. ZLB-period ETZ estimates from K-ANSM(2) and K-ANSM(3) specifications with lower bounds as indicated. Note that down (up) arrows represent monetary policy easing (tightening) events as detailed in appendix A.

6.4 Effective Monetary Stimulus

Figures 6 and 7 plot the ETZ estimates from all six models, respectively over the full sample and the ZLB/unconventional period. EMS estimates are empirically robust. That is, different K-ANSM specifications produce similar EMS estimates. As shown in figures 8 and 9, the EMS estimates are particularly robust when standardized as z scores, which is relevant for using them as data in econometric analysis.

One issue with the EMS measures shown here is that they dips from late 2011, which is a counterintuitive response to the monetary policy easing events. As discussed in Krippner (2015), the EMS measures could be improved by using information additional to the yield curve data to help estimate the Level state variable used as a proxy for neutral rate.

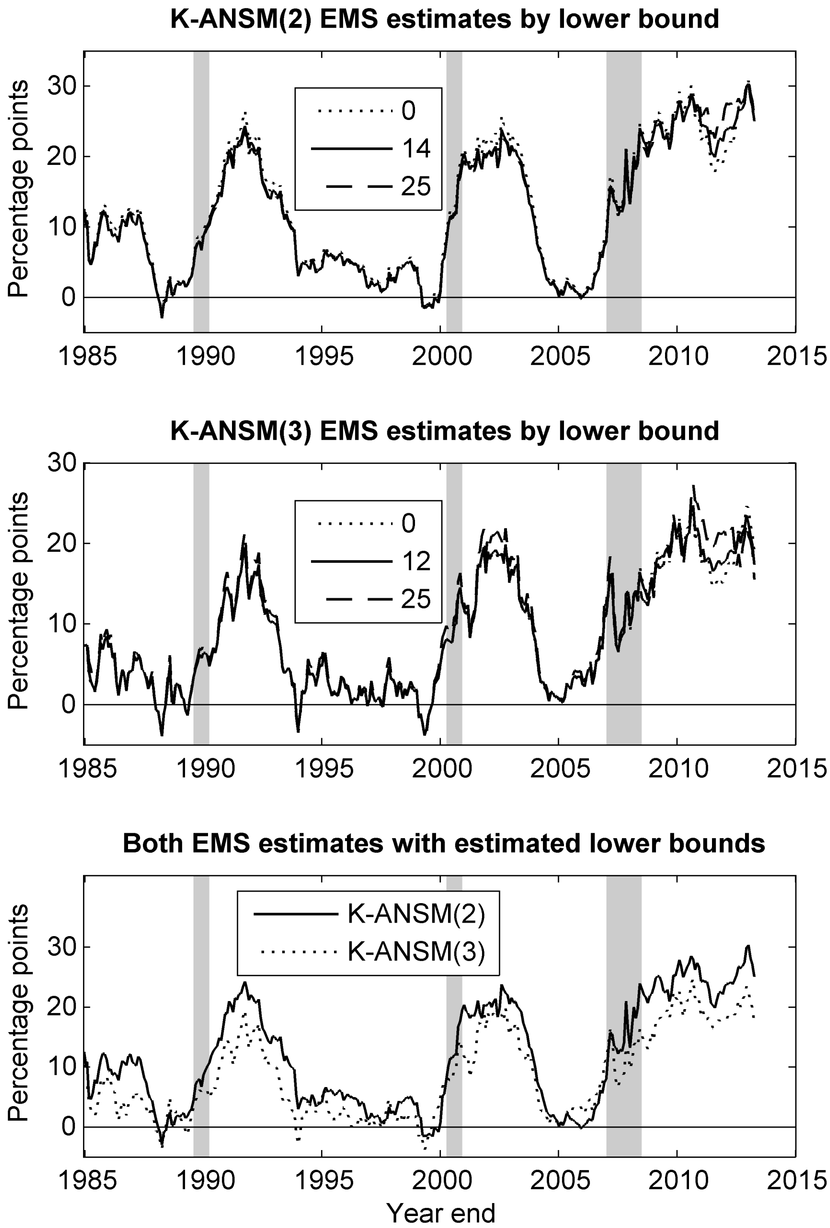


Figure 6: ZLB-period EMS estimates from K-ANSM(2) and K-ANSM(3) specifications with lower bounds as indicated. Note that down (up) arrows represent monetary policy easing (tightening) events as detailed in appendix A.

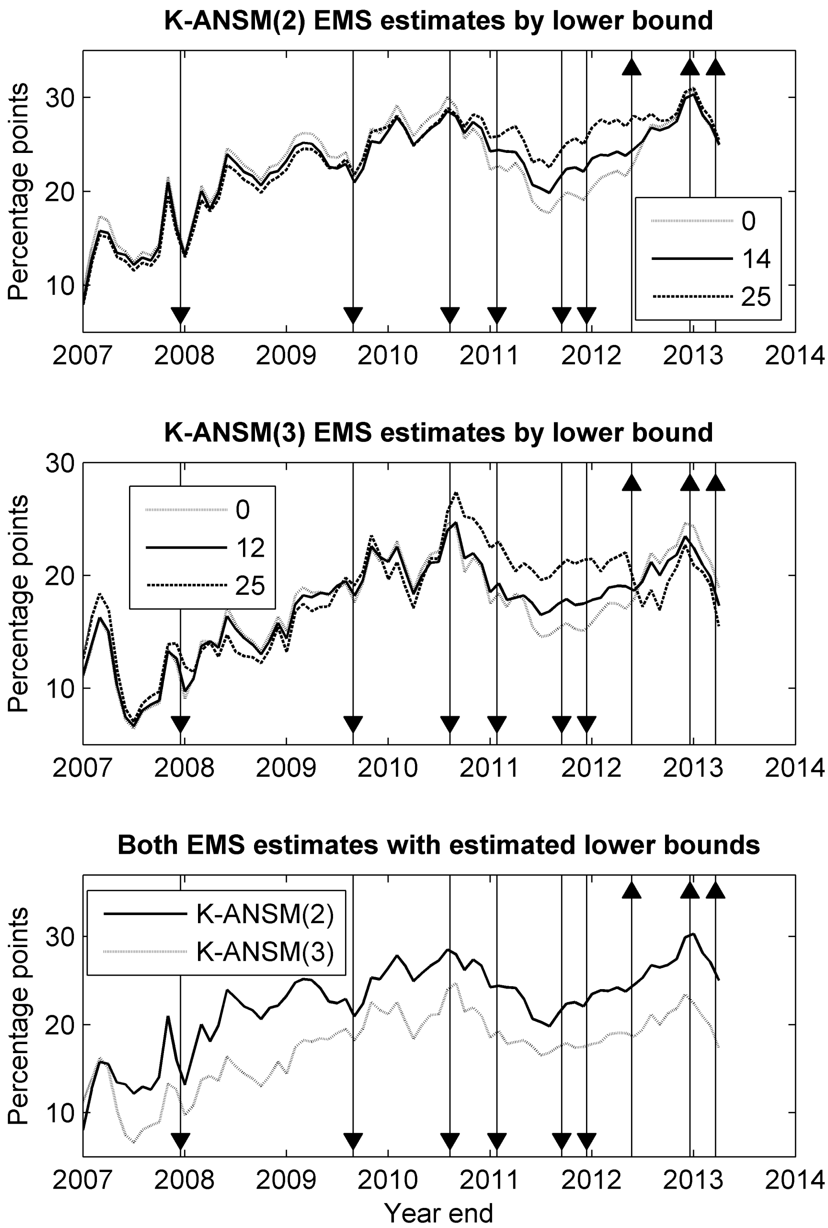
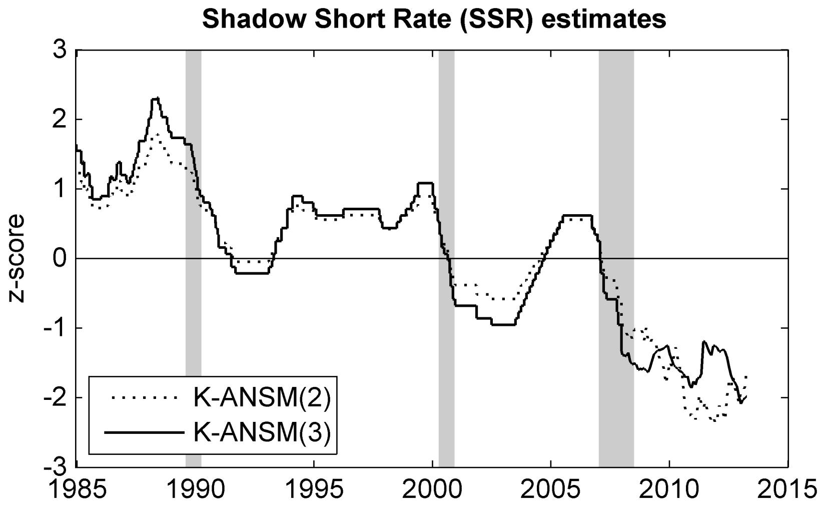


Figure 7. ZLB-period EMS estimates from K-ANSM(2) and K-ANSM(3) specifications with lower bounds as indicated. Note that down (up) arrows represent monetary policy easing (tightening) events as detailed in appendix A.

6.5 SSR and ETZ comparison as z scores

Figures 8 and 9 plot the z scores (i.e. [value - mean] / [standard deviation]) for the SSR estimates combined with the FFTR series up to November 2008, and the EMS estimates. The z scores for the EMS series are very robust, while those for the SSR are not.



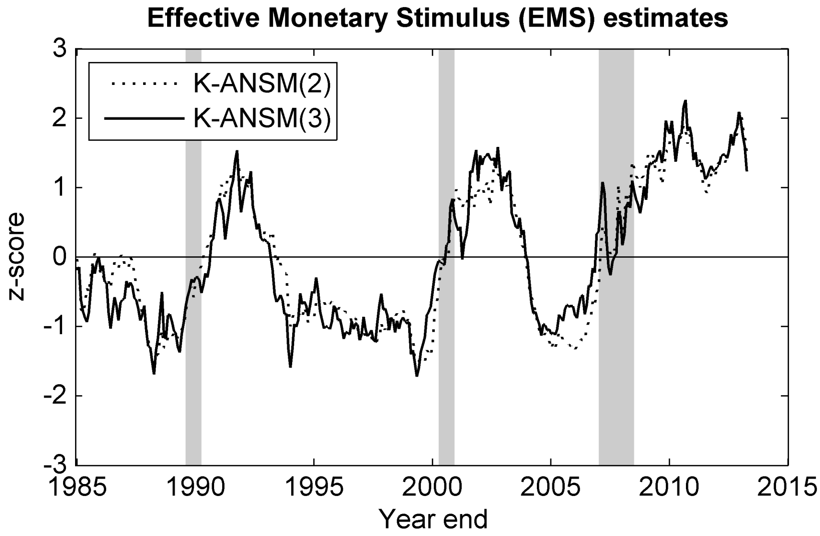


Figure 8. Full-sample FFTR + SSR estimates and full-sample EMS estimates from K-ANSM(2) and K-ANSM(3) specifications with estimated lower bounds, all expressed as z-scores.

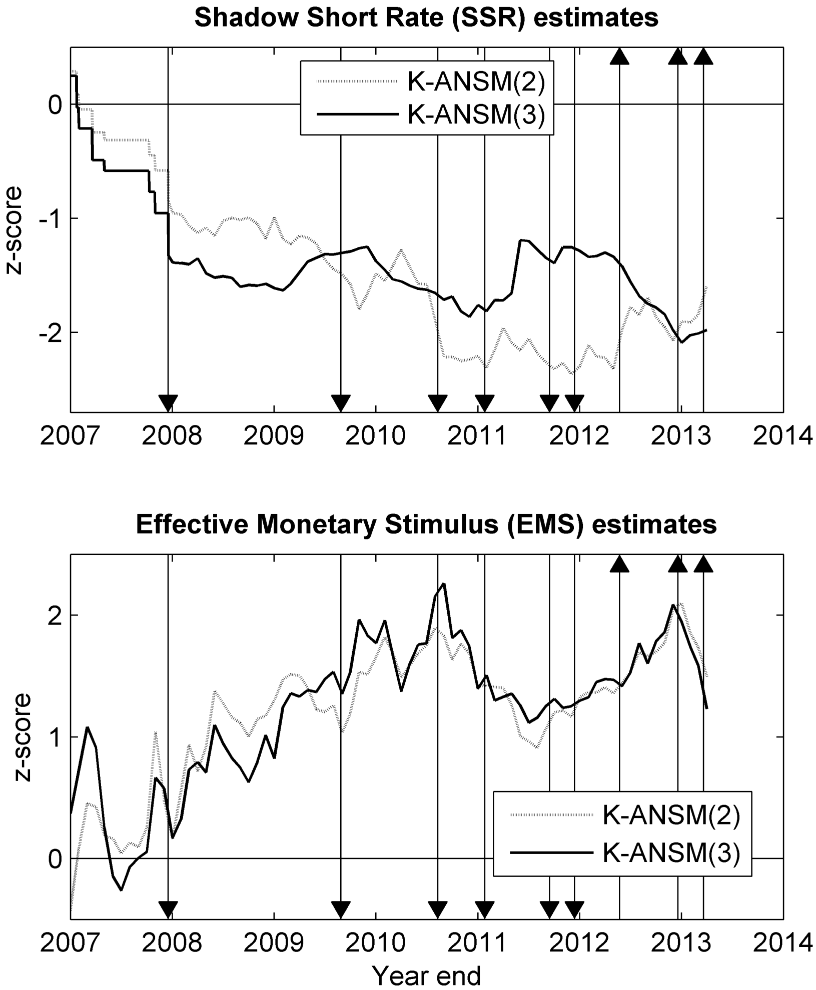


Figure 9. ZLB-period FFTR + SSR estimates and subsample EMS estimates from K-ANSM(2) and K-ANSM(3) specifications with lower bounds as indicated, all expressed as z-scores. Note that down (up) arrows represent monetary policy easing (tightening) events as detailed in appendix A.

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A List of monetary policy events

The list below summarizes the dates of the announcements indicated in the figures, along with my easing or tightening classification, and a brief description of the event itself. Note that I have also included other events that occurred during the same month as the main event, and sometimes I have combined close-by events to keep the indicators at a manageable number and distinct from each other within the figures.

1. Tuesday, December 16 2008 (easing): The FOMC end-of-meeting statement announced a 0 to 0.25 percent range for the FFTR, from the 1 percent target rate that had prevailed since the Wednesday, October 29 statement, effectively beginning the ZLB environment. Note that this date in the figures also captures the liquidity measures put in place by the Federal Reserve prior to December 16, in particular following the Monday, September 15 Lehmans' bankruptcy. In addition, the first large scale asset purchase program announcement, the so-called "Quantitative Easing 1", or QE1, was announced on Tuesday, November 25. QE1 amounted to purchases of $1.725 trillion of mainly asset-backed securities up to when it ended in March 2010.

2. Friday, August 27 2010 (easing): FOMC Chairman Bernanke foreshadowed "Quantitative Easing 2", or QE2, at a speech in Jackson Hole. QE2 was subsequently introduced on Wednesday, November 3 2010, and amounted to purchases of $0.6 trillion of US Treasuries up to when it ended in June 2011. Another influence during this month was the Tuesday, August 10 FOMC statement that acknowledged a slowing of the economy.

3. Tuesday, August 9 2011 (easing): The FOMC statement announced the first explicit extended calendar forward guidance for the FFTR, with a conditional expectation that it would remain near zero to mid-2013. Another influence during this month was Bernanke's announcement on Friday, August 26 that the upcoming September 21 FOMC meeting would be extended to two days to allow a fuller discussion of the range of tools that could be used for additional monetary stimulus. I have combined this announcement indicator with an announcement in the following month:

    - Wednesday, September 21 2011 (easing): The FOMC statement announced the maturity extension program, the so-called "Operation Twist". Operation Twist was initially a $0.4 billion program to sell shorter maturity Treasury securities and buy longer-term Treasury securities, but the Wednesday, June 20 2012 FOMC statement announced its extension and it ultimately amounted to $0.67 trillion when it ended in late 2012.

4. Wednesday, January 25 2012 (easing): The FOMC statement announced an extension of the calendar forward guidance to late-2014.

5. Thursday, September 13 2012 (easing): The FOMC statement announced an extension of the calendar forward guidance to mid-2015 and the introduction of "Quantitative Easing 3", or QE3. QE3 was an open-ended program to purchase $40 billion of asset-backed securities per month.

6. Wednesday, December 12 2012 (easing): The FOMC statement announced a change from calendar forward guidance to guidance based on an unemployment rate of 6.5 percent. At the same meeting, QE3 was increased to $85 billion purchases per month by adding $45 billion of longer-term Treasury securities.

7. Wednesday, May 22 2013 (tightening): Chairman Bernanke foreshadowed the potential tapering of QE3 at a congressional testimony on the economic outlook. I have combined this announcement indicator with an announcement in the following month:

    - Wednesday, June 19 2013 (tightening): Chairman Bernanke in his press conference following the FOMC meeting mentioned that 14 of 19 FOMC participants expected the first increase in the target rate to occur in 2015.

8. Wednesday, December 18 2013 (tightening): The FOMC statement announced the first reduction of QE3, from $85 billion to $75 billion per month.

9. Wednesday, March 19 2014 (tightening): The FOMC statement announced the third reduction of QE3 from $65 billion to $55 billion per month, and also removed the forward guidance based on an unemployment rate of 6.5 percent in favor of a qualitative guideline of maximum employment and two percent inflation. The FOMC member projections for the FFTR as at year-end 2015 and year-end 2016 were revised up slightly relative to the December projections, and FOMC Chairwoman Yellen in the associated press conference mentioned the possibility of an increase in the FFTR in early 2015.