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The effect of conventional and unconventional euro area monetary policy on macroeconomic variables

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Non-technical summary

Research Question

How can the effect of monetary policy on the economy be modelled consistently across periods when the conventional metric for monetary policy, short-maturity interest rates, is constrained near zero? We propose using an alternative monetary policy metric, the "Effective Monetary Stimulus" (EMS), that is designed to reflect both conventional and unconventional monetary policy actions (e.g. quantitative easing). Our investigation also offers insights on whether the transmission of monetary policy in the euro area has changed since the Global Financial Crisis of 2008/09 (GFC).

Contribution

We introduce the concept of the EMS, and show that it can be closely proxied by a simple combination of observable variables, predominantly long-maturity interest rates. We compare how the EMS performs in a range of economic models against the short-maturity interest rate, particularly the ability of both to plausibly describe the dynamics of the euro area inflation and economic activity in response to unanticipated changes (shocks) to monetary policy.

Results

Our results suggest that the EMS is superior to short-maturity interest rates as a monetary policy metric, even prior to the GFC. The EMS obtains more stable and plausible structural relationships with inflation and economic activity in the euro area across our sample, although the responses to monetary policy shocks in the lower bound period have weakened and are no longer statistically significant. Our results indicate that euro area monetary policy has remained accommodative since the GFC, and this has helped to keep inflation and economic activity higher than they might have been otherwise.

Nichttechnische Zusammenfassung

Fragestellung

Wie kann in Zeiten, in denen die gängige Messgröße der Geldpolitik, d. h. das Niveau der kurzfristigen Zinsen, bei nahe null verharrt, die Wirkung der Geldpolitik auf die Wirtschaft einheitlich modelliert werden? Wir schlagen die Verwendung einer alternativen geldpolitischen Messgröße vor, und zwar des "Effective Monetary Stimulus" (EMS), der sowohl der konventionellen Geldpolitik als auch geldpolitischen Sondermaßnahmen (wie etwa der quantitativen Lockerung) Rechnung tragen soll. Aus unserer Untersuchung ergeben sich auch Erkenntnisse darüber, ob sich die Transmission der Geldpolitik im Euro-Währungsgebiet seit der globalen Finanzkrise von 2008/2009 verändert hat.

Beitrag

Wir stellen das Konzept des EMS vor und zeigen, dass mittels einer einfachen Kombination beobachtbarer Variablen, vor allem Langfristzinsen, eine recht genaue Annäherung möglich ist. Wir vergleichen das Verhalten des EMS in unterschiedlichen ökonomischen Modellen mit dem der Kurzfristzinsen und untersuchen dabei insbesondere die Fähigkeit dieser beiden Messgrößen, die Dynamik von Inflation und Wirtschaftstätigkeit im Euro-Raum bei plötzlichen Änderungen der Geldpolitik (Schocks) plausibel zu beschreiben.

Ergebnisse

Unsere Ergebnisse lassen darauf schließen, dass der EMS als geldpolitische Messgröße den Kurzfristzinsen überlegen ist, und dies selbst vor Beginn der globalen Finanzkrise. Der EMS ergibt in unserem Untersuchungszeitraum stabilere und plausiblere strukturelle Zusammenhänge in Bezug auf den Preisauftrieb und die konjunkturelle Aktivität im Eurogebiet, wenngleich die Reaktionen auf geldpolitische Schocks im Niedrigzinsumfeld zurückgegangen und statistisch nicht mehr signifikant sind. Unsere Ergebnisse weisen darauf hin, dass die Geldpolitik im Eurogebiet seit der globalen Finanzkrise akkommodierend geblieben ist. Dies hat dazu beigetragen, die Teuerung und die Wirtschaftstätigkeit auf einem Niveau zu halten, das andernfalls möglicherweise nicht erreicht worden wäre.

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The effect of conventional and unconventional Euro area monetary policy on macroeconomic variables*

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Abstract

We investigate the effect of monetary policy on European macroeconomic variables using a small-scale vector autoregression (VAR) and the "Effective Monetary Stimulus" (EMS). The EMS is a monetary policy metric obtained from yield curve data that is designed to consistently reflect the overall stance of monetary policy across conventional and uncoventional monetary policy environments. Empirically, using the EMS in our VAR obtains plausible and stable structural relationships with prices and output developments across and within conventional and unconventional environments, and more so than short-maturity rates or alternative metrics, suggesting that it provides a useful practical monetary policy metric for policy makers. The VAR results show that European monetary policy shocks have been accommodative since 2007, although their effect has become more uncertain compared to the conventional policy period.

Keywords: Monetary Policy, Zero Lower Bound, Dynamic Term Structure Model.

JEL classification: E43, E44, E52.

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1 Introduction

In this article, we investigate the effect of monetary policy on European macroeconomic variables using a small-scale vector autoregression (VAR) and a monetary policy metric that allows for the conduct of monetary policy by conventional and unconventional means.

The broad motivation for our investigation takes several interconnected perspectives, so we first briefly list them here and then expand on each further below. First, short-maturity nominal interest rates are constrained by the lower bound in many major economies at present, and so provide an incomplete and hence misleading indication of the stance of monetary policy. A more encompassing metric of monetary policy for policy monitoring and particularly for quantitative analysis is required. Second, small scale monetary VAR models have been useful tools for policy makers in the past, connecting policy actions to the ultimate policy goals of output stabilization and price stability. It would therefore be desirable to provide an analogous model that applies in lower bound environments. Third, our model is of practical relevance to the operation of monetary policy in the euro area, the second largest economic region in the world.

Short-maturity interest rates (hereafter, short rates) are often used in macroeconomic time series models to reflect the stance of monetary policy. However, in recent years, short rates have approached the lower bound in many major economies, and so can no longer provide a complete indication of the overall stance of monetary policy. For example, figure 1 shows that the policy interest rate and short-maturity interest rates in the euro area have remained close to zero since 2009 (apart from a short-lived tightening episode during 2011) which would suggest a relatively steady policy stance by the European Central Bank (ECB).[1] However, the ECB has actually adopted a more accommodative stance than near-zero three-month interest rates suggest, through unconventional monetary policy actions. Those actions include long-term financing operations and asset purchasing programs, which are reflected in the ECB's balance sheet in figure 1, and forward guidance and announced but unimplemented policy programmes (e.g. Outright Monetary Transactions), which influenced financial markets and monetary conditions but not the ECB's balance sheet. A monetary policy metric that consistently accounts for the overall effect of the conventional operation of monetary policy via policy interest rates and the range of different unconventional monetary policy actions more recently would therefore be useful.

For this reason, we use the concept of the effective monetary stimulus (EMS) from Krippner (2014) as the benchmark monetary policy metric in our VAR. We detail the EMS in section 3, but as an overview for the purposes of this introduction, the EMS at each point in time quantifies, in a single summary value, the expected path of actual (i.e. lower-bounded) short-maturity interest rates and risk premiums relative to the long-run nominal natural interest rate (i.e. the rate consistent with stable inflation and a zero output gap). Calculating this quantity over the entire sample period gives an EMS time series that indicates the stance of monetary policy with a common basis across and within conventional and unconventional environments.

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[1] The policy rate series uses the Main Refinancing Operations (MRO) rate and then the deposit rate from 8 October 2008 when that became the dominant policy rate following the announcement of full allotment for MROs. Note that, for the ease of exposition throughout the paper, we use "ECB" to refer to the Eurosystem's joint monetary policy.

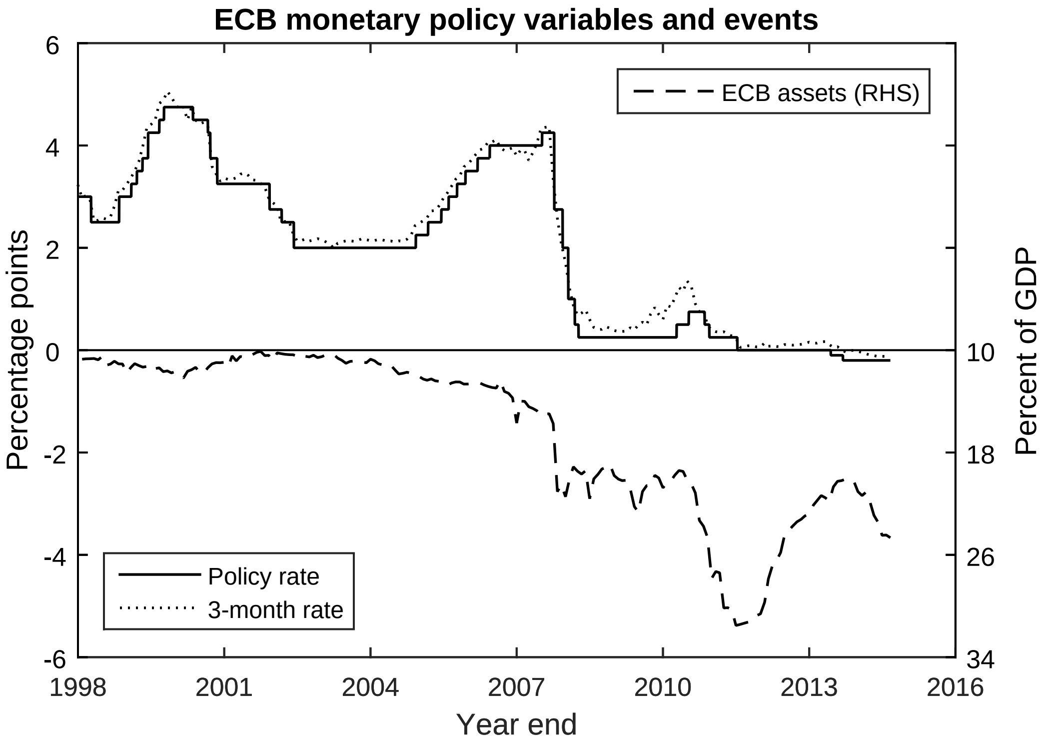

Figure 1: ECB policy rate and assets held on the ECB balance sheet.

The EMS is estimated from shadow/lower bound term structure models in Krippner (2014), but we show in this paper that it can also be closely proxied by a simple combination of observable variables, with the primary component being longer-maturity interest rates. This result is particularly appealing from two perspectives: (1) it enables us to present results that are not subject to the issue of generated regressors; (2) it provides formal justification for using longer-maturity interest rates as a monetary metric, which in turn relates to event studies of unconventional monetary policy that use such rates (e.g. see Williams (2011) for an overview of such studies). We can furthermore use a shadow/lower bound term structure model to decompose longer-maturity rates into expected policy and risk premium components, which are generally acknowledged to relate respectively to the forward guidance and quantitative actions of central banks; e.g. see the discussion in Woodford (2012). Hence, while it is not the primary focus of our present paper, we also undertake a preliminary investigation of the relative importance of the expected policy and risk premium components of the EMS.

We use the time-varying parameter VAR of Primiceri (2005) for our estimation. Small scale VARs are often used to investigate the interrelationships of monetary policy and macroeconomic variables, where the latter are typically those that reflect the concepts of key interest to policy makers, i.e. inflation or inflation expectations to reflect developments in prices, the output gap or the unemployment rate to reflect economic slack or pressure, and sometimes the exchange rate. The allowance for time variation provides a flexible modeling approach that appropriately allows for the relatively stable economic and financial developments earlier part of our sample and the more variable years around the global financial crisis and the euro area debt crisis.[2] Our setup also allows us to check whether macroeconomic variables respond differently to monetary policy shocks in a zero lower bound environment than in a period of conventional monetary policy shocks, which we discuss further below in the context of our results.

We use German macroeconomic variables in our benchmark model, because that allows for a wide variety of robustness checks with alternative macroeconomic data for our overall sample (a training period from 1992 to 1998 prior to the introduction of the euro, and the actual estimation period over the period of monetary union). We obtain very similar results using euro area macroeconomic variables analogous to our German benchmark dataset.

Our first set of results suggests that the EMS is a better monetary policy metric than the short rate (or shadow short rates). Specifically, we find more plausible and reliable impulse responses to economic activity and inflation from our VAR with the EMS as the monetary policy metric rather than with short-maturity interest rates (or shadow short rates). Those results hold for the full sample and the lower bound period, as expected given the constraint of short-maturity rate over the lower bound period. But importantly, the results also hold for a sample covering only the non-lower-bound period, so the EMS appears to be a better monetary policy metric than the short rate in the period where both could vary freely, hence allowing a "like-for-like" comparison.

Regarding the outright results for the VAR featuring the EMS as the monetary policy metric, we find that it obtains stable and plausible structural relationship with inflation and output developments over both conventional and unconventional policy periods in our sample. The size of monetary policy shocks remains fairly constant across the sample, although their persistence is larger in the unconventional period. The median responses of inflation and output to monetary policy shocks have the same signs and profiles across the sample, but the responses in the unconventional policy period are weaker and no longer statistically significant. Overall, our small-scale EMS VAR appears to provide useful rules of thumb for policy makers across conventional and unconventional monetary policy environments.

Given the stable structural relationships in our model, we are therefore able to offer a characterization of the monetary policy shocks and a counterfactual analysis for ECB monetary policy from the time of the Global Financial Crisis (GFC); i.e. what would likely have been the hypothetical realizations of the state variables if the monetary policy shocks had not occurred? First, we find that monetary policy shocks have been expansionary for most of the time since 2007. Consistent with that expansionary policy, prices and industrial production have been elevated relative to the counterfactual.

The outline for the remainder of the paper is as follows. Section 2 contains a review of the closely related literature. In section 3 we provide a brief summary of our modeling approach. In section 4, we introduce the concept and the calculation of the EMS measure. Section 5 describes the data used in our benchmark estimations, and the main results of those estimations, in particular impulse responses, are presented and discussed in section 6. Section 7 contains a counterfactual analysis. In section 8, we summarize the sensitivity of our results to variable selection, and section 9 concludes.

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[2] Cogley and Sargent (2005) is another example of time-varying parameters.

2 Literature review

In this section, we discuss the currently limited literature that uses monetary policy metrics other than observable short rates in empirical macroeconomic time series models that include conventional and unconventional monetary policy periods.[3] Our article study is generally consistent with that literature, and extends it from various perspectives, as we briefly mention below and detail later in subsequent sections.

The first two examples, Wu and Xia (2016) and Francis, Jackson, and Owyang (2014), are both for the United States, and replace the short rate with shadow short rates (SSRs) estimated from shadow/lower bound term structure models. We highlight upfront that caution is required when using SSR estimates as data. In particular, Krippner (2015a) highlights that SSRs estimated from three-factor models, such as those of Wu and Xia (2016), are essentially overfitted and therefore have magnitudes, profiles, and dynamics that are very sensitive to even small changes to the model specification and data. The Wu and Xia (2016) results for the macroeconomic model using the SSR estimates are therefore likely to be specific to the shadow/lower bound term structure model choices made by the authors. Conversely, Krippner (2015a) shows that two-factor SSR estimates, such as that of Krippner (2015b) used in Francis et al. (2014), are more robust to estimation choices, i.e. with similar profiles and dynamics, but still with some magnitude sensitivity.[4]

Wu and Xia (2016) uses a constant parameter FAVAR for modelling the transmission of monetary policy shocks, and test whether structural relations changed between the conventional and lower bound period. Their findings broadly coincide with ours; i.e. there are stable structural relationships between monetary policy shocks and macroeconomic variables across the sample, but shock transmissions during the zero lower bound period are more uncertain/less significant.

Francis et al. (2014) begins by questioning whether the SSR in principle provides a suitable monetary policy metric for a VAR, because the SSR in the lower bound period is an unobserved and estimated quantity that is not directly influenced by macroeconomic variables (unlike the Federal Funds Rate in the conventional monetary policy period). Nevertheless, the authors find empirically that using the Krippner (2015b) two-factor SSR series obtains stables structural relationships over the conventional and unconventional policy period. Conversely, Francis et al. (2014) find that using the Wu and Xia (2016) three-factor SSR series results in ambiguous evidence for parameter stability.

Using the EMS resolves the issues mentioned in Francis et al. (2014). First, the expected path of actual short-maturity interest rates is in principle influenced by macroeconomic variables, second, we can obtain a proxy for the EMS that is calculated exclusively from observed data, and third, we find that the EMS turns out to be a plausible indicator for monetary policy in the non-zero lower bound periods. Our full sample results are consistent with the Francis et al. (2014) full sample results.

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[3] There is obviously a much wider literature on unconventional monetary policy; we have already mentioned event studies, and formally founded macroeonomic models, e.g. Gertler and Karadi (2011) and Aruoba and Schorfheide (2015) are another approach.

[4] The series is available on the website "http://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy" and are updated monthly. With respect to relative robustness, our two- and three-factor SSR results for the euro area in appendix C are analogous to those of Krippner (2015a).

Lombardi and Zhu (2014) for the United States and Kucharcukova, Claeys, and Vasicek (2014) for the euro area, replace the short rate with essentially a monetary conditions index estimated from a factor model.[5] Lombardi and Zhu (2014) includes interest rates, monetary aggregates, and Federal Reserve balance sheet data for the factor model estimation. Using the resulting index in small-scale VAR obtains monetary policy shocks that are more realistic in the unconventional period, while the VAR using the Federal Funds Rate severely underestimates the extent of monetary policy accommodation following the GFC. Our analogous estimations of monetary policy shocks for the euro area obtain similar results.

Kucharcukova et al. (2014) develop a monetary conditions index for the euro area analogous to Lombardi and Zhu (2014), and it additionally includes the exchange rate. The VAR results show that the monetary conditions index produces similar but more uncertain/less significant effects on output and prices than the short-maturity interest rate. Our analysis obtains similar results.

3 The model

In this section, we discuss our use of the time-varying parameter VAR (TVP-VAR) of Primiceri (2005). Section 3.1 outlines why we use that framework for our investigation, section 3.2 provides an overview of the framework itself and the benchmark model that we apply, and section 3.3 details our prior and initialization process. Note that sections 4 and 5 provide a detailed description of the data we use for our model estimations, but for the purposes of clarity in this section, we note that our benchmark models all contain four variables; the 3-month interest rate or EMS as our monetary policy metric, a price index, an output gap proxy, and a commodity price index.

3.1 Why use the Primiceri (2005) TVP-VAR?

The Primiceri (2005) TVP-VAR allows for time variation in both the interrelationships of the VAR variables and the variance of model innovations. Those aspects make it highly applicable to our investigation because the sample period that we consider covers distinctly different environments at different parts of the sample.

On the face of it, as discussed in the introduction and to be reiterated in section 4, one aspect that has clearly changed over the sample period is the conduct of monetary policy, from conventional means using variable interest rate settings to near-zero interest rate settings plus unconventional actions. However, as also discussed in those sections, our use of the TVP-VAR is not necessarily to allow for that change; one advantage of the EMS is that it should, in principle, be able to provide a consistently scaled metric for the monetary stance over both conventional and unconventional environments and therefore maintain stable relationships within a VAR.

Rather, the important change over our sample period that we want to allow for is the macroeconomic and financial market environment. That is, the sample covers the

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[5] The Lombardi and Zhu (2014) measure is called the Shadow Rate, but we use the alternative name here to clearly distinguish it from the SSR estimates obtained from shadow/lower-bound term structure models, and to be consistent with the terminology used in Kucharcukova et al. (2014).

relatively stable environment up to the mid-2000s, the more turbulant years of the GFC and the euro area debt crisis, and then the lingering environment from the latter events. These changes are likely to have at least led the magnitudes of innovations to the macroeconomic data to vary over the sample, which the allowance for stochastic volatility in the TVP-VAR will account for. At the same time, the TVP-VAR will accommodate any changes to the structural relationships in the economy, which may have occurred if economic agents respond differently in the different environments. For example, a certain scale of policy easing may cause different macroeconomic responses depending on whether it takes place within normal macroeconomic conditions or in a low interest rate environment. The TVP-VAR will capture such changes because it allows for gradual changes in the VAR structural relationships over time.

Our model approach therefore allows us to assess whether monetary policy shocks and their effect on the economy have changed significantly in the euro area. For Germany and the euro area, there is little comparable evidence available to the best of our knowledge. Evidence on time variation in macro-financial data is either peripherally covered in cross country studies, e.g. Del Negro and Otrok (2008), or the time variation is analyzed with a focus on other areas of the economy, e.g. Berg (2015) provides an analysis of time variation in fiscal multipliers.

3.2 Model specification

In the following, we describe the TVP-VAR of Primiceri (2005) that we use for estimating the time-varying dynamics of our state vector y_t (which contains four variables in its benchmark form). In our estimation, we take the adjustment to the original ordering of the MCMC steps into account that is suggested by Del Negro and Primiceri (2015). For the purposes of our paper, we only briefly summarize the model description and the specification of priors from Primiceri (2005), and we refer readers to the original article for a detailed discussion and a documentation of the estimation procedure.

We consider a VAR process of the form:

$$y_t = c_t + B_{1,t} y_{t-1} + \ldots + B_{k,t} y_{t-k} + u_t. \tag{1}$$

The coefficients $B_{i,t}$, $i = 1, \ldots, k$ and the innovations u_t can vary over time. We use $k = 4$ lags in our application. The variance-covariance matrix of the residuals u_t, Ω_t, can be decomposed as:

$$A_t \Omega_t A_t = \Sigma_t \Sigma_t', \tag{2}$$

where A_t is a lower triangular matrix with elements $\alpha_{ij,t}$, $j = 1, \ldots, k$, in the lower triangle and ones on the main diagonal. Σ_t is a diagonal matrix with the time-varying elements $\sigma_{1,t}, \ldots, \sigma_{n,t}$ on its main diagonal. Note that the variance changes in any state variable can transmit to the other state variables because the matrix A is not diagonal.

The number of parameters to be estimated is kept small by assuming that the time variation of the parameters can be described by (geometric) random walks, i.e.

$$B_t = B_{t-1} + \nu_t, \tag{3}$$

$$\alpha_t = \alpha_{t-1} + \zeta_t, \tag{4}$$

$$log(\sigma_t) = log(\sigma_{t-1}) + \eta_t. \tag{5}$$

where B_t represents the vectorized matrix of coefficients $B_{1,t}, \ldots, B_{k,t}$, and the vectors α_t and σ_t respectively contain the free or non-zero elements of A_t or Σ_t, respectively. The variances of the residuals are assumed to be normally distributed and uncorrelated with each other.

3.3 Priors and initializations

Our prior specifications are in line with those in Primiceri (2005). We also use a training sample, from April 1993 to December 1998, to define priors. Korobilis (2014) stresses that a training sample specification has a particular advantage of numerical stability when used for estimating time-varying-parameter models. We use OLS point estimates of parameters over the training sample as hyperparameters.

The prior distribution of the coefficient matrix of the VAR equation, $B_{i,t}$, is assumed to be normal, and its first two moments are set equal to the OLS estimates on the training sample:

$$B_0 \sim N(\hat{B}_{TS}, 5 * V(\hat{B}_{TS})) \tag{6}$$

The prior distribution of σ_t, the diagonal elements of the variance matrix of the VAR equation, is normal with the mean of the corresponding training sample OLS estimate and a diagonal variance matrix:

$$\log(\sigma_0) \sim N(\log(\hat{\sigma}_{TS}), 5 * I_n) \tag{7}$$

Analogously, for the prior distribution of A_t we assume:

$$A_0 \sim N(\hat{A}_{TS}, 5 * V(\hat{A}_{TS})) \tag{8}$$

where $V(\hat{A}_{TS})$ is the variance of $\hat{A}_{TS}$ in the training sample.

For S and Q, the variance covariance matrices of ζ_t and $B_{i,t}$, respectively, inverse-Wishart distributions are assumed:

$$S \sim iW(k_S^2 * 5 * V(\hat{A}_{TS}), 5) \tag{9}$$

$$Q \sim iW(k_Q^2 * 69 * V(\hat{B}_{TS}), 69) \tag{10}$$

Because we incorporate $M = 4$ state variables, we have to assume at least $M + 1 = 5$ degrees of freedom for the distribution of S; a lower number of degrees of freedom would result in the mean of the inverse Wishart distribution not being defined. Similarly, we assume 69 degrees of freedom for the distribution of Q, because $\hat{B}_{TS}$ has $M + M^2 * k = 68$ elements. Essentially, our choice for the degrees of freedom implies that the priors are as least informative as possible.

For W, the variance covariance matrices of η_t, we assume an inverse-Gamma distribution:

$$W \sim iG(k_W^2 * 5 * I_n, 5) \tag{11}$$

To simplify the estimation, as in Primiceri (2005), we also adopt the assumption that S has a block structure.

The prior beliefs about time variation in the covariance matrix of the processes of Q, α_t and $log(\sigma_t)$ are set as in Primiceri (2005), $k_Q = 0.01$, $k_S = 0.1$ and $k_W = 0.01$. We find that the results are only negligibly affected by moderate changes in these parameters. Primiceri (2005) documents thoroughly that the posterior inference is not very sensitive to choices of these hyperparameters.

4 The Effective Monetary Stimulus

In this section we discuss the Effective Monetary Stimulus (EMS) as a metric for monetary policy. In section 4.1, we introduce the principles underlying the EMS. Section 4.2 describes the calculation of the model-free EMS that we will focus on in our benchmark empirical application, and also provides an overview of the model-based EMS from which the EMS concept arose. In section 4.3, we provide an overview of why we believe the EMS is more appealing, in principle and empirically, compared to alternative monetary policy metrics that could otherwise be considered for our analysis; i.e. policy rates plus balance sheet data, shadow short rates, and the time to policy rate “lift-off”. We also mention at the end of section 4.3 some avenues to further develop and potentially improve the EMS as a monetary policy metric.

Because the EMS is a new concept, or alternatively a formalization of using longer-maturity interest rates as a monetary policy metric, in appendix A we provide a much more detailed discussion and relevant background material on the case for the EMS. We also provide further discussion on the potential improvements that could be made to the particular EMS series that we have obtained and applied in this paper.

4.1 Overview of the EMS

Mechanically, as indicated in figure 2, the EMS is the area between the lower-bounded nominal forward rate curve and the long-horizon nominal natural interest rate (LNIR), out to a given horizon (in this case 10 years). As we will detail in section 4.2, the EMS explicitly accounts for two elements that are key to the overall stance of monetary policy: (1) the policy rate and its expected path relative to the LNIR; and (2) risk premiums in interest rates.

Regarding the first element, a policy rate setting below (above) the natural interest rate represents an accommodative (restrictive) stance of monetary policy. Expectations about the cumulative policy interest rate/natural rate gap are also relevant for the degree of monetary stimulus, because it will be an important consideration for the intertemporal consumption and investment decisions of economic agents. Textbooks, e.g. Walsh (2003), emphasize the role of policy expectations in principle and Gürkaynak, Sack, and Swanson (2005) is an example that empirically establishes the importance of policy expectations, via a “future path of policy” factor. A related quote, in the context of the apparent market fixation on policy "lift-off" in the United States, also provides a colloquial reminder that the policy rate path matters more than any single rate on that path:

> "For the purpose of meeting our goals, the entire path of interest rates matters more than the particular timing of the first increase" – Federal Reserve Vice Chairman Stanley Fischer, Jackson Hole, 29 August 2015.

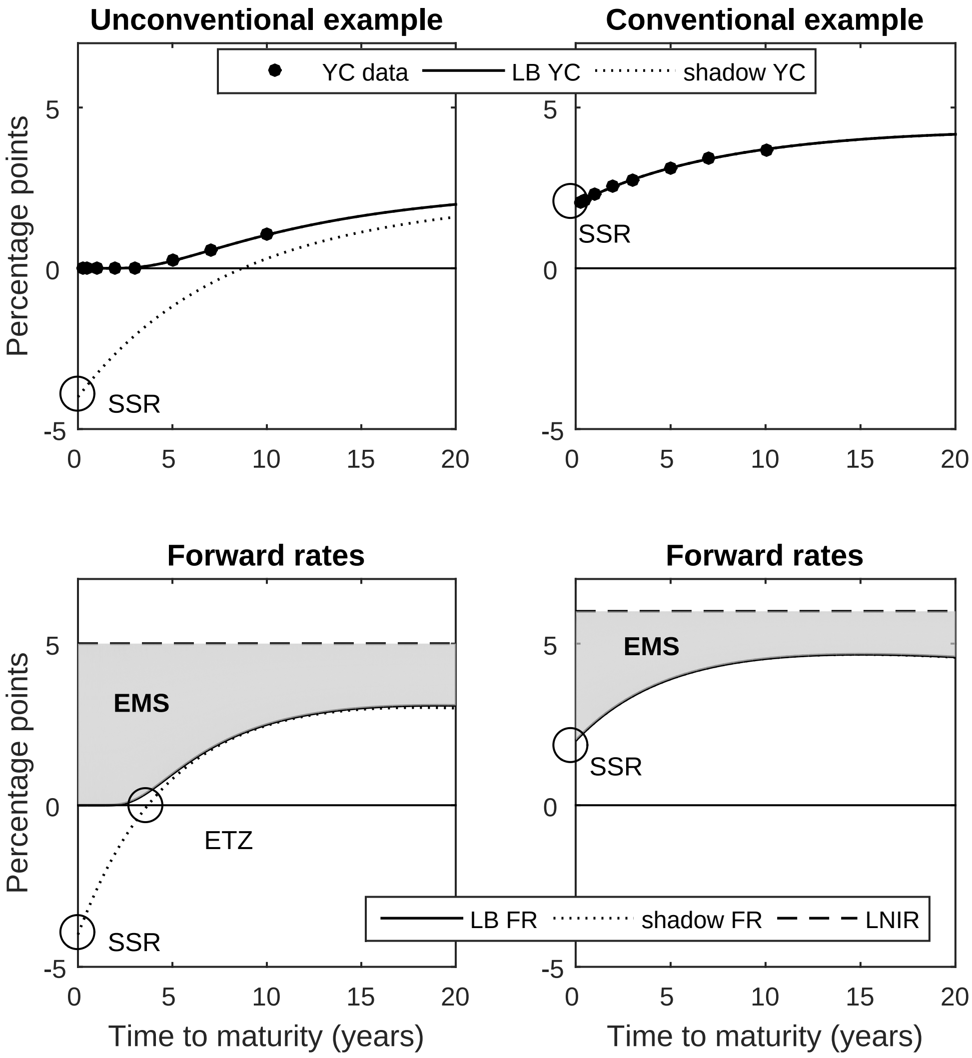

Figure 2: Yield curve data and the concept of the EMS. YC is yield curve, LB is lower bound, FR is forward rate, and LNIR is the long-horizon nominal natural interest rate. The SSR and ETZ (Expected Time to Zero) are discussed in section 4.3.

Regarding the second element of the stance of monetary policy, risk premiums have been emphasized as source of unconventional monetary policy stimulus via quantitative easing, targeted asset purchases and the portfolio balance effect; e.g. see Woodford (2012). However, risk premiums will also influence effective monetary conditions in conventional monetary policy environments. For example, even as the Federal Reserve raised the US policy rate in the mid-2000s, 10-year bond rates did not rise in tandem. That so-called "bond conundrum" was in part attributable to depressed risk premiums (e.g. see the Adrian, Crump, Mills, and Moench (2014) estimates), which left 10-year bond yields and associated financing rates in the wider economy (e.g. mortgage rates) lower than might otherwise have been expected.

Figure 2 illustrates how the concept of the EMS applies consistently in unconventional and conventional monetary policy environments. Panel 1 of figure 2 illustrates an unconventional monetary policy environment where forward rates and the yield curve data are constrained by the lower bound on nominal interest rates. In this case, the forward rate curve remains at near-zero levels until a future "lift-off horizon", from where it mean reverts to the LNIR plus a long-horizon risk premium (LRP). Note that the LRP is negative in this example, so the long-horizon forward rate is below the LNIR, but the LRP can adopt negative or positive values as it evolves over time.

Panel 2 illustrates an unconventional monetary policy environment where forward rates and the yield curve data are unconstrained by the lower bound on nominal interest rates. In this case, the forward rate curve does not spend any time at near-zero levels and it freely mean reverts to the LNIR plus a risk premium.

Note that the EMS in panel 1 is larger than in panel 2, and the larger EMS value represents a more accommodative stance of monetary policy. Mechanically, the larger EMS in panel 1 reflects that the forward rate curve is on average more below the LNIR in panel 1 than the same comparison in panel 2. Both the forward rate curve and the LNIR can change over time (e.g. the LNIR is 5 percent in panel 1 and 5.5 percent in panel 2), so both can contribute to changes in the EMS. However, the time series for the LNIR should in principle be much more persistent than the time series of forward rates, and that property is a feature of our LNIR proxy to be discussed in 4.2.1. The forward rate curve changes more quickly, driven by changes in the expected path of the policy rate and/or risk premiums underlying the yield curve data.

As a final point for this overview section, note that the EMS is not under the strict and direct control of the central bank, like a policy rate or balance sheet actions. Specifically, because the EMS is obtained from yield curve data, it will be influenced by any factors that impact on longer-maturity interest rates, not just central bank actions. Therefore the EMS should be treated as a market expectation variable subject to central bank influence rather than a quantity explicitly controlled by the central bank. With that caveat we will, however, continue to refer to the EMS as metric for stance of monetary policy.

4.2 Calculating the EMS

In this section, we provide an overview of how we calculate the EMS. We begin in section 4.2.1 with a description of how we obtain the LNIR, which is required to make the EMS concept operational. In section 4.2.2, we discuss the model-free EMS series that we employ in our main application in section 6. Section 4.2.3 describes the model-based EMS and its decomposition into expected policy and risk premium components, which we employ to obtain the results in section 8.2.

4.2.1 LNIR

We obtain the LNIR as an observable variable using Consensus Forecast survey data. Specifically, we use the data set of Consensus Forecast surveys of expected average real output growth and inflation for the 6-10 year horizon, and combine those into a nominal output growth result. Figure 3 plots the result. Note that the values are only available biannually (in April and October) and to obtain a monthly series we simply hold the previous values until the next value is available. Also note that, despite the survey result being for the 6-10 year horizon, we are treating them as asymptotic values. The justification is that if a parametric model were applied to the survey expectations data in the manner of Aruoba (2016), the asymptotic value of that model would be dominated by, and hence very close to, the longest-horizon survey data.[6]

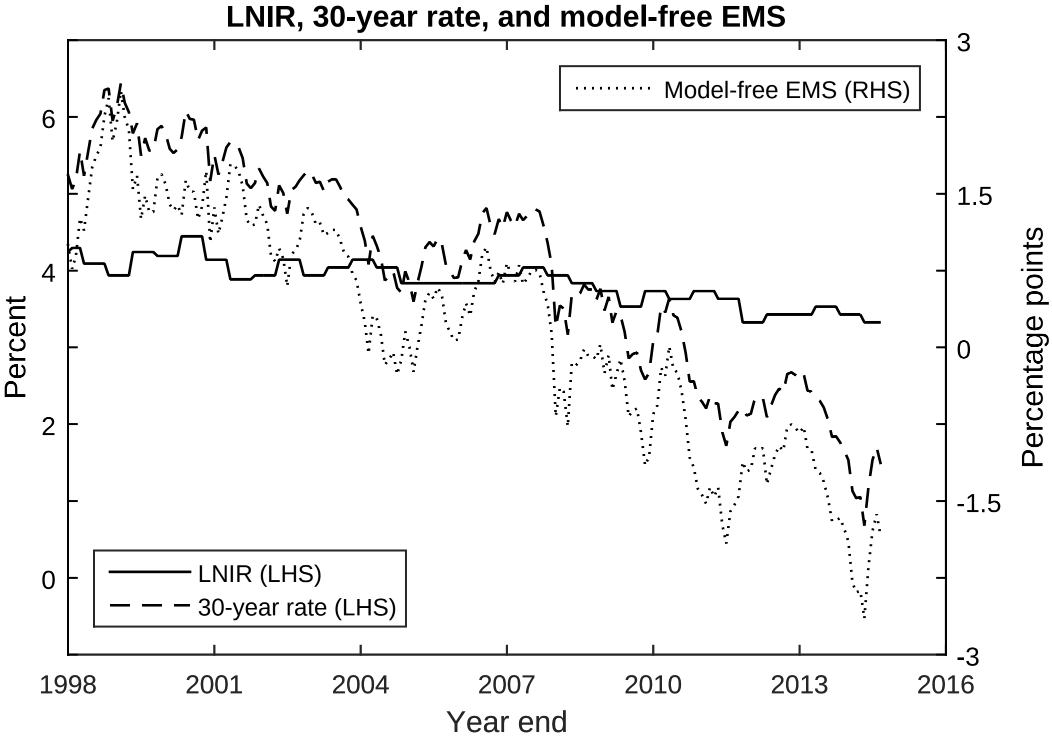

Figure 3: Time series of the LNIR, the 30-year rate, and the associated model-free EMS.

The justification in principle for using long-horizon nominal output growth as a proxy for the LNIR is the standard result from the Solow-Swan model and the Ramsey neoclassical models; e.g. see Barro and Sala-i-Martin (2004). Specifically, in the steady state of those models, the real interest rate is within a constant of real output growth.[7] Adding a

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[6] Aruoba (2016) uses the Nelson and Siegel (1987) specification, so the asymptotic value is the estimated Level component.

[7] The Ramsey-Kass-Koopmans steady state result is often expressed as the interest rate being within a constant of output growth per capita. To reconcile that expression with our statement in the text, note that the subjective discount rate r_δ in the consumption Euler equation must at least equal population growth n in order to satisfy the transversality condition. Hence, r_δ may be rewritten as $\mathrm{r}_\delta = n + \Delta\mathrm{r}_\delta$,

steady state inflation rate then produces the analogous nominal relationship. The Consensus Forecast long-horizon surveys provide an average of analyst long-horizon expectations of real output growth and inflation, and therefore represent an observable for the steady state nominal interest rate we require; i.e. a long-run/equilibrium short-maturity interest rate. We are aware of Consensus Forecast long-horizon surveys being used in this manner by the Bank of England and the European Central Bank.

As mentioned in section 4.1, changes to the LNIR are one source of changes to the EMS, because it changes the gap between the expected policy path and the LNIR. This can be quite material over the passage of time. For example, figure 3 shows that the LNIR falls from 4.3 percent in 1998 to 3.3 percent in 2015. Presumably, the LNIR changes will in turn be due to analyst views on such aspects as long-horizon potential output growth (in turn due to changes in population growth, productivity growth, etc.) and/or long-horizon inflation expectations (in turn due to perceptions about central bank inflation targets, policy credibility, etc.). However, we simply use the series as data and make no assumptions about their underlying drivers.

As a point of clarification, the LNIR we use differs both in concept and often in magnitude from short- and medium-horizon estimates of nominal natural interest rates. For example, Laubach and Williams (2015) notes that short-horizon real natural interest rates are defined and estimated as those that would prevail if all prices in a given model were fully flexible, and Laubach and Williams (2015) itself estimates a medium-horizon real natural rate estimate from a small-scale model incorporating inflation, the output gap, and trend output growth rates. In practice, such estimates can differ substantially from the real natural interest rate underlying the LNIR (i.e. surveyed expectations of long-horizon output growth), particularly if the economy and the short rate are far from their steady states. As noted in Laubach and Williams (2015) p. 2, the different approaches to defining and calculating the real natural rate should not necessarily be viewed as competing or contradictory; rather, the perspectives are complementary but for different horizons. That said, one practical advantage of the LNIR is that it is an observable variable, so we do not have to allow for the typically large model and estimation uncertainties that would exist for the model-based approaches. Nevertheless, surveys are by no means perfect: an unavoidable issue is that they represent the views of a small (but arguably reasonably informed) subset of financial market participants and the general population, so they can only ever be an approximation to the actual expectations within financial markets and the macroeconomy.

One avenue for future work would be to test the sensitivity of the EMS to LNIR variations and alternative point estimates of nominal neutral rate estimates. However, figure 3 shows that the interest rate contributes the most variation to the EMS, so we have no reason to expect that our EMS series or our results from applying it would change much.

4.2.2 Model-free EMS

Figure 2 and the discussion in section 4.1 introduced the EMS as a quantity based on the area between the lower-bounded forward rate and the LNIR up to a given horizon τ_{H}.

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where $\Delta \mathrm{r}_\delta$ is some positive increment. The population growth in r_δ therefore nets out with steady state per capita consumption growth, hence giving our stated version of the relationship.

The mathematical expression for that area is an integral,[8] and we scale that by τ_{H} (for reasons that will soon be apparent) to obtain the EMS, i.e.:

$$\mathrm{EMS}\left(t, \tau_{\mathrm{H}}\right) = \frac{1}{\tau_{\mathrm{H}}} \int_{0}^{\tau_{\mathrm{H}}} \left[\underline{\mathrm{f}}\left(t, \tau\right) - \mathrm{LNIR}\left(t\right)\right] \, \mathrm{d}\tau \tag{12}$$

where $\mathrm{EMS}(t, \tau_{\mathrm{H}})$ is the EMS at time t for a given horizon τ_{H}, $\underline{\mathrm{f}}(t, \tau)$ is the lower-bounded forward rate at time t as a function of horizon τ, and $\mathrm{LNIR}(t)$ is the LNIR at time t, but which has no dependence on the horizon τ. Note that the EMS is a signed quantity; $\underline{\mathrm{f}}(t, \tau)$ below the LNIR (as in figure 2) would produce a negative value, and $\underline{\mathrm{f}}(t, \tau)$ above the LNIR would produce a positive value (i.e. a restrictive stance of monetary policy). An EMS value could also potentially be the net of positive components for some horizons and negative components for other horizons, which would arise from $\underline{\mathrm{f}}(t, \tau)$ rising or falling through the $\mathrm{LNIR}(t)$ value for some horizons.

Equation 12 can be simplified by separating the $\underline{\mathrm{f}}(t, \tau)$ and $\mathrm{LNIR}(t)$ terms, i.e.:

$$\begin{aligned} \mathrm{EMS}\left(t, \tau_{\mathrm{H}}\right) &= \frac{1}{\tau_{\mathrm{H}}} \int_{0}^{\tau_{\mathrm{H}}} \underline{\mathrm{f}}\left(t, \tau\right) \, \mathrm{d}\tau - \frac{1}{\tau_{\mathrm{H}}} \int_{0}^{\tau_{\mathrm{H}}} \mathrm{LNIR}\left(t\right) \, \mathrm{d}\tau \\ &= \underline{\mathrm{R}}\left(t, \tau_{\mathrm{H}}\right) - \mathrm{LNIR}\left(t\right) \end{aligned} \tag{13}$$

where the lower-bounded interest rate $\underline{\mathrm{R}}(t, \tau_{\mathrm{H}})$ arises from the standard definition that connects interest rates and forward rates (in this case, both subject to the lower bound); e.g. see Filipović (2009) p.7. Expressing the EMS is terms of interest rates is one reason why scaling by τ_{H} is convenient. Two other reasons are: (1) it allows $\mathrm{EMS}(t, \tau_{\mathrm{H}})$ to be viewed intuitively as the average difference between $\underline{\mathrm{f}}(t, \tau)$ and $\mathrm{LNIR}(t)$ out to the horizon τ_{H}; and (2) it obtains similar EMS magnitudes for different horizons, because the EMSs are effectively annualized, thereby allowing the more ready comparison of EMS calculations for different horizons. Of course, for a given horizon τ_{H} the unscaled quantity $\tau_{\mathrm{H}} \cdot \mathrm{EMS}(t, \tau_{\mathrm{H}})$ would have precisely the same statistical properties as $\mathrm{EMS}(t, \tau_{\mathrm{H}})$, so the choice is inconsequential for our subsequent empirical analysis.

Importantly, $\underline{\mathrm{R}}(t, \tau_{\mathrm{H}})$ is an observed variable; it is simply the τ_{H}-maturity interest rate (which is subject to the lower bound constraint, but there is no need to assume or estimate the lower bound for the model-free version of the EMS). Using an observed interest rate $\underline{\mathrm{R}}(t, \tau_{\mathrm{H}})$ is particularly appealing because, in conjunction with our observable $\mathrm{LNIR}(t)$ proxy discussed in the previous section, it enables us to obtain observable EMS data rather than requiring EMS estimates that would be subject to model and estimation uncertainties.

Regarding the appropriate maturity τ_{H}, we choose to use a 30-year interest rate. Our choice is a compromise between practical and theoretical considerations. From a practical perspective, the 30-year rate is the longest benchmark interest rate quoted in major markets. From a theoretical perspective, the longest-maturity interest rate is closest to

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[8] Some readers may be more familiar with discrete-time term stucture notation rather than our continuous-time notation, in which case the forward rate would be expressed as $\underline{\mathrm{f}}(t, i, i+1)$, where i is an integer representing multiples of discrete time steps Δt. The integral would then be the summation $\sum_{i=0}^{I-1} \left[\underline{\mathrm{f}}\left(t, i, i+1\right) - \mathrm{LNIR}\left(t\right)\right] \Delta t$, and interest rates would be $\underline{\mathrm{R}}(t, I) = \frac{1}{I} \sum_{i=0}^{I-1} \underline{\mathrm{f}}(t, i, i+1)$. Note that all rates are continuously compounding, whether using continuous- or discrete-time notation, which is why integrals or summations are appropriate.

the infinite horizon for consumption utility maximization that underlies many standard macroeconomic models. Figure 3 plots the model-free EMS, along with the model-based estimates discussed in the following section.

However, any given interest rate on the yield curve has the potential of being subject to practical market influences; e.g. 30-year bonds in the euro area have been in demand over our sample period from pension funds seeking very-long-maturity interest rate securities. Hence, we also check the sensitivity of our results to using interest rates for shorter maturities.

Appendix E contains a detailed discussion and a series of empirical results related to the choice of τ_{H}. The main results are that the EMS series based on 7- and 10-year interest rates essentially produce the same z-score series as our benchmark EMS series, i.e. they coincide in standardized values. Hence, so long as the interest rate extends beyond the typical business cycle, the choice of τ_{H} is not critical for our subsequent empirical analysis. As a further robustness check, we have also estimated our models with the EMS based on interest rates for different times to maturity, and section 8.2 discusses that the results are all very similar. Conversely, a τ_{H} value that is less than the typical business cycle should not be used because it would omit information relevant to the stance of monetary policy over the business cycle. For example, our results in appendix E show that the 3-year rate has materially different statistical properties to the 7-, 10-, and 30-year EMS series, and our robustness checks in section 8.2 show less plausible impulse responses.

4.2.3 Model-based EMS

The model-free EMS in the previous section came about from the concept of the EMS based on a shadow/lower bound term structure model from Krippner (2014, 2015b). Section A.2 of appendix A contains further details on that background. Appendix E.2 shows that using a model to produce the EMS obtains values very similar to the model-free EMS, but the latter will generally be preferable for empirical work because it is completely observable.

However, a model-based EMS offers one advantage over the model-free EMS; i.e. it allows the decomposition of the EMS into expected policy and risk premium components. That decomposition may prove useful, because the expected policy and risk premium components are generally considered to relate to the two main unconventional monetary policy actions; i.e. forward guidance and QE programmes; e.g. see Woodford (2012). Furthermore, whereas the model-free EMS implicitly assumes that a given percentage point change in either component has an equal effect, the macroeconomic effects of changes to the expected policy component of the EMS could differ from the effects of a risk premium change. For this reason, and because the relative magnitudes of the expected policy and risk premium components change with τ_{H}, we also undertake some preliminary investigations using the expected policy and risk premium components of the EMS.

A model-based EMS (and its decomposition) is obtained by using an estimated interest rate series (and its decomposition) from an appropriate term structure model. Specifically:

$$\begin{aligned}
\mathrm{EMS}\left(x_t, \tau_{\mathrm{H}}\right) &= \underline{\mathrm{R}}\left(x_t, \tau_{\mathrm{H}}\right) - \mathrm{LNIR}\left(t\right) \\
&= \left[\underline{\mathrm{R}}^{\mathrm{EP}}\left(x_t, \tau_{\mathrm{H}}\right) - \mathrm{LNIR}\left(t\right)\right] + \underline{\mathrm{R}}^{\mathrm{RP}}\left(x_t, \tau_{\mathrm{H}}\right) \\
&= \mathrm{EMS}^{\mathrm{EP}}\left(x_t, \tau_{\mathrm{H}}\right) + \underline{\mathrm{R}}^{\mathrm{RP}}\left(x_t, \tau_{\mathrm{H}}\right) \qquad (14)
\end{aligned}$$

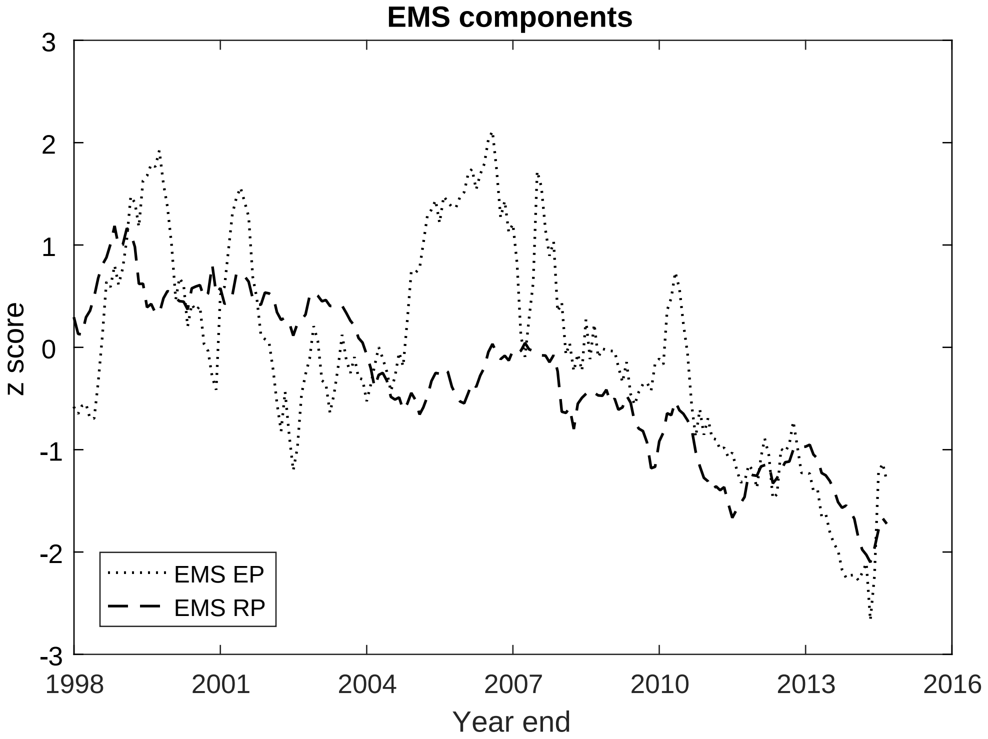

Figure 4: The expected policy and risk premium components of the EMS.

where $\underline{\mathrm{R}}(x_t, \tau_{\mathrm{H}})$ is the estimated interest rate, $\underline{\mathrm{R}}^{\mathrm{EP}}(x_t, \tau_{\mathrm{H}})$ is the expected policy component, $\underline{\mathrm{R}}^{\mathrm{RP}}(x_t, \tau_{\mathrm{H}})$ is the risk premium component,[9] and all are a function of the estimated state variable x_t at time t (and the estimated model parameters).

Appendix B provides an overview of the shadow/lower-bound term structure model, from Krippner (2015b), that we use to obtain the policy expectation/risk premium decomposition for interest rates.[10] Figure 4 plots the z scores of the model-based EMS components $\mathrm{EMS}^{\mathrm{EP}}(x_t, \tau_{\mathrm{H}})$ and $\underline{\mathrm{R}}^{\mathrm{RP}}(x_t, \tau_{\mathrm{H}})$. Note that model-implied interest rates are typically very close to actual interest rates, so the model-free and model-based EMS are almost identical, as illustrated in section E.2 of appendix E. Figure 4 shows that declines in both the expected policy and the risk premium have contributed to declines in the EMS.

As a final point, the decomposition of lower-bounded forward rates provided by the model shows clearly how the EMS is accounting for the expected path of the lower-bounded short rate relative to the LNIR, and the risk premium component. Specifically, the model lower-bounded forward rate $\underline{\mathrm{f}}(x_t, \tau)$, at time t and as a function of horizon τ, may be defined as:

$$\underline{\mathrm{f}}(x_t, \tau) = \mathbb{E}_t\left[\underline{\mathrm{r}}(x_t, t+\tau)\right] + \mathrm{MRP}(x_t, t+\tau) \tag{15}$$

where $\mathbb{E}_t\left[\underline{\mathrm{r}}(x_t, t+\tau)\right]$ is the expected path of the lower-bounded short rate, and $\mathrm{MRP}(x_t, t+\tau)$ is the marginal risk premium component of the lower-bounded forward rate, both at time

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[9] The risk premium component also includes the volatility effect that arises from the compounding returns of a volatile short rate.

[10] Christensen and Rudebusch (2013) contains an analogous model, and also estimates of the risk premium component.

t for horizon τ. Substituting the expression for $\underline{\mathrm{f}}(x_t,\tau)$ into equation 12 gives:

$$\begin{aligned}\mathrm{EMS}\left(x_t,\tau_{\mathrm{H}}\right) &= \left[\frac{1}{\tau_{\mathrm{H}}}\int_0^{\tau_{\mathrm{H}}} \mathbb{E}_t\left[\underline{\mathrm{r}}\left(x_t,t+\tau\right)\right]-\mathrm{LNIR}\left(t\right)\,\mathrm{d}\tau\right] \\ &\quad +\frac{1}{\tau_{\mathrm{H}}}\int_0^{\tau_{\mathrm{H}}}\mathrm{MRP}\left(x_t,t+\tau\right)\,\mathrm{d}\tau \qquad (16)\end{aligned}$$

4.3 Comparison with alternative monetary policy variables

There are several other candidate variables that could be chosen to represent the stance of monetary policy. In this section we briefly discuss the main drawbacks for each of those alternatives, which we believe leaves the EMS as the most compelling metric. Appendix A contains a more in-depth discussion, including further drawbacks for the alternatives, and also comments on how the EMS itself could potentially be improved. Appendices C, D and E respectively contains a full set of SSR, Expected Time to Zero (ETZ), and EMS results with euro area data to support our comments below on those quantities.

Two observable variables that relate to the stance of monetary policy are the short rate and the size of the central bank balance sheet. As discussed in the introduction, the biggest drawback of the short rate is that it no longer provides a complete summary of the stance of monetary policy when it is constrained by the lower bound, because it does not reflect additional unconventional actions by the central bank. Similarly, the central bank balance sheet does not reflect forward guidance (or any other actions that do not affect the central bank balance sheet), and it remains relatively constant during the conventional monetary policy period.

The second two alternative metrics of monetary policy are the SSR and the ETZ, which are model-implied quantities obtained from shadow/lower bound term structure models. As mentioned in section 2, SSR estimates can be highly variable depending on the model specification and the data used for estimation. That is especially the case for SSR estimates from three-factor models, where the differences in their magnitudes, dynamics, and cycles essentially argue against any meaningful empirical application. The SSR estimates from two-factor models are more robust, with similar dynamics and cycles, although still unavoidable variability in the magnitudes of SSR when they are negative.

The ETZ is a model-implied expected horizon to policy rate “lift-off”. The biggest drawback as a monetary policy metric is that the Expected Time to Zero is undefined in conventional monetary policy periods; i.e. there is no concept of “lift-off” when the policy rate and the forward rate curve associated with the yield curve data are all above near-zero levels.

Finally, the EMS itself could be further developed and potentially improved, which we detail in appendix A.4. In brief, some avenues are: (1) calculate a real version of the EMS, given that real interest rates should in principle be more relevant than nominal interest rates; (2) find a proxy observable variable for a natural/steady state level risk premium, if possible, so that the risk premium component becomes more analogous to the expected policy component, and the magnitudes of the two components become more similar; and (3) incorporate the paths of other financial market variables, such as the exchange rate and equity market prices, that are relevant to the decisions of economic agents. The latter would produce something akin to a monetary conditions index, but with the structure suggested by the concept of the EMS.

5 Data and model estimation

In this section we discuss the macroeconomic and commodity price data we use for estimating our model. In section 5.1, we first discuss why there is no ideal data set for a small-scale VAR relevant to the euro area, and why we have chosen to focus on German data sets for our analysis with robust checks using euro area data. In section 5.2, we detail the actual data we have used for our benchmark applications to be reported in section 6; we discuss the alternative data we have used for robust checks in section 8. Section 5.3 briefly discusses how we estimate the TVP-VAR already outlined in section 3.

5.1 Discussion on euro area data sets

As mentioned in section 3, a small-scale monetary VAR requires at least a monetary policy metric, a measure of deviations of realized output from potential output, and a measure of inflation. Ideally, that data should be available over a relatively long sample period and be "self consistent". By self-consistent, we mean that the monetary policy metric responds to the evolution of the macroeconomic data (as the central bank sets policy in response to deviations of macroeconomic data from the central bank's macroeconomic objectives), and that the macroeconomic data in turn responds to monetary policy settings (so the macroeconomic objectives are achieved on average).

The sample period and self-consistency considerations present a challenge from the perspective of monetary models relevant to the euro area. A fully self-consistent euro area data set is only available from January 1999, from the introduction of the euro currency and the setting of euro area monetary policy by the ECB, but that would present a limited sample length given the desirability of using a training sample as we mentioned in section 3. Creating an artificial data set for the euro area prior to 1999 creates a longer sample, but the monetary policy variable would not be strictly self-consistent because there was no single monetary authority to respond to euro area macroeconomic data in aggregate prior to January 1999. Similarly, using a data set for any single country would not be self-consistent after January 1999, when the ECB set the stance of monetary policy for all economies in the euro area.

Given the considerations above, we therefore employ both a German and a euro area dataset in our analysis. In effect, our German results therefore indicate how the monetary policy of the ECB affects German macroeconomic variables, and there is an implicit (but we think reasonable) assumption that the German macroeconomic data are sufficiently correlated with the euro area macroeconomic data that the ECB takes into account when setting monetary policy for the EMU. We begin the German macroeconomic dataset in April 1993 to avoid data associated with the German reunification in 1990 (because that data would reflect a one-off event unrelated to the ongoing conduct of monetary policy).

The euro area dataset uses artificial aggregate macroeconomic data prior to 1999, and we match the German data set by beginning in April 1993. In addition, this avoids earlier periods where the monetary policies of future EMU countries were more heterogeneous. The EMS and short rate variables are the same for each data set, as we discuss in the following section.

We will focus on the results from the German dataset in this paper, because that allows us to run more robustness checks with various alternative macroeconomic indicators that are available for Germany from the early 1990s onwards. The results with the euro area dataset are discussed in section 8, along with a range of robustness checks, and we note upfront that those results are generally consistent with those we obtain for our German data sets. Hence, we are confident that the results we describe in this section are generally applicable to the consideration of monetary policy in the euro area.

Even while beginning in 1993, the period of our investigation is not particularly long for a macroeconomic application. Hence, we use data that is available at a monthly frequency.

5.2 Description of benchmark data sets

The model-free EMS requires an LNIR series and a series of 30-year interest rates. We construct a piecewise series for both due to data availability, and also to impose German monetary policy as the de facto setting for the euro area prior to January 1999.

For the LNIR data we use German Consensus Forecast data up to December 1998, an equal-weighted combination of German and French Consensus Forecast data from January 1999 to March 2003, and then euro area Consensus Forecast data when it first became available in April 2003.

For the 30-year interest rate series, we use German 30-year government bond interest rates up to December 1998, an equal-weighted combination of 30-year German and French government bond interest rates from January 1999 to May 2008, and then 30-year overnight indexed swap (OIS) data from June 2008, when reliable 30-year rates first became available. The OIS data is most preferable because they are interest rates that are directly relevant to the whole euro area. However, the combination of the German and French data provides a close proxy in the earlier periods. Importantly, our use of OIS begins prior to the GFC and European sovereign crisis. During those periods, bond yields were influenced by safe-haven/risk-aversion factors, and so would not necessarily provide a good proxy for monetary policy expectations and the risk premiums associated with those expectations.

As a benchmark comparison to our results obtained with the EMS, we also estimate the standard small monetary VAR setup by using a short-maturity interest rate instead of the EMS. We also calculate model-free EMS series using the interest rates of alternative maturities to test the sensitivity to our choice of 30 years. All of the interest rate data we use are created on the same piecewise basis as the 30-year rate data, and the original data are obtained from Bloomberg.

Regarding a measure of deviations of realized output from potential output, our choice of a monthly frequency mentioned in section 5.1 prevents us using the output gap. As a monthly proxy, we calculate an industrial production gap, which has been employed elsewhere in the literature; e.g. see Clarida, Gali, and Gertler (1998) for the United States, and Kucharcukova et al. (2014) for the euro area. The German data is from the German Federal Statistical Office, and industrial production had a 25.8% share of German GDP in 2015. The euro area data for seasonally adjusted industrial production and the producer price index for domestic sales excluding energy are from Eurostat. We use the log level deviation of industrial production from its time-varying trend obtained from the Hodrick-Prescott filter (e.g. see Engel and West (2006) and Taylor and Davradakis (2006)).[11] As suggested by Ravn and Uhlig (2001), we apply a smoothing parameter of 129600 for a series of monthly observations.

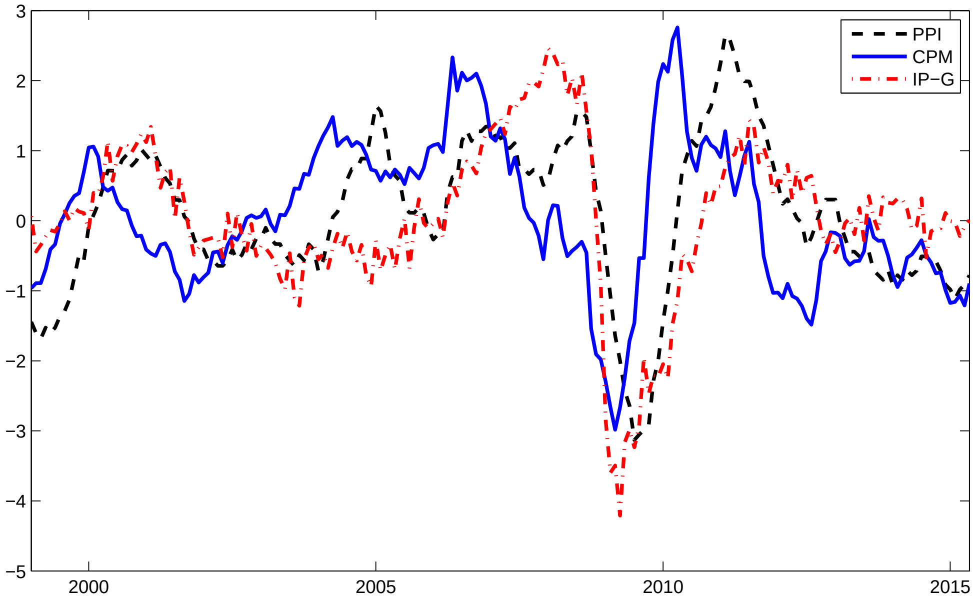

Figure 5: The macroeconomic and commodity price data for our benchmark estimations. PPI and CPM series are annual inflation rates, and IP-G is the log level deviation of industrial production from its time-varying trend. The series are standardized as z scores and shown for our main estimation sample starting in January 1999.

For our price measure, we use a producer price index because that matches our use of industrial production as our output measure. For Germany, we use the index for commercial goods sold in inland (PPI), which is ex-energy, from the German Federal Statistical Office. The PPI has the advantage of controlling at least in part for exchange rate effects on the prices without having to introduce another variable.[12] The effects of a monetary policy shock on exchange rates have been found to be puzzling in some vector autoregression analyses, particularly in case of Germany, e.g. see Sims (1992) and Grilli and Roubini (1996). Related, movements in the exchange rate can also support the incidence of a price puzzle, i.e. a positive response of the price index to a contractionary monetary policy shock.[13] For the euro area, we use the inland PPI ex-energy from Eurostat.

The final variable we include in both data sets is a commodity price index, which has a long precedent in the related literature, e.g. see Sims (1992) and Christiano, Eichenbaum,

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[11] Alternatively to the application of the Hodrick-Prescott filter, one can use a quadratic time trend to detrend the data, as it is done in the aforementioned study of Clarida et al. (1998).

[12] Elbourne and de Haan (2009) is an example that includes the exchange rate as a separate variable, and Kucharcukova et al. (2014) include the exchange rate as a component in the monetary conditions index. We prefer to retain parsimony, given our aim to test the EMS as a monetary policy metric, but adding the exchange rate would be a useful extension in future work.

[13] For example, a puzzling depreciation of the local currency after a tightening shock would make imports more expensive, potentially leading to an increase in overall inflation.

and Evans (1996). As those authors point out, including commodity prices helps to alleviate the price puzzle, because it takes into account anticipated inflationary pressure that is not yet reflected in the other variables of a small-scale VAR. We use the IMF commodity price index for metals (CPM).[14]

We transform the PPI and the CPM data into annual rates of inflation. All variables, including the EMS and the IP gap, are then standardized to have mean zero and unit variance. Figure 5 illustrates the data.

5.3 Estimation

We use the data from April 1993 to December 1998 as the training sample for our estimations. Our actual estimation sample starts in January 1999, which coincides with the introduction of the EMU, and the last observation is May 2015, which is the last observation available at the time we began the analysis. For each estimation, we draw 30000 times from the Gibbs sampler, and the first 20000 draws are removed as burn-in.

We identify shocks in the VAR as is standard in the literature. That is, we assume a recursive ordering of shocks, and we order the macroeconomic variables ahead of the monetary policy variable. The macroeconomic variables can therefore only react with a lag to monetary policy shocks, while a shock to the macroeconomic variables can affect the monetary policy variable contemporaneously. We order CPM inflation directly after PPI inflation because the former is used as a proxy for anticipated inflation. However, ordering CPM inflation (a fast-moving variable) after the industrial production gap (a slow-moving variable) does not materially change the results presented in section 6.

To best motivate the application of the EMS as a monetary policy metric, we estimate our VAR with the EMS as the policy variable and compare it to a more standard version with the three-month rate as the policy variable, keeping the other variables the same. We consider this comparison for two different samples, namely a sample in which the lower bound was not binding (1999-2008), and a sample covering also the full sample that includes the period where the short rate has been constrained by the lower bound (1999-2015).

The estimation over the conventional policy sub-sample alone is important to allow a direct “like-for-like” comparison between the short rate and the EMS when both were freely varying, and could therefore be used as monetary policy metrics. The estimation over the full sample then allows us to assess how the EMS, which continues to vary freely in the unconventional period, has performed as a monetary policy metric across the conventional and unconventional periods. The sample size is not yet large enough to obtain statistically significant results for the unconventional period alone, but we have nevertheless undertaken a qualitative robustness check and we also mention those results in the following section.

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[14] Incorporating another commodity price index, particularly the index on agricultural goods, leads to very similar results. For the commodity price data, see http://www.imf.org/external/np/res/commod/index.aspx. We also obtain plausible results without a commodity price index, as discussed in section 8.3.

6 Results

In this section, we discuss the results from our benchmark model estimations with either the short rate or the EMS as the monetary policy metric. Section 6.1 briefly discusses the results for the time-varying volatility allowed for in the model. Section 6.2 discusses the impulse responses of the variables in the VAR to a monetary policy shocks, over both the pre-lower-bound sub-sample and the full sample period.

6.1 Time-varying innovations

Figure 6 contains plots of the forecast error variances, Σ_t, for the variables in the TVP-VAR estimated with the short rate (shown as black lines) or the EMS (shown as blue-dashed lines) as the monetary policy metric. In both cases, the macroeconomic data and commodity prices show heightened volatility (i.e. variance of shock innovations) around the time of the GFC, with a gradual return to around pre-GFC levels. This pattern highlights the desirability of applying a TVP-VAR with stochastic volatility to our data sets, as anticipated in the discussion of section 3.1.

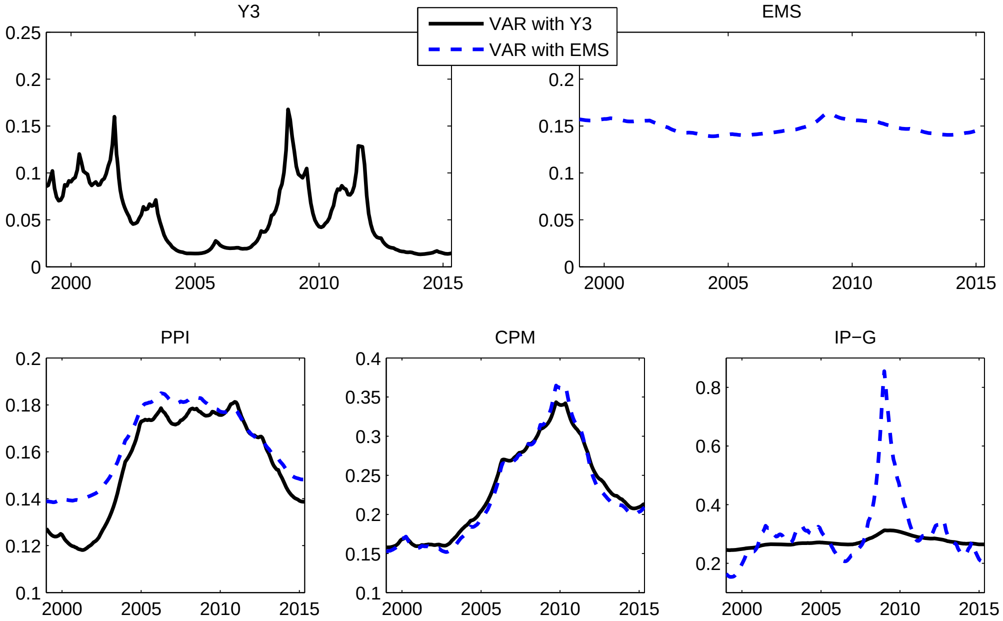

Figure 6: Posterior means of the time-varying standard deviations of the forecast residuals of the VAR. Blue-dashed lines refer to a VAR featuring the EMS as monetary policy indicator; black lines refer to a VAR with the short rate instead of the EMS measure.

For the short rate model, the forecast error variance of the short rate (upper left panel) shows marked variability, spiking at the beginning of the 2000s and at the high points of the GFC in 2007 and the sovereign debt crisis in 2011. Naturally, the short rate volatility has remained close to zero in recent years, because the lower bound has constrained short rate movements. The short rate model therefore suggests that monetary policy has not been particularly active in recent years; indeed the forecast error variance of the short rate at the end of the sample is as low as in the mid-2000s, a period of tranquil economic and financial developments. The recent low volatility highlights that the short rate does not reflect unconventional policy actions, such as asset purchasing programs and forward guidance, adopted in recent years. Even prior to the lower-bound period, using just the short rate disregards shocks to the expected path of monetary policy and risk premiums.

By contrast, for the EMS model, the forecast error variance of the EMS remains relatively stable over the entire sample (upper right panel). Hence, there is no distinct time variation in the size of the shocks across the times of conventional monetary policy and unconventional monetary policies at the end of the sample.Note that, as mentioned in section 3.2, any change in the variance of the monetary policy variable over time should also induce changes to the variances of the other state variables, because A_t in equation 2 is not diagonal. From that perspective, the transmission of the EMS with more stable shocks to macroeconomic variables seems more appropriate than the widely varying shocks of the short rate. In other words, the economy continuously reacts to unanticipated changes in the current and expected path of the policy rate and risk premiums, rather than just reacting at times when unanticipated policy rate changes occur.

6.2 Impulse responses

In this section we discuss the impulse responses to monetary policy shocks over both the pre-lower-bound sub-sample (section 6.2.1) and the full sample period (section 6.2.2). For all figures, the values on the ordinates are the responses of the series to the monetary policy metric shock and all are measured in standard deviations of the series. We report impulse responses for the beginning, middle, and end of the sample to illustrate the time variation in the relationships. The confidence intervals on all figures are the 16th and 84th percentiles, as in Primiceri (2005), which we will use as the threshold for statistical significance in our discussions.

6.2.1 Conventional policy sub-sample

Figure 7 provides the impulse responses for the VAR featuring the short rate as policy indicator. Even though we have used commodity prices as a standard means of controlling for the price puzzle, as discussed in section 5.2, the PPI inflation response nevertheless initially shows a small price puzzle, as evidenced by inflation being significantly higher for about a year after the shock occurrence. However, the PPI inflation response turns negative over the medium term, as one would expect, to a statistically significant extent. In contrast, the response of the industrial production gap is not plausible in any period or horizon under consideration; it initially expands significantly and turns highly insignificant after one year. Note that, from section 6.1, the size of the short rate shock is higher in the year 2000 than in later years. That results in the distinct differences in the magnitudes of PPI inflation and IP gap response in the first row of figure 7. However, in terms of significance and persistence, the impulse responses broadly coincide for all periods considered.

Figure 8 provides the impulse responses for the VAR featuring the EMS as the policy indicator. The PPI inflation results are more plausible than in figure 7, with an initial insignificant response followed by a significant drop over the medium term. More importantly, the IP gap now reacts as expected, decreasing significantly in response to a

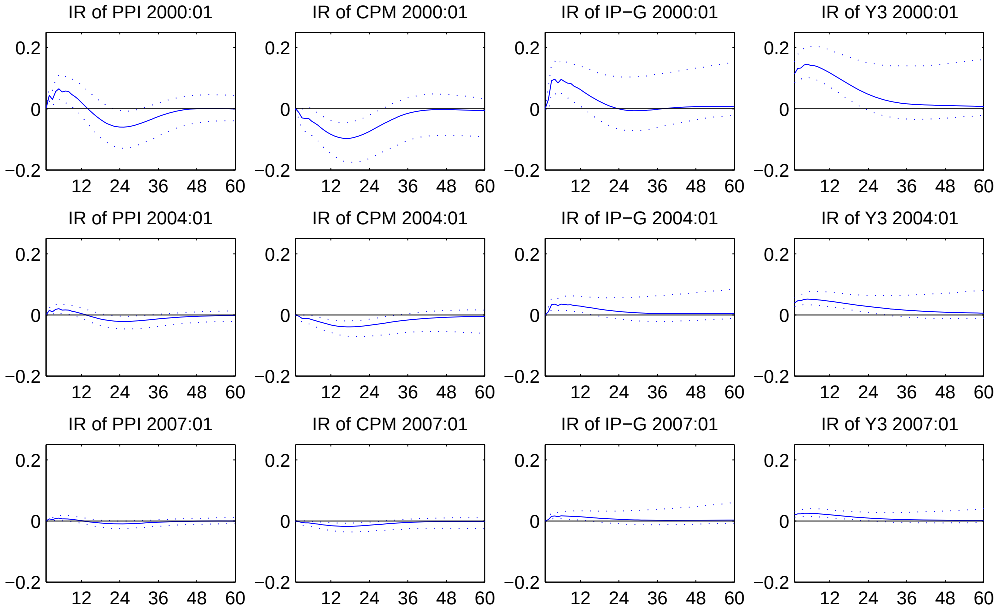

Figure 7: Impulse responses to a 3-month rate shock in a non-zero lower bound sample (1999-2008). The upper row depicts the responses in January 2000, the middle row those in January 2004, and the lower row those from January 2007. Dashed lines indicate 16% and 84% confidence intervals.

tightening shock in all periods. The impulse responses broadly coincide for all periods considered, which reflects that the sizes of EMS shocks are almost constant over time.

For completeness, we note that the inflation responses of the commodity price index CPM are similar to the PPI inflation responses, in magnitude, profile, and significance. Of course, as discussed in Sims (1992) and Christiano et al. (1996), the commodity price index is only present to control for expected price developments and the results should not be taken to imply that a monetary policy shock in one economy is a material driver of a global commodity price index.

Overall, the EMS appears to be more suitable than the short rate as a monetary policy metric in the period where the lower bound is not binding. We believe that one reason for the better performance of the EMS is that it reflects information from the entire yield curve that the short rate does not reflect, but which can influence the transmission of monetary policy. For example, the EMS indicates an easier stance of monetary policy in 2008 than in 2004, whereas the short rate signals a tighter stance. The difference reflects a fall in the risk premium, which kept euro area bond rates approximately constant even as the ECB raised its policy rate from 2.00 percent in 2005 to 4.25 percent in July 2008.[15] This development was analogous to the so-called bond “conundrum” which occurred a bit earlier in the US market. The macroeconomic developments around this period were also more consistent with the steady EMS rather than the higher policy rate; i.e. inflation

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[15] Our estimates have the 10-year risk premium falling by around 70 basis points during this period, which coincides with the 70 basis points from the Adrian, Crump, and Moench (2013) model applied to German yield curve data.

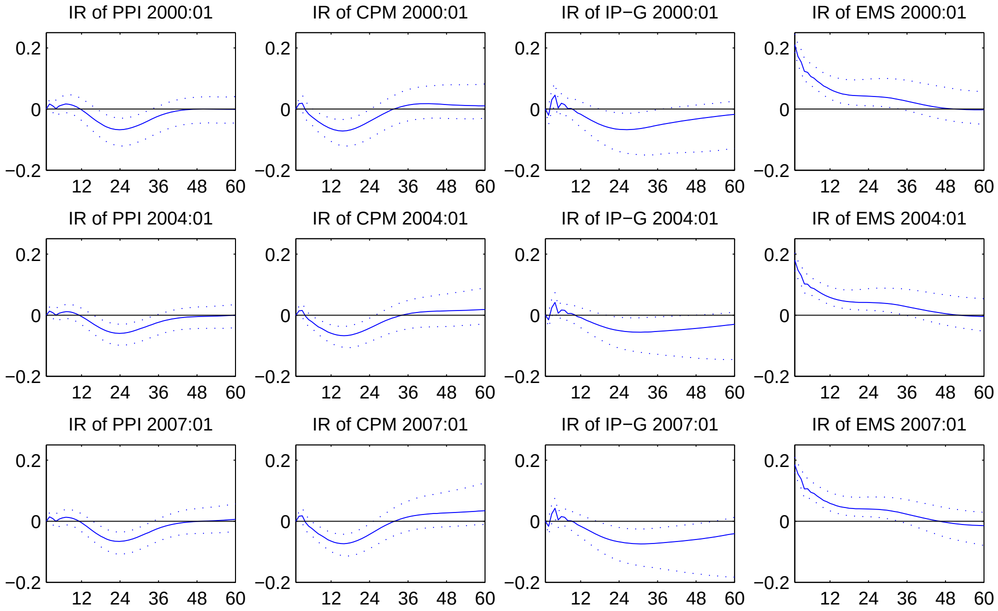

Figure 8: Impulse responses to an EMS shock in a non-zero lower bound sample (1999-2008). The upper row depicts the responses in January 2000, the middle row those in January 2004, and the lower row those from January 2007. Dashed lines indicate 16% and 84% confidence intervals.

moved around the policy target rather than declining, and the IP gap increased rather than declining (indeed, it reached its highest value in our sample period in 2008).

6.2.2 Impulse responses for the full sample

We consider now the entire sample that is available, namely from January 1999 to May 2015, which covers both the non-lower-bounded period and a period in which the zero lower bound is binding. Figure 9 provides the impulse responses for the VAR featuring the short rate as the monetary policy metric, and figure 10 for the VAR with the EMS as the monetary policy metric.

The impulse responses with the short rate turn out to be similar to those from the non-zero lower bound sample. That is, PPI inflation responds with a minor price puzzle initially and then plausibly declines for medium horizons. This decline, however, remains marginally insignificant at all periods. The responses of the IP gap to tightening shocks remain implausible at all points in time. The magnitudes of the responses of PPI inflation and the IP gap are small, reflecting the limited movement of short rate constrained by the lower bound.

The model featuring the EMS as policy indicator continues to provide more plausible results, as we now discuss in more detail.

Beginning with the EMS itself, the median values indicate that the own-response of the EMS to an EMS shock have become more persistent at the end of the sample (see the bottom-right sub-plot of figure 10). That is, the impulse response turns insignificant

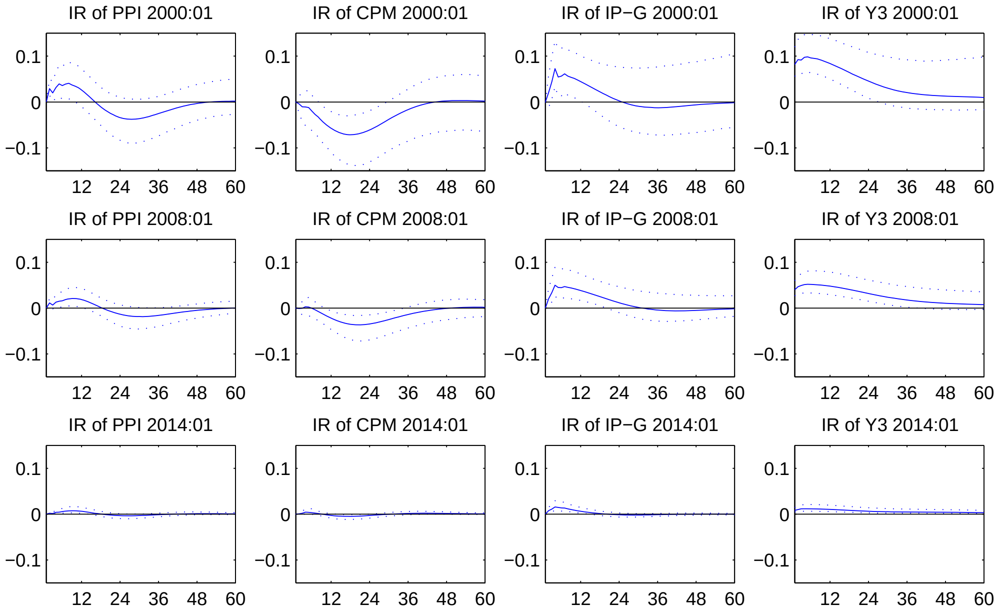

Figure 9: Impulse responses to a 3-month interest rate shock in a sample covering both a non-zero lower bound period and a period in which the lower bound is binding (1999-2015). The upper row depicts the responses in January 2000, the middle row those in January 2008, and the lower row those from January 2014. Dashed lines indicate 16% and 84% confidence intervals.

after about four years at the beginning of the sample (top-right sub-plot), while it is still marginally significantly different from zero after five years in 2014. In contrast to the case of the short rate, the size of the shock is relatively stable over time. Hence, the variation in the impulse responses originates mainly from time variation in the propagation mechanism rather than from different magnitudes in the policy innovations.

The change in the persistence of EMS shocks is consistent with the change in both the instruments and intentions of monetary policy between the conventional and unconventional monetary policy periods. That is, in the first part of our sample, EMS shocks were delivered via surprises in the policy rate and/or expectations of policy rate settings, and agents could reasonably expect those adjustments to be temporary with respect to the economic cycle. Conversely, in the second part of our sample, EMS shocks were delivered via quantitative policy actions and long-horizon forward guidance, which the ECB has explicitly communicated are intended to last for an extended period of time.

The response of PPI inflation to an EMS shock prior to the lower-bound period (the first two sub-plots in the first column of figure 10) is similar to that discussed in section 6.2.1, i.e. there is a significant medium-horizon decline in inflation. However, for the lower-bound period, inflation does not decline significantly anymore, over any horizon (although it at least avoids the initial price puzzle evident for the short rate model). This absence of significance is caused by a lower median medium term response. Hence, although monetary policy shocks have become more persistent in the lower-bound period, their impact on inflation appears to have weakened.

The IP gap in the longer-sample estimation now responds counterintuitively for short

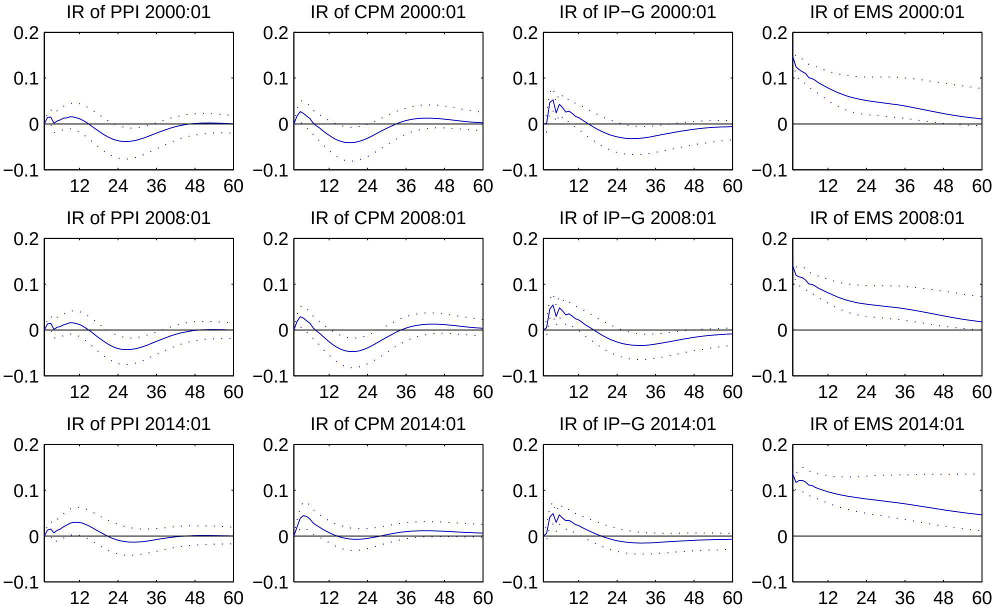

Figure 10: Impulse responses to an EMS shock in a sample covering both a non-zero lower bound period and a period in which the lower bound is binding (1999-2015). The upper row depicts the responses in January 2000, the middle row those in January 2008, and the lower row those from January 2014. Dashed lines indicate 16% and 84% confidence intervals.

horizons, initially increasing in response to a tightening shock. Nevertheless, unlike the short rate results, the impulse responses turn negative after about a year, significantly prior to the lower bound period but insignificantly for 2014. The absence of significance is again due to a smaller median response to monetary policy shocks.

Our lower significance for responses to inflation and economic activity in recent years is consistent with Wu and Xia (2016), for the United States, and Kucharcukova et al. (2014) for the euro area. This may represent changes to the investment decisions of companies in an environment of extraordinary low interest rates, or it may be due to structural relations that are beyond the dimension of our VAR (e.g. uncertainty).

The size of the impulse responses of the macroeconomic variables to a shock on the EMS is mostly higher than when using the short rate as a monetary policy metric. Because the shock size is one standard deviation in both cases, the different responses are due to the informational content of the monetary policy indicators. Hence, the larger impulse responses using the EMS reflects additional information about the stance of monetary policy relevant for the economy compared to the policy rate, particularly in the unconventional period.

Again for completeness, the impulse responses of the commodity price index CPM inflation are similar to the responses of PPI inflation discussed above.

As a robustness check on the results for the unconventional period, we have repeated the exercise with an estimation from 2008 to 2015 using all the results prior to then as the training sample. The results show median estimates of the impulse responses that are very similar to those discussed above. Predictably, however, the smaller sample period delivers wider confidence intervals for the impulse responses, so many of the impulse responses are no longer significant.

In general, the results discussed above suggest that the EMS provides a useful monetary policy metric over conventional and unconventional monetary policy periods, and our benchmark model appears to be useful for considering the effects of monetary policy over both periods.

7 Counterfactual analysis

In this section we provide a characterization of monetary policy shocks and a counterfactual analysis for ECB monetary policy from the time of the GFC; i.e. what would likely have been the hypothetical realizations of the state variables if the monetary policy shocks had not occurred? Note that counterfactuals from TVP-VARs in the literature are often insignificant, and our results are no exception in most cases. However, the exercise is nevertheless useful to ensure that the results are qualitatively plausible.

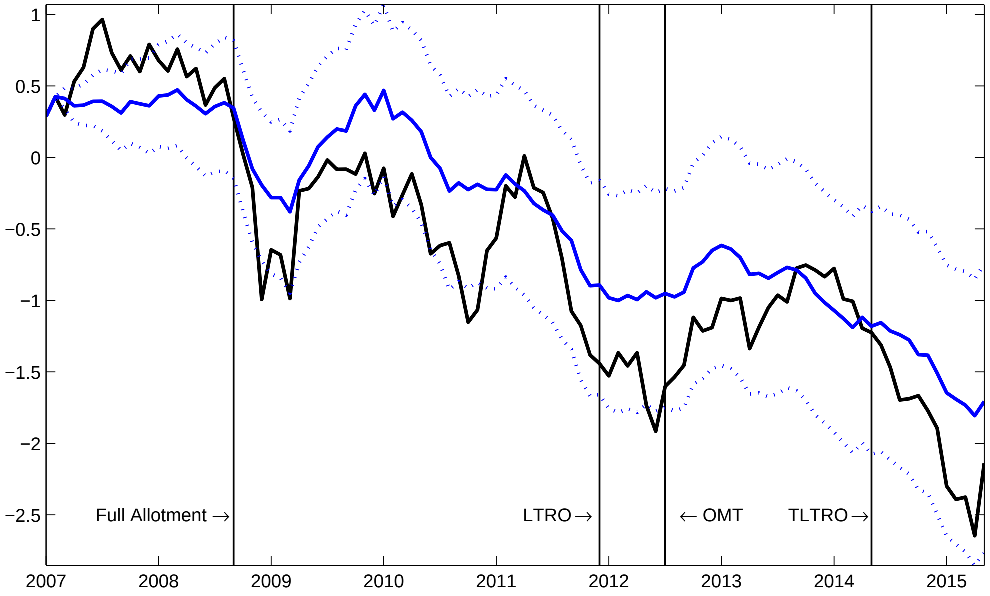

Figure 11: Realized EMS (black line) and the counterfactual indicator (blue line) assuming no monetary policy shocks had occurred. Dashed lines indicate 16% and 84% confidence intervals.

To illustrate the nature of the monetary policy shocks from the perspective of the EMS, figure 11 plots the realized EMS,which includes monetary policy shocks, and the counterfactual EMS with our estimated shocks excluded. Note that these are in natural units, i.e. percentage points, for easier interpretation. It is apparent that monetary policy shocks have been mostly expansionary over the lower bound period, by up to around 0.8 percentage points, which is consistent with the accommodation that the ECB intended to provide with its unconventional monetary policy actions. For example, in the last month of the sample, May 2015, the realized value of the EMS is below the counterfactual EMS by 0.40 percentage points.

However, there are notable exceptions where monetary policy is contractionary. Investigating these periods further, we found that they predominantly coincided with episodes of rising US bond rates. Up to mid-2007, US bond rates had been rising on the Federal Reserve's tightening cycle. In early 2011, US bond rates rose as on market optimism of a US economic recovery in the wake of QE2 implemented in late 2010. A domestic influence in the euro area was the anticipation and then delivery of a 0.50 percent policy rate increase. Finally, US and global bond rates rose markedly in the wake of the Federal Reserve's comment on tapering its bond purchases, which led markets to anticipate a less expansionary monetary policy stance. Higher US bond rates in turn influence higher euro area bond rates, resulting in the EMS temporarily becoming less accommodative.

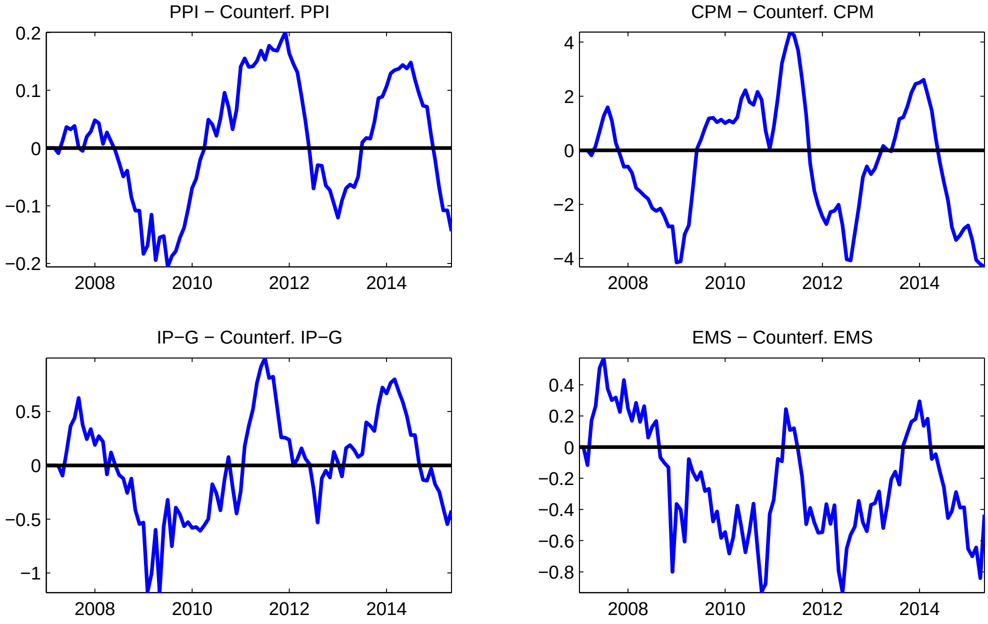

Figure 12: Difference of the realized values of variables to their counterfactual values which would have prevailed if no monetary policy shocks had occurred. Units are percentage points for the EMS, and percent for the other variables.

Note that in the periods mentioned above, with the exception of 2011, the ECB most likely did not intend and/or did not actively seek to adopt a less expansionary stance of policy. This highlights that the EMS reflects information from the entire yield curve, and longer-maturity yields are not under direct control of the central bank. It also highlights that domestic monetary conditions can be highly influenced by global developments, and central banks may have to be more active to offset those influences if they are not consistent with the intended stance of domestic monetary policy.

To gauge the estimated influence of monetary policy actions on the macroeconomy, figure 12 plots the EMS shocks and the deviations of the other variables from their counterfactual values, again in their natural units for more ready interpretation. The averages of PPI inflation and IP gap counterfactual difference are positive, consistent with the counterfactual EMS, and the dynamics are generally plausible. That is, PPI inflation and the IP-gap broadly fall (rise) after a tightening (easing) in the EMS. Notable examples are the higher-than-counterfactual values around 2010-12 following the more-accommodative-than-counterfactual EMS during 2009-11, and the lower-than-counterfactual values in 2014-15 following the less-accommodative-than-counterfactual EMS in 2013-14.

8 Alternative specifications

In this section, we provide an overview of the results obtained using alternative data and models. These are intended as robustness checks, from various perspectives, on the benchmark results in section 6. Section 8.1 contains robustness checks with alternative variables in the four-variable model, i.e. continuing to use an inflation measure, a proxy for inflation expectations, an economic activity measure, and a monetary policy measure. We also discuss the results from our implementation with euro area data. Section 8.2 contains robustness checks with the EMS for different horizons, and with model-based estimates of the EMS and its components. Section 8.3 contains the results without a proxy for inflation expectations.

Because this section discusses a wide range of results, we have stylistically summarized many of them in table 1 rather than producing figures for each in the main text. However, the impulse response results are available in appendix F and any other associated figures are available by request to the authors. As an example of how to interpret the table entries, columns a, b, c, and d correspond to the impulse response results respectively plotted in figures 7, 8, 9, and 10.

8.1 Estimates with alternative data

We have used a producer price index for our inflation measure, but the harmonized consumer price index (HCPI, from Eurostat) provides a broader measure of price developments. Furthermore, the ECB aims to achieve price stability as measured by HCPI developments. If we replace annual PPI inflation by annual HCPI inflation, the responses are generally similar, but some of the inflation responses remain insignificant over all horizons (see column e).

We have used the commodity price index CPM as an instrument to incorporate anticipated inflation. A measure of inflation expectations could serve the same purpose. Therefore, we replace the CPM by inflation expectations taken from the Consensus Forecast survey, specifically the pro-rated average of the current and following calendar-year expectations to create a monthly constant one-year horizon expectations measure. The impulse response estimates we obtain do not overturn those using commodity prices (see column f), but they are not significant at most horizons. The exception is the IP gap, which responds counterintuitively for short horizons. It seems that commodity prices might therefore be controlling for something other than purely inflation expectations, or at least the survey-based measure we have used.

We have used the industrial production gap as the indicator for economic activity. A ready alternative available at a monthly frequency is the unemployment rate (from the German Federal Employment Agency). As shown in column g of table 1, we obtain broadly similar results to those with industrial production; i.e. the unemployment rate increases significantly following a monetary policy shock, and PPI inflation decreases significantly in the medium term.

Furthermore, following the approach of Bernanke, Boivin, and Eliasz (2005), we have estimated the model with a macroeconomic factor to represent economic activity (column h). A macroeconomic factor has the advantage that it incorporates information from a broad macroeconomic data set in a VAR of limited dimensions. For our macroeconomic factor, we take the first principal component from a panel of 74 macroeconomic series describing the labor market, industrial production, prices, surveys and financial developments. The underlying series are transformed, orthogonalized to the EMS and standardized to have zero mean and unit variance. The impulse responses of the macroeconomic factor are in line with those from our benchmark model, although the PPI inflation responses are insignificant.

We have used the 3-month rate as the monetary policy indicator in our short rate estimations. We have also trialled a two-factor SSR from Krippner (2015b) as an alternative (see column i). Despite being estimated and somewhat sensitive, appendix C shows that two-factor SSRs are more robust empirically than the three-factor SSRs, and we have chosen a series that falls around the middle of the range of estimates. The implications of an unanticipated monetary policy tightening for the economy are largely similar to the benchmark short rate results; i.e. the response of the PPI inflation has a short-horizon price puzzle with a medium-horizon decline, and the industrial production gap counterintuitively widens before becoming insignificant. The similarity is not surprising, because the SSR essentially coincides with the 3-month rate in the conventional period.

However, one notable difference of the SSR results from the benchmark short rate results is that the size of the shock to the SSR remains largely stable over time, because the SSR can still vary when the lower bound is binding for the short rate. Hence, the impulse responses in the unconventional period remain very similar to those in the conventional monetary policy period. These results suggest that a two-factor SSR is a better proxy for monetary policy than a short-maturity rate in periods of unconventional monetary policy. Nevertheless, our results overall indicate that the EMS is better than both the short rate and the two-factor SSR in both conventional and unconventional periods.

Finally, we also estimate the model with the inland PPI ex energy and the industrial production gap as aggregate macroeconomic data for the euro area. With the EMS as monetary policy indicator, the inflation responses are just slightly less significant than in the case of German data (see column j). Also the impulse responses of the industrial production gap are similar to those for Germany, but they are insignificant at each point in time, rather than being significant for medium term horizons. When estimating the VAR with the short rate as monetary policy indicator, we also find the same counterintuitive response of the IP gap as for the German dataset (see column k).

Overall, the impulse responses resulting from using alternative variable sets have similarly shaped median responses, although they sometimes differ in their significance. Our results with the benchmark variable set of PPI, CPM, industrial production gap and the EMS for Germany therefore appears to be representative of the results that could otherwise be obtained from alternative small-scale VARs over the considered sample.

Table 1: The table summarizes the results of impulse responses to a monetary policy shock in alternative specifications of the VAR. Checks in the first two rows indicate the sample, and in the remaining rows whether a certain variable reacts significantly with the expected sign to a monetary policy shock. A variable that reacts significantly, but implausibly, is marked with a cross. Insignificant responses are labelled by a 0. Commodity prices are incorporated as a control variable, sotheir responses are not of interest for our analysis (∅).

		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x
1999-2008		√	√																						
1999-2015				√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Variable type	Name																								
Prices:	PPIIN	√	√	0	√		0	√	0	√			√	√	√	0	0	0	0	0	0	0	√	√	0
	HCPI					0																			
	PPIexEn. (EA)										√	0													
Inflation Exp.	Survey (CF)						0																		
	Commodity pr.	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅		
Real economy	IP	×	√	×	√	√	0			×			0	√	√	×	×	×	√	0	0	√	×		
	Macro factor								√															√	√
	Unemployment							√																	
	IP (EA)										0	×													
Policy variable/s	Policy rate	√		√								√													
	EMS(30)		√		√	√	√	√	√		√													√	
	SSR									√															√
	EMS(3) (MB)												√												
	EMS(10) (MB)													√											
	EMS(30) (MB)														√										
	EMS(3)-EP															√									
	EMS(10)-EP																√								
	EMS(30)-EP																	√				√	√		
	EMS(3)-RP																		√						
	EMS(10)-RP																			√					
	EMS(30)-RP																				√	√	0		

8.2 Estimates with alternative EMS metrics

Section 4.2.3 introduced the model-based estimate of the EMS. We have tested our benchmark EMS model with estimates of the EMS obtained from the shadow/lower-bound term structure model outlined in appendix B (i.e. using the estimated 30-year interest rates from that model, and the LNIR).[16] The results are very similar, as indicated in column n of table 1. This result is not surprising, given that appendix E shows that the model-free EMS and the model-implied EMS comove very tightly, which in turn reflects that the model-estimated interest rate is very close to the observed interest rate (i.e. the model residual is very small).

So far we have calculated the EMS with a horizon of $\tau_{\mathrm{H}} = 30$ years. To ensure that our results are not sensitive to our particular choice, we have also tested our benchmark EMS model results with model-based EMS value using $\tau_{\mathrm{H}} = 3$ years and 10 years (the model-free EMS results are virtually identical). The 10-year EMS results (column l) are very similar to those with the 30-year EMS, which is unsurprising given that appendix E.1 shows that all EMS series with $\tau_{\mathrm{H}} \geq 7$ years have very similar statistical properties when summarized as z scores. Conversely, and consistent with our discussion in section 4.2.2 that τ_{H} should be chosen to correspond at least with the length of the typical business cycle, the results for the 3-year EMS (column n) show less plausible impulse responses, with an insignificant response for the IP gap.

Section 4.2.3 introduced the EMS decomposition into an expected policy component, which we will denote EMS-EP, and a risk premium component, which we will denote EMS-RP. As an initial investigation into the relative importance of the two components, we use each of these generated data series independently as the monetary policy variable in our model, with horizons $\tau_{\mathrm{H}} = 3$, 10, and 30 years.

The results for the EMS-EP show implausible responses for the IP gap, and only one plausible and significant response for PPI inflation; see columns o, p, and q. The results for the EMS-RP have only a few plausible and significant responses for the IP gap and PPI inflation; see columns r, s, and t. In addition, the size of shocks to both the EMS-RP and the EMS-EP show material variation over time, with both being smaller in the unconventional period than before.

By comparison, our benchmark EMS results and the 7- and 10-year variants mentioned earlier produce plausible results that are typically significant, and the EMS shocks in our benchmark setup of section 6 do not show much time variation. Hence, it appears that both the expected policy and risk premium components are important when assessing the overall stance of policy and the likely effect on the evolution of the macroeconomy.

Related to the previous paragraph, we also undertake a further preliminary investigation using both the EMS-EP and EMS-RP in the monetary VAR, and the results again suggest that both components play important roles. Column u shows the results when we order EMS-RP last, hence allowing EMP-EP to react to EMS-RP shocks with a lag. The responses of PPI inflation and the IP gap both show significant declines on a tightening shock. A tightening EMS-RP shock also induces a decline in the EMS-EP, which is consistent with the central bank trying to offset higher bond yields due to rising risk

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[16] For all the model-based EMS estimates and their components in this paper, we use the estimates as data without addressing the issue of generated regressors. The paragraph at the end of this section contained related discussion.

premiums with a lower expected policy rate path.

Column v shows the results when we order EMS-EP last, hence allowing EMS-RP to react to EMS-EP shocks with a lag. Inflation declines in response to a tightening shock, but the results for the IP gap are mixed; there is initially a positive response to a tightening shock, turning negative for longer horizons, but insignificantly. A tightening EMS-EP shock induces an insignificant increase in the EMS-RP.

These preliminary results indicate the desirability of more fully exploring the role of shocks to EMS-EP and EMS-RP components on macroeconomic variables, which we intend to progress in future work. In particular, isolating the responses to EMS-EP and EMS-RP shocks while conditioning the response of the other EMS component to be zero may offer some guidance on the relative responses that each component has on the macroeconomy.

Note that we have simply treated the model-based EMS estimates and their components as as being observed without error when using them in our estimations and related impulse response results. A more ideal treatment would allow for the uncertainty of the EMS and component estimates, which would widen the confidence intervals of the impulse responses. While easy to do in principle, with bootstrapping/resampling, the number of replications required makes this avenue computationally infeasible for our TVP-VAR model, given that a single TVP-VAR estimation takes several hours. It is much more desirable to use the model-free EMS, as for our analysis in previous sections, to avoid these issues with the model-based EMS. However, the EMS-EP and EMS-RP are only available as estimated quantities, so analysis with those components should appropriately allow for their estimation uncertainty.

8.3 Models without an inflation expectation control variable

The benchmark VAR models and alternatives discussed so far incorporate a variable to proxy inflation expectations, which is a standard approach to control for their potential role in producing the counterintuitive empirical relationship known as the price puzzle. In this section, we estimate models with the EMS and the macrofactor but without an inflation expectations control variable. The rationale is, because the EMS should already incorporate an expectations component (in this case a policy rate expectation) indirectly related to future inflation, it may be possible to dispense with the direct control for inflation expectations.

From that perspective, column w provides a summary of the results using just PPI inflation, the macroeconomic factor, and the EMS. The resulting impulse responses are very similar to those from the analogous model including commodity prices. Indeed, PPI decreases more significantly in response to an EMS tightening shock.

We have also undertaken estimations using PPI, the macrofactor, the EMS-EP, and the EMS-RP (also with the order of the EMS components switched). The results are very similar to those already outlined at the end of the previous section, where the IP gap is used as the real variable and commodity prices are included. However, the alternative results show significant declines in the macrofactor after an EMS-EP shock, rather than the initially counterintuitive and then insignificant responses of the IP gap noted previously.

Our preliminary investigations therefore suggest another potential advantage of using the EMS as the monetary policy variable in a VAR; i.e. it may eliminate the need to use a commodity price variable to control for inflation expectations.

9 Conclusion

In this paper, we have investigated the effect of monetary policy on German and euro area macroeconomic variables using a small-scale time-varying parameter vector autoregression (TVP-VAR) and the "Effective Monetary Stimulus" (EMS). The EMS is a monetary policy metric obtained from yield curve data that is designed to consistently reflect the overall stance of monetary policy across conventional and unconventional monetary policy environments. In both environments, the EMS quantifies policy rate settings and their expectations relative to a long-horizon nominal natural rate, and risk premiums in longer-maturity interest rates. Importantly, we show that a model-free EMS can be obtained from the observables of long-maturity interest rates and using survey data as a proxy for the long-horizon nominal natural rate.

Empirically, using the EMS in our VAR obtains plausible and stable structural relationships with prices and output developments across and within conventional and unconventional environments. Specifically, tightening (easing) EMS shocks result in lower (higher) inflation and economic activity, and those responses do not vary materially over the sample period. These results suggest that the EMS provides a useful practical monetary policy metric for central banks in lower-bound-constrained interest rate environments. Indeed, even over just the conventional part of our sample, the EMS outperforms the traditional three-month interest rate as a monetary policy metric, which is consistent with the EMS in principle reflecting more information on the overall stance of monetary policy compared to the short-maturity interest rate alone.

Our counterfactual results indicate that monetary policy shocks have mostly been expansionary since 2007, which has resulted in inflation and activity being higher than they otherwise might have been. These results are qualitative only, because our results display the typical insignificance associated with counterfactual analysis obtained from TVP-VAR models, but they are nevertheless consistent with the ECB having provided stimulus through unconventional policy actions, i.e. in addition to the near-zero policy rate setting that has prevailed since 2007.

Finally, we have conducted extensive robustness checks with alternative data. While not all of the alternative results are significant, they do not overturn the results from our benchmark comparison of the EMS versus the three-month rate (or an estimated shadow short rate series). The robustness checks also show our initial investigation into the contribution of the expected policy and risk premium components of the EMS for monetary policy transmission. We find that neither of these components individually performs as well as the aggregate EMS. Hence, both channels appear to be important. Supporting that, our preliminary investigations with both components included largely replicate the results using the aggregate EMS.

In summary, the EMS concept and the practical inception we have introduced in this paper shows promise as a monetary policy metric over both conventional and unconventional monetary policy periods. Further work will be useful to test the usefulness of the EMS in that regard. First, the EMS could be tested for other economies. For the United States, we have already obtained similar results to those mentioned in this paper. In particular the EMS performs better than the Federal Funds Rate as a monetary policy metric in both conventional and unconventional environments. Second, further exploration of the roles of the expected policy and risk premium components of the EMS would be useful, which would extend our preliminary investigations in this paper. Allowing for macroeconomic uncertainty may be useful in this regard, because the influence of risk premium changes associated with periods of increased uncertainty may differ from risk premium changes that occur for other reasons. Third, it might be possible to improve the EMS as a monetary policy metric, as discussed in section 4.3.

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A Monetary policy metrics

In this appendix, we discuss in detail why we believe the Effective Monetary Stimulus (EMS) is the most compelling monetary policy metric for our analysis, and likely for quantitative monetary policy analysis in general across conventional and unconventional environments. The explanation requires a diversion to discuss alternative metrics for the stance of monetary policy that could otherwise be considered for our analysis, but which we illustrate are less preferable, for varying reasons, than the EMS.

In section A.1 we first consider two observable variables as metrics of monetary policy, i.e. the policy interest rate and the size of the ECB balance sheet. In section A.2 we introduce the estimated variables obtained from the shadow/lower bound term structure modelling, namely the Shadow Short Rate and the Expected Time to Zero. The EMS is also obtained from that same modelling framework, following the original concept in Krippner (2014, 2015b), but section A.2 explains how the version we have proposed in this paper allows the EMS to be obtained as the model-free value we have outlined in section 4.2.2, and the advantages of that version. In section A.3, we discuss the properties of the different monetary policy metrics, and we discuss some potential improvements to the EMS in section A.4.

A.1 Observable monetary policy variables

Although the institutional details differ from country to country, monetary policy is conventionally conducted by setting the nominal interest rate at which the central bank lends and receives high powered money with the interbank market and by buying and selling short-term debt securities to target short-term nominal interest rates around that setting. The setting of the policy interest rate influences market interest rates and asset prices in the economy, and ultimately the macroeconomic variables of inflation and output growth that the central bank seeks to target. An observed freely varying short-maturity interest rate, which we will treat in what follows as synonymous with the policy interest rate, is therefore a typical candidate to quantitatively summarize the stance of monetary policy.

However, conventional monetary policy becomes constrained once policy interest rates are near-zero, which figure 1 (in the main text) shows was the case for Europe since late 2008, apart from a short-lived policy tightening episode in 2011. The policy interest rate cannot be meaningfully lowered further because the availability of physical currency effectively offers a risk-free investment at a zero rate of interest, and a zero return would be more attractive than central bank deposits or buying securities that offer a negative interest rate.[1]

To provide further monetary stimulus beyond a zero policy rate setting, central banks can and have used a range of unconventional monetary policy actions. One category of unconventional monetary policy is quantitative easing (QE), such as large-scale asset purchases, targeted asset purchases, and liquidity provisions. Examples are the ECB's

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[1] If a central bank set its lending rate below zero, that would also allow an arbitrage for settlement banks, via borrowing to obtain holdings of physical currency. Note that non-zero lower bounds, either negative or positive, can exist due to the central bank's logistical arrangements, institutional frictions, and costs associated with holding physical currency. For example, the ECB had a −0.4% policy rate (deposit facility) at the time of writing (set on 16 March 2016). However, the financial incentive to hold physical currency will dominate at some threshold negative interest rate. Central banks may also be reluctant to test that threshold because, before it is reached, the direct benefit of monetary accommodation can be offset by the indirect effect on bank profitability and hence lending; see Brunnermeier and Koby (2016).

covered bond and asset-backed securities purchase programmes, and long-term refinancing operations.[2] Another category of unconventional monetary policy is explicit long-horizon forward guidance on policy rates (as opposed to shorter-horizon indications in conventional monetary policy periods). For example, the ECB introduced such guidance in the policy statement following the 4 July 2013 meeting.[3]

In an unconventional monetary policy environment, the policy interest rate alone therefore does not provide a complete gauge of the overall stance of monetary policy, because it omits any indication of the additional stimulus from unconventional monetary policy actions. Additional and/or alternative metrics to the policy rate are therefore necessary to appropriately capture that additional stimulus.

The central bank balance sheet suggests itself as an observable variable that can quantify the additional stimulus, because it will reflect QE actions undertaken by the central bank. Figure 1 in the main text plots the ECB balance sheet as a percentage of Gross Domestic Product.

However, there are many reasons why the balance sheet will not provide a complete and/or reliable gauge of unconventional monetary policy stimulus. First, the balance sheet does not account for forward guidance, so one category of unconventional monetary policy will be completely unaccounted for. Other reasons include:

- Financial markets often react strongly to the announcements of QE programmes (or even the anticipation of a likely announcement), as distinct from when the balance sheet changes actually occur. Therefore, financial markets will transmit much of the stimulus effects from QE programme announcements to the economy before any changes to the central bank balance sheet actually occur. For example, longer-maturity euro-area yields (and the euro) fell before and immediately after the 22 January 2015 Public Sector Purchase Programme (PSPP). Yields actually rose moderately as the ECB balance sheet later expanded.[4]

- Central bank balance sheets can change without an intended change to the stance of monetary policy. For example, in 2012 the ECB's balance sheet contracted as banks voluntarily paid back large amounts of Long-term Refinancing Operations (LTROs) from 2011, but that did not occur due to any policy tightening actions from the ECB.[5]

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[2] US quantitative actions included liquidity measures from late 2008, and three programmes of asset purchases: QE1 beginning in November 2008, QE2 beginning in November 2010 (after being foreshadowed in August 2010), and QE3 beginning in September 2012 (with an increase in December 2012).

[3] The ECB statement included the following sentence: "The Governing Council expects the key ECB interest rates to remain at present or lower levels for an extended period of time." In addition, the ECB President Mario Dragi mentioned in the accompanying press conference: "The Governing Council has taken the unprecedented step of giving forward guidance in a rather more specific way than it ever has done in the past." The US Federal Reserve adopted such long-horizon forward guidance from the time the Federal Funds Target Rate was cut to a range of 0 to 25 basis points, and more explicitly from August 2011. Woodford (2012) is a useful reference that discusses different methods of unconventional monetary policy, albeit from a US perspective.

[4] As a US example, bond yields reacted more when Chairman Bernanke foreshadowed QE2 on 27 August 2010, than when the progamme was formally introduced and implemented from 3 November 2010.

[5] As a US example, the liquidity measures instituted in late 2008 were wound back in early 2009 as markets no longer required them. However, QE1 and forward guidance to maintain a near-zero policy rate remained in place.

- Programs intended to change the stance of monetary policy and/or financial conditions may not change the balance sheet. For example, the ECB announced the Outright Monetary Transactions (OMT) programme on 26 July 2012, which was successful in easing the sovereign bond yields of peripheral euro-area economies, but no transactions actually occurred subsequently.[6]

- Programs with the same balance sheet implications may be designed to seek different effects. For example, the ECB Asset-Backed Securities Purchase Programme (ABSPP) and Covered Bond Purchase Programmes (CBPPs) are targeted asset purchases that ease private sector credit spreads, while the PSPP of mainly sovereign bonds is closer to pure quantitative easing.[7]

- It is not clear whether the size or change in the central balance sheet should be used. Commentators often refer to the balance sheet size as an indicator of unconventional monetary policy stimulus, but actual and/or expected balance sheet changes are arguably more relevant.

A final point relates to the use of policy interest rate and balance sheet data in an econometric context. That is, while both series are observable variables that relate to the stance of monetary, figure 1 shows that neither the policy interest rate nor the balance sheet have consistent statistical properties, in terms of their variance and cycles, over the entire sample period. Hence, aside from each series by itself not being a complete indicator for the overall stance of monetary policy, neither series by itself would be suitable for econometric analysis with respect to the transmission of monetary policy to the macroeconomy over both conventional and unconventional periods.

Similarly, including both variables (likely with appropriate dummy parameters) would also be troublesome. The econometric results would be dominated by the variation in the policy interest rate in the conventional part of the sample, and dominated by the variation in the balance sheet in the unconventional part of the sample, but without any link to appropriately scale for the different effects that interest rate and balance sheet changes have on the macroeconomy. While it may be possible, in principle, to standardize the two series into a single monetary policy measure, that would be challenging in practice because there are no obvious and/or reliable theoretical or empirical relationships to rely on, e.g. in terms of common influences on the money supply and its growth.

A.2 Monetary policy metrics from yield curve data

Term structure models of the shadow/lower bound class offer a means of inferring the stance of monetary policy from observed yield curve data. For the purposes of this section, we provide just the essential overview and intuition of shadow/lower bound models (SLMs) that readers require to interpret the three candidate monetary policy metrics that are readily obtainable from SLMs. An overview of the SLM framework and the specifications

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[6] A US example is "Operation Twist", where longer-maturity Treasury bonds were substituted for short-maturity Treasury bills. The programme was intended to ease longer-maturity government rates, but there was no net impact on the size of the Federal Reserve's balance sheet.

[7] See Woodford (2012) for discussion on the differences in unconventional monetary policy actions. As US example, QE1 involved mainly purchasing mortgage-backed securities to ease conditions in that particular market, while the purchase of government bonds during QE2 was closer to pure quantitative easing.

we employ in this paper are contained in appendix B, along with references to more detail in other papers.

SLMs are based on the principle that the lower-bounded short rate at time t, $\underline{\mathrm{r}}(t)$, may be viewed as the sum of two components: (i) a shadow short rate $\mathrm{r}(t)$ that can adopt positive or negative values; and (ii) an expression $\max\left[-\mathrm{r}\left(t\right),0\right]$ that accounts for the option investors have to hold physical currency to avoid a negative return if the shadow short rate is negative. In summary, the lower-bounded short rate $\underline{\mathrm{r}}(t) = \mathrm{r}(t) + \max\left[-\mathrm{r}\left(t\right),0\right]$, which gives $\underline{\mathrm{r}}(t) = \mathrm{r}(t)$ if $\mathrm{r}(t) \geq 0$ and $\underline{\mathrm{r}}(t) = 0$ if $\mathrm{r}(t) < 0$ (therefore establishing the zero lower bound). As mentioned in footnote A.1, the lower bound may not necessarily be strictly zero in practice, and we allow for a non-zero lower bound in our applications.

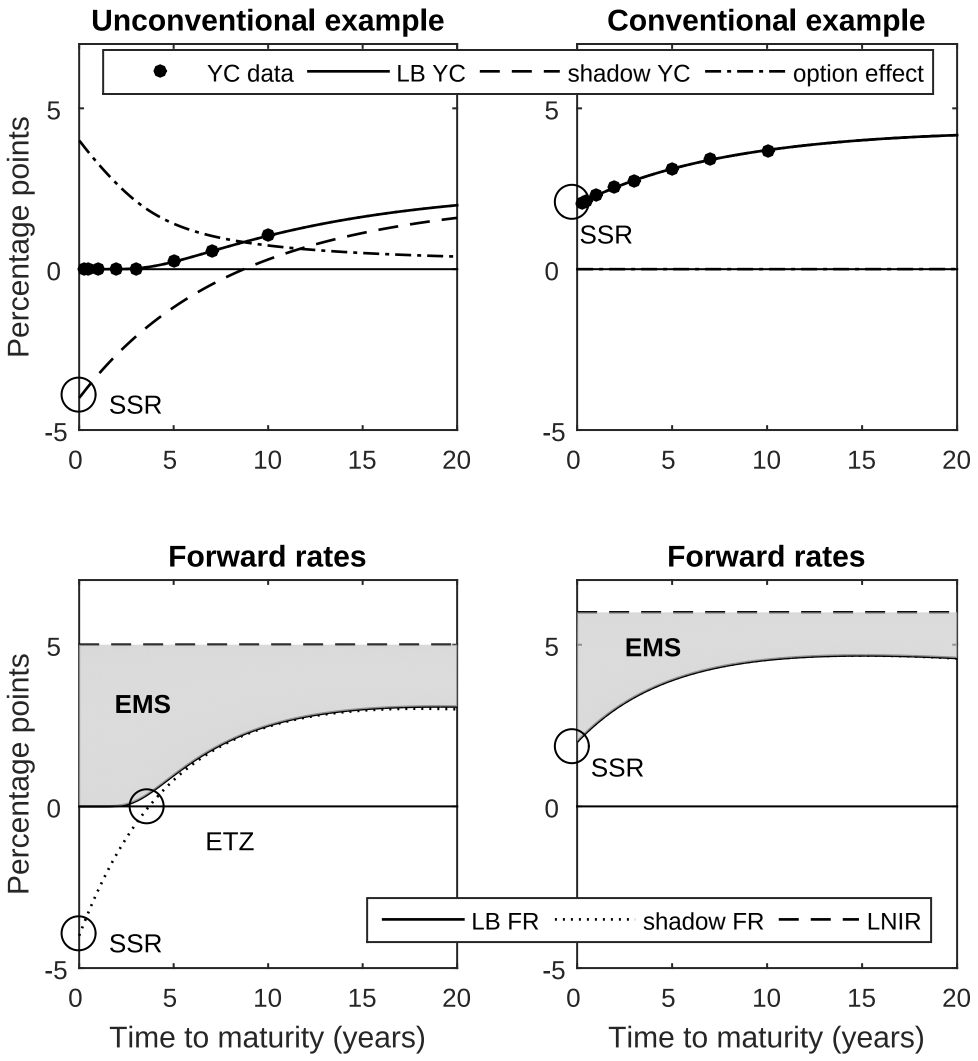

Figure A.1: Examples of monetary policy metrics obtained from shadow/lower-bound term structure models and yield curve data in conventional and unconventional monetary policy periods.

Bond yields represent the expected return from a compounding investment in the short rate up to the time of maturity. Hence, given the shadow short rate/currency option decomposition of the short rate, the whole observed actual yield curve (i.e. interest rates as a function of time to maturity at time t, all subject to the zero lower bound) may be analogously viewed as the sum of two components: (i) a shadow yield curve as a function of maturity that would exist if physical currency was not available; and (ii) an option effect that the availability of physical currency provides to investors to avoid any realizations of negative shadow short rates that could potentially occur at any time up to each given maturity.

Figure A.1, stylistically illustrates the yield curve data and the results obtained from our SLM, respectively in an unconventional/lower-bound-constrained and conventional/ unconstrained environment. This replicates figure 2 in the main text, except we have included the option effect described above.

Associated with each figure are the three monetary policy metrics that can readily be obtained from the estimated SLM; that is, the Shadow Short Rate (SSR), the Expected Time to Zero (ETZ), and the Effective Monetary Stimulus (EMS). We discuss each of these, and the yield curve data, with respect to the unconventional and conventional environments we have illustrated.

The left-hand side of figure A.1 illustrates an unconventional monetary policy environment where the yield curve data is materially constrained by the lower bound on nominal interest rates. The option effect is very material due to the proximity of the yield curve data to the lower bound, and therefore the high probability that the option to hold physical currency will be valuable over the lifetimes of the bonds that form the yield curve. The shadow yield curve contains negative interest rates for some maturities, and the SSR is the shortest maturity rate on the shadow yield curve (conceptually like the policy rate). Negative values of the SSR provide a gauge of the near-zero policy rate plus unconventional monetary policy actions, and the SSR can move down (up) as unconventional policy becomes more accommodative (restrictive).

The bottom-left plot of figure A.1 illustrates the ETZ, which is the horizon at which the expected path of the shadow forward rate crosses up through zero (or any other threshold could be used). It essentially indicates when the lower-bounded short rate, and hence the actual policy rate, is expected to lift off from zero.[8] The ETZ becomes longer (shorter) as unconventional policy becomes more accommodative (restrictive), because longer (shorter) values imply a longer (shorter) expected period with a near-zero policy rate. However, the ETZ and other lift-off metrics are only defined when the yield curve is in a lower-bound constrained environment.

The bottom-left plot of figure A.1 also illustrates the EMS. We have already discussed the EMS extensively in section 4 of the main text, and here we provide some further relevant background. The concept of the EMS was originally proposed in Krippner (2014, 2015b), but with the calculation based on the area between the expected path of the SSR under the risk-adjusted $\mathbb{Q}$ measure with zero truncation for negative values, and the estimate of the Level component of the SLM used as a proxy for the LNIR.

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[8] The expected path of the SSR could also be used, either under the risk-adjusted $\mathbb{Q}$ measure (which is similar to the forward rate curve, and therefore includes a risk premium) or under the physical $\mathbb{P}$ measure (which excludes any risk premium effect, and is therefore on the same basis as surveyed lift-off expectations). Bauer and Rudebusch (2016) and Wu and Xia (2016) present a closely related lift-off metric, i.e. the median time to a threshold of 25 bps from a sample of simulated shadow short rate paths. Bauer and Rudebusch (2016) also presents a modal lift-off metric, following Kim and Singleton (2012), which is conceptually equivalent to the ETZ (but it uses a 25 bp threshold rather of zero, and the path of the SSR rather than the shadow forward curve). Bauer and Rudebusch (2016) shows that their median and modal lift-off metrics are very close to each other.

The version of the EMS we use in this paper is preferable for several reasons. First, and most important, it better accounts for the stimulatory effect of long-horizon risk premiums by using an external proxy for the LNIR. The issue with using the estimated Level component of the SLM is that it closely follows the level of longer-maturity yields. Hence, quantitative easing actions that lower the risk premium in those yields can lower the Level component, which therefore compresses the area between the zero-truncated SSR path and the Level. Actions to provide further monetary accommodation can therefore counterintuitively lead to a tightening in the original EMS. The survey proxy for the LNIR, as discussed in section 4.2.1, is exclusive of such risk premium effects, and therefore declines in the risk premiums for longer-maturity yields will more correctly be picked up as additional monetary accommodation.

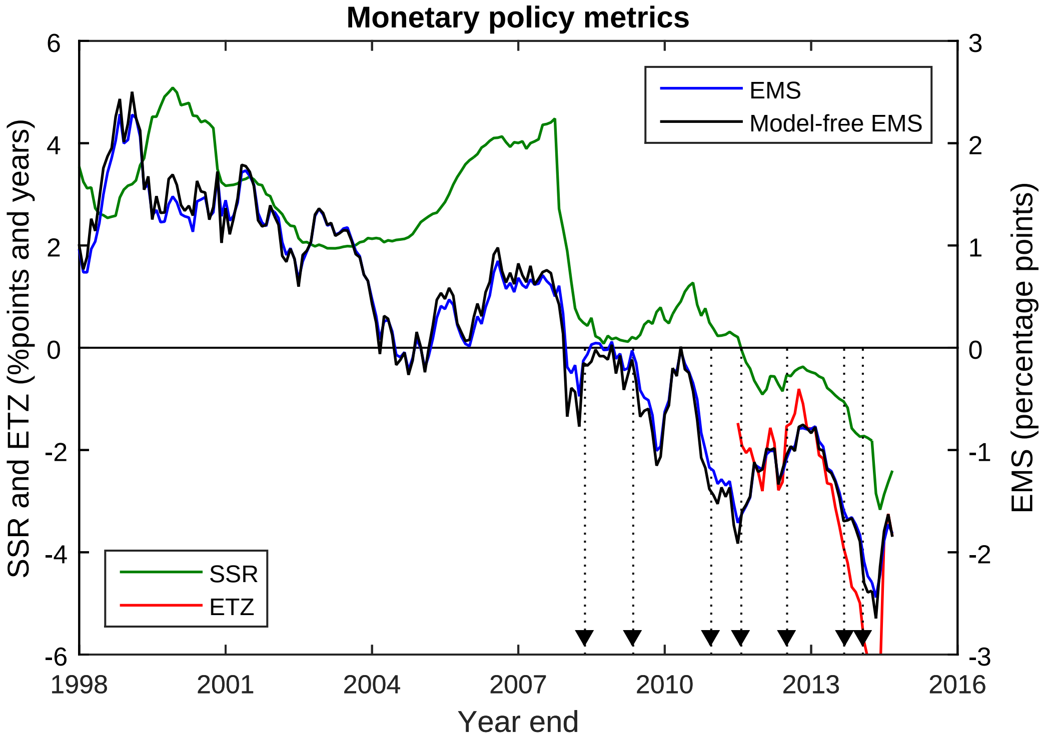

Figure A.2: Examples of the time series of monetary policy metrics obtained from a shadow/lower-bound term structure model. The ETZ has been negated to coincide with the SSR and EMS, and its largest value is 8.2 years.

The second difference to Krippner (2014, 2015b) is that our EMS uses the lower-bounded forward rate curve rather than the zero-truncated SSR path under the risk-adjusted $\mathbb{Q}$ measure. This makes little difference to the calculation, because the expected path of the SSR under the risk-adjusted $\mathbb{Q}$ measure is very similar to the shadow forward rate curve, and the respective truncation or option-based lower-bound mechanisms play very similar roles when converting either the SSR path or the shadow forward rate curve to their lower-bounded (i.e. "effective") values. However, as highlighted in section 4 of the main text, the distinct advantage of basing the EMS concept on the lower-bounded forward rate rather than the zero-truncated shadow short rate is that it leads to a model-free EMS, because an observed interest rate can be compared directly to the LNIR.

Regarding SLM monetary policy metrics in a conventional monetary policy environment, this is illustrated in the right-hand side of figure A.1. The yield curve data is not constrained by the lower bound on nominal interest rates, and the option effect is immaterial (and therefore not noticeable in the figure) due to the yield curve data being far from the lower bound. The estimated shadow yield curve therefore essentially coincides with the LB yield curve. The SSR is still the shortest maturity interest rate on the shadow yield curve, but it is now essentially coincident with the lower-bounded/actual short rate or policy interest rate. The bottom-right plot of figure 2 illustrates that the ETZ is undefined in a conventional monetary policy environment, because all of the values of the shadow forward rate curve are above zero.

Obtaining estimates of the SSR, ETZ, and the EMS at each point in time provides a time series for each that could potentially be used as a monetary policy metric for quantitative analysis. For example, figure A.2 plots the SSR, ETZ, and the EMS time series obtained from our benchmark SLM, and also the model-free EMS.

A.3 Choosing a monetary policy metric

The previous section has suggested three estimates from shadow/LB term structure models that could potentially be employed as monetary policy metrics for monitoring and quantitative analysis. This section discusses why, for those purposes, the EMS suggests itself as the leading candidate of the three metrics.

Beginning with SSR estimates, they have been proposed as an intuitive metric for the routine monitoring of the stance of unconventional policy and quantitative analysis; see Krippner (2011-2015), Bullard (2012, 2013), and Wu and Xia (2016).[9] As those authors detail, SSRs are like a policy interest rate, but can freely evolve to negative values to reflect a near-zero policy rate plus unconventional policy actions (whereas the policy rate itself would not be a complete measure of the overall stance of monetary policy due to its constraint at near-zero values).

However, the SSR has three issues. The first issue is empirical, i.e. SSRs are necessarily estimated quantities and are therefore subject to uncertainties. In particular, point estimates of SSRs in unconventional periods can be very sensitive to choices on the model specification (e.g. the choice of lower bound parameter and the number of state variables), and also the data (e.g. the maturity span of the yield curve data and the sample period); see Bauer and Rudebusch (2016), Krippner (2015a,b), and Christensen and Rudebusch (2015). Krippner (2015a) also provides a detailed discussion of why SSR estimates from three-factor models are especially sensitive; essentially it is due to the flexibility of three factors overfitting the yield curve data, which sometimes allows the SSR to remain close to the lower-bound-constrained short-maturity interest rate data, therefore counterintuitively indicating no effect from unconventional monetary policy actions. Krippner (2015a) also shows that three-factor SSR estimates do not generally move consistently with major unconventional monetary policy events, often rising (falling) on easing (tightening) events. Conversely, the profiles and dynamics of SSR estimates from two-factor models are more robust, adopt materially negative values when short-maturity interest rates are constrained by the lower bound, and generally move consistently with

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[9] Lombardi and Zhu (2014) creates an alternative indicator for the stance of monetary policy, which is also named the SSR, but it is derived from central balance sheet data, monetary aggregates, interest rates, and credit spreads. Kucharcukova, Claeys, and Vasicek (2014) create a similar measure for the euro area, and more appropriately name it a monetary conditions index.

major unconventional monetary policy events. However, there remains some unavoidable variation in the magnitudes of two-factor SSR estimates between different models, in the absence of any standardization.[10]

The results discussed in the previous paragraph are for the United States, with the exception of Christensen and Rudebusch (2015) for Japan. Our graphical appendix C illustrates that the same empirical issues arise for the euro area. Specifically, three-factor SSR estimates show marked sensitivity to the lower bound setting and the yield curve data used for estimation, the SSRs from some models essentially replicate the short-maturity interest rate in the sample, and the SSRs do not generally move consistently with major unconventional monetary policy events. The two-factor SSR estimates show material variations in magnitude, but the profiles and dynamics are generally similar between models and largely consistent with unconventional actions. Hence, appropriately standardized versions of two-factor SSR estimates for the euro area are likely to be useful in practice if one requires a policy rate analogue in unconventional monetary policy periods.

The second issue with SSRs is theoretical. That is, negative SSRs (or any interest rates on the shadow yield curve) are not actually rates that are directly relevant to the decisions of economic agents. Rather, economic agents are influenced by actual interest rates in the economy, which are determined by wholesale short-maturity interest rates and their expectations (plus any appropriate margins), and such rates are constrained by the lower bound. SSR estimates reflect unconventional actions indirectly, essentially through the effect that the latter have on longer-maturity interest rates compared to just a near-zero policy rate alone.

The third issue is also theoretical, i.e. the SSR does not reflect an expectations component of monetary policy, which is generally acknowledged to be an important transmission channel.[11] This is the case even in a conventional monetary policy environment, where the SSR is essentially synonymous with policy rates and short-maturity interest rates. By omitting the information on the expected path of the SSR (and hence the expected lower-bounded short rate), the SSR in both conventional and unconventional environments omits monetary policy information relevant to economic agents (and hence to financial markets and the macroeconomy).

The ETZ, or closely associated lift-off estimates, have also been raised as a potential unconventional monetary policy metric; see Krippner (2015b) and Bauer and Rudebusch (2016). As those authors show for the United States, ETZ estimates are empirically more robust than SSR estimates. Our ETZ results for the euro area in our graphical appendix C are not quite as definitive; the profiles and dynamics of the ETZ estimates are generally very similar between different model specifications and data, but we find material variations in the magnitudes.

In any case, ETZ estimates have two major issues with respect to providing a quantitative monetary policy metric. The first is that the ETZ is only defined in unconventional environments. Specifically, the ETZ is undefined in the illustration of the conventional monetary policy environment in figure A.2, because the entire forward rate curve is above

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[10] The similarity of the profiles and dynamics means that standardizing the different series, e.g. scaling to match the Taylor (1999) rule during the unconventional monetary policy period, would produce similar SSR series between different models.

[11] For a theoretical discussion see, for example, Walsh (2003). Empirically, Gürkaynak, Sack, and Swanson (2005) is an example that establishes the importance of both the prevailing level and expectations of the Federal Funds Target Rate, resulting from Federal Open Market Committee statements, for financial markets.

zero. Similarly, figure A.2 shows that the ETZ is in general undefined for the euro area prior to December 2012, and many of the results in appendix D show occasional periods of undefined results after that time. Therefore, the ETZ by itself cannot provide a consistent quantitative metric across both conventional and unconventional monetary policy environments, or even continuously within unconventional monetary policy environments in many cases. Potentially, an ETZ series could be included with a policy rate series for quantitative analysis, but the same econometric issues discussed for the balance sheet data and policy rate series discussed in section A.1 would apply. The second issue with the ETZ is that it does not account for the profile of the expected SSR path once it becomes positive. Hence, like to the SSR, the ETZ omits information relevant to the stance of monetary policy.

The EMS concept was proposed in Krippner (2014, 2015b) to address the empirical and theoretical issues associated with the SSR and ETZ monetary policy metrics. Unlike the ETZ, the EMS is defined over both conventional and unconventional monetary policy environments, and it accounts for the profile of the expected policy rate path once it becomes positive. Unlike the SSR, the EMS is calculated from the lower-bounded forward rates, which are the rates that are "effective" in the economy, in the sense of representing the actual policy interest rate and its expected path that will influence the actual borrowing and lending rates available to economic agents.

Importantly, as demonstrated in Krippner (2014, 2015b) for the United States, even EMS series based on shadow/lower-bound models are robust to different specifications and data, which we have confirmed for the euro area in appendix E. Indeed, the model-free EMS we have introduced in this paper offers the additional advantage of not being subject to any specification and estimation uncertainties, because it uses observable data for the LNIR and observable interest rates. The model-free EMS will vary by the chosen horizon τ_{H} but, as mentioned in section 4.2.2 and detailed in appendix E.1, the statistical properties of the resulting series are very similar among difference choices of long-maturity interest rates.

As an aside, observable long-maturity interest rates by themselves may even provide an adequate monetary policy metric for many empirical purposes. That is, most of the time variation in the EMS is due to the long-maturity interest rate, with the LNIR contributing relatively little in comparison, so the long-maturity interest rate and the EMS are very similar series from a statistical perspective. Second, when considering the surprise element of the EMS over short periods, it should be sufficient to use just the change in long-maturity interest rates because the change in the slowly-moving LNIR is negligible.

With respect to the second point of the previous paragraph, the change in the 10-year interest rate has already been widely used as an indicator of monetary policy surprises in event studies covering unconventional monetary policy periods; e.g. see Williams (2011) for an overview of such studies. The concept of the EMS is therefore already being used implicitly in practice, but the foundation for the EMS within the shadow/lower-bound term structure framework formalizes the role of 10-year interest rates (or any other suitably long-maturity interest rate) as a monetary policy metric. More importantly, the EMS foundation further suggests that 10-year interest rates also be used in conventional monetary policy periods, rather than short-maturity interest rates. That is, in both environments the 10-year interest rate, or any suitable long-maturity interest rate as discussed more fully in section E.1, reflects the expected path of policy rates and risk premiums that are relevant for the decisions of economic agents.

For model-based EMS estimates, appendix E establishes for the euro area that they are very robust and very close to the model-free EMS series, regardless of the model specification and the data. These results in turn simply reflect that the residuals for the yield curve data are small.

As highlighted in section 4.2.3, the estimated EMS can be decomposed into expected policy and risk premium components. Appendix E.2 shows that those two components are robust with respect to the different model specifications and data we have tested, particularly when standardized as z scores. As mentioned in section 4.2.3, the expected policy and risk premium components are generally acknowledged to relate respectively to forward guidance and QE actions, so estimates of those components should allow for further investigation into those channels of monetary policy transmission. From that perspective, the robustness of the estimated components illustrated in appendix E.2 is desirable, because we can reasonably assume that our results obtained from using the EMS components from our benchmark model and estimation, as outlined in appendix B, will be generally representative of the results that could otherwise have been obtained using the EMS components from a different model and estimation. That said, of course, markedly different model specifications than those we have employed could well result in larger differences from our EMS components, with associated flow-on effects to any subsequent macroeconomic model results.

A.4 Improvements to the EMS

The model-free EMS and model-based EMS estimates we have presented and applied in this paper could be further developed and potentially improved, and in this section we discuss several perspectives that have occurred to us.

First, we have used a nominal EMS in this paper. Decomposing the EMS and LNIR into real and inflation components would be an interesting and important extension. Economic agents should respond to the real EMS, because it is the path of the real short rate relative to the real long-run interest rate and real risk premiums that should be relevant to their decisions. A model-free real EMS could be obtained using inflation-indexed bond rates and the real component of the LNIR as noted in this paper. However, the relatively short history of inflation-indexed bond rates and their financial market premiums due to their lower liquidity relative to nominal bond yields present two likely complications in such an exercise. A model-based real EMS from a model including nominal bond rates and the profile of surveyed inflation expectations may be able to allow for these issues, and also provide the real EMS components.

Second, we have implicitly assumed for the model-free EMS and model-based EMS estimates in this paper that changes to risk premiums in interest rates pass fully into the EMS, and that those changes have an equivalent macroeconomic effect to changes in the expected policy component. This is a strong assumption, and it would likely benefit from further consideration and potential adjustment. Specifically, some of the risk premium movements may be structural, in which case the EMS in this paper would likely overstate the stimulus from the risk premium decline to some extent.[12] The stimulus from risk premium movements might better be measured in a similar way to the expected policy component, i.e. as the expected cumulative deviation from a perceived natural/steady state level of the risk premium that can vary over time (e.g. due to persistent and

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[12] Conversely, the EMS specification in Krippner (2014, 2015b) implicitly assumes that all of the risk premium movements are structural, and so understates the easing via risk premiums.

gradual decline in inflation risk premiums over several decades). However, unlike the LNIR, an observable proxy for the time-varying permanent component of the risk premium component is not readily apparent in principle or practice.

A related issue is that the magnitudes of the risk premium component dominate those of the expected policy component. Appropriately allowing for the structural/persistent change in the risk premium component may resolve that dominance. In the interim, using the model-based components separately or jointly offers an indirect avenue for mitigating the implicitly imposed dominance of the risk premium component. On the other hand, it may be that the risk premium component is inherently dominant; in a related but different context, Munro (2014) discusses how monetary policy may actually work more through risk premiums.

Third, we have used an indirect proxy for the LNIR in this paper. Surveys of long-horizon expectations for short-maturity interest rates would provide a more direct LNIR proxy. Unfortunately, to our knowledge, such a series is not available for the euro area. However, an annual time series is available for the United States, specifically from the Survey of Professional Forecasters database available on the Federal Reserve Bank of Philadelphia website, so we can at least check the potential implications of using our indirect LNIR proxy compared to the more direct LNIR proxy if it were available. Plotting the US long-horizon short-rate series with our indirect LNIR proxy for the United States shows that the former is always lower, but by a relatively small and approximately constant amount over time. The time variation in the US long-horizon short-rate series is also small relative to US long-maturity interest rates. These results suggest that our model-free EMS and model-based EMS estimates for the euro area would not be much different if a more direct proxy for the LNIR were available and employed.

Fourth, which relates to the previous point, our EMS-EP estimates are lower than zero over almost the entire sample period, which suggests a lengthy period of accommodative monetary policy. The LNIR could be mechanically rebased by a constant to give a mean of zero for the EMS-EP over the sample. The EMS-EP would therefore contain periods of accommodative and restrictive monetary policy. However, this mechanical rebasing would have no effect on our analysis, because the statistical properties of both the expected policy and risk premium components would remain the same.

Finally, the EMS concept could be extended to other asset classes that monetary policy influences. For example, the exchange rate could in principle be considered in terms of an expected path and a risk premium component relative to a long-horizon steady state value. Equity prices and credit spreads are two other examples. Appropriately combining these different metrics together would offer a more complete indicator of financial market influences on the economy, akin to a monetary conditions index but with a more formalized foundation.

B Shadow/lower bound term structure models

In this appendix we outline the benchmark and alternative shadow/lower-bound term structure models that we use to obtain the model-based monetary policy metrics used in our paper. Section B.1 provides an overview of the general shadow/lower-bound model (SLM) framework. In section B.2, we provide an overview of our benchmark specification and estimation, and how the monetary policy metrics are obtained from the results. We refer readers to Krippner (2015b) for complete details, and Krippner (2016) will contain further details on our specification and estimation of our particular model. In section B.3, we discuss the alternative SLMs that we use to test the robustness of different monetary policy metrics from SLMs.

B.1 SLM framework

The concept of SLMs was originally introduced in Black (1995) and is based on the lower bound mechanism

$$\underline{\mathrm{r}}\left(t\right) = \max\left[\mathrm{r}\left(t\right), \mathrm{r}_{\mathrm{LB}}\right] \tag{B.1}$$

where $\mathrm{r}(t)$ is the shadow short rate that can freely adopt negative values, and $\underline{\mathrm{r}}(t)$ is the lower bounded or actual short rate which is constrained to a minimum value of the lower bound parameter r_{LB}. Unfortunately, the direct application of Black's (1995) framework with any dynamic process to represent the shadow short rate is relatively intractable and examples are therefore generally limited; e.g. Bomfim (2003) and Kim and Singleton (2012).

However, Krippner (2015b) derives a framework with a Gaussian affine term structure model (GATSM) process for the shadow short rate that closely approximates the Black (1995) framework and is much more tractable, for any number of factors. Wu and Xia (2016) derive the discrete time equivalent.[1] The key result in both derivations is the closed form analytic expression for lower bounded forward rates $\underline{\mathrm{f}}(x_t, \tau)$:

$$\underline{\mathrm{f}}\left(x_t, \tau\right) = \mathrm{r}_{\mathrm{LB}} + \left[\mathrm{f}\left(x_t, \tau\right) - \mathrm{r}_{\mathrm{LB}}\right] \cdot \Phi\left[z\left(x_t, \tau\right)\right] + \omega\left(\tau\right) \cdot \phi\left[z\left(t, \tau\right)\right] \tag{B.2}$$

with:

$$z\left(x_t, \tau\right) = \frac{\mathrm{f}\left(x_t, \tau\right) - \mathrm{r}_{\mathrm{LB}}}{\omega\left(\tau\right)} \tag{B.3}$$

where τ is the time to maturity, and $\Phi\left[\cdot\right]$ and $\phi\left[\cdot\right]$ are respectively the unit normal cumulative density and density functions. The shadow forward rate function $\mathrm{f}(x_t, \tau)$ and volatility function $\omega\left(\tau\right)$ are dependent on the GATSM specification for the shadow term structure in terms of the state variables x_t and their associated parameters.

The general GATSM specification is:

$$\mathrm{r}\left(t\right) = a_0 + b_0' x_t \tag{B.4}$$

where x_t is the $N \times 1$ vector of state variables, a_0 is a constant, and b_0 is a constant vector.[2] The state variables follow a vector Ornstein-Uhlenbeck process under the physical $\mathbb{P}$ measure, i.e.:

$$x_t = \theta + \kappa\left[\theta - x_{t-1}\right] + \sigma\varepsilon_t \tag{B.5}$$

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[1] Krippner (2015b) shows that the approximation is within a maximum of less than 3 basis points for the 10-year maturity and 10 basis points for the 30-year maturity. Similar results are obtained in Christensen and Rudebusch (2015) and Wu and Xia (2016).

[2] All parameter vectors and matrices should be taken as being conformable to x_t.

where θ is a constant representing the long run value of x_t, κ is a constant mean reversion matrix, σ is a constant volatility matrix, and ε_t is an $N \times 1$ vector of independent unit normal innovations.

The linear market price of risk specification $\Pi(t) = \gamma + \Gamma x_t$ provides the risk-adjusted $\mathbb{Q}$ measure process for the state variables:

$$x_t = \tilde{\theta} + \tilde{\kappa}\left[\tilde{\theta} - x_{t-1}\right] + \sigma\varepsilon_t \tag{B.6}$$

which is analogous to equation B.5 with $\tilde{\kappa} = \kappa + \Gamma$ and $\tilde{\theta} = \tilde{\kappa}^{-1}(\kappa\theta - \gamma)$. The state variables x_t and parameters $\tilde{\kappa}$, $\tilde{\theta}$, and σ define closed form analytic expressions for $\mathrm{f}(x_t, \tau)$ and $\omega(\tau)$ which, together with the parameter r_{LB}, define the closed form analytic expression $\underline{\mathrm{f}}(x_t, \tau)$ in equation B.2.

B.2 Our benchmark specification and estimation

The benchmark SLM we apply uses the standard three-factor (Level, Slope, and Bow [curvature]) arbitrage-free Nelson and Siegel (1987), hereafter ANSM(3), as the shadow yield curve representation within the Krippner (2015b) SLM framework outlined in the previous section.[3] We hereafter denote that SLM the K-ANSM(3). Krippner (2015b) and Christensen and Rudebusch (2015, 2016) detail the complete specification and the results for the forward rate $\mathrm{f}(x_t, \tau)$ and $\omega(\tau)$.

Equation B.5 is the state equation for the K-ANSM(3). We impose the constraints on θ and κ as detailed in Krippner (2015) and Christensen and Rudebusch (2016). In addition, for internal consistency, we impose the constraint that $\lim_{h\to\infty}\mathbb{E}_t[\mathrm{r}(t+h)] = \mathrm{LNIR}(t)$; i.e. at each point in time t, the expected long-horizon value of the short rate under the physical $\mathbb{P}$ measure is set equal to the steady-state short rate at time t, which is the LNIR(t) as discussed in section 4.2.1. We are aware of this approach being used for term structure modeling at the European Central Bank and the Bank of England.

The measurement equation for our benchmark EMS combines yield curve data and survey data, which follows Priebsch (2013) in the context of SLMs.[4] Specifically:

$$\begin{bmatrix} \underline{\mathrm{R}}(t) \\ \mathbb{E}_t\left[\underline{\mathrm{R}}(t+h)\right] \end{bmatrix} = \begin{bmatrix} \underline{\mathrm{R}}(x_t, \tau) \\ \mathbb{E}_t\left[\underline{\mathrm{R}}(x_{t+h})\right] \end{bmatrix} + \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \end{bmatrix} \tag{B.7}$$

where $\underline{\mathrm{R}}(t)$ is a $K \times 1$ vector of yield curve data for time t, $\mathbb{E}_t\left[\underline{\mathrm{R}}(t+h)\right]$ represents the $J \times 1$ vector of survey information at time t with varying horizons represented by h, $\underline{\mathrm{R}}(x_t, \tau)$ and $\mathbb{E}_t\left[\underline{\mathrm{R}}(x_{t+h})\right]$ respectively represent the functions that provide the model-implied interest rates and survey values given the state variable vector $x_t = [L_t, S_t, B_t]'$ and the model parameters, η_{1t} is the yield curve residual vector, and η_{2t} is the survey information residual vector. We specify the standard deviations of residuals to be homoskedastic, as in Bauer and Rudebusch (2016) and Wu and Xia (2016).

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[3] The ANSM(3) imposes three restrictions under the risk-adjusted $\mathbb{Q}$ measure relative to the most flexible three-factor GATSM. See Krippner (2006, 2015b) and Christensen, Diebold, and Rudebusch (2011) for further details on the ANSM(3).

[4] Including survey data when estimating term structure models estimation was originally advocated in the 2005 working paper of Kim and Orphanides (2012). It greatly improves the robustness and precision of the estimated policy expectation and risk premium components.

$\underline{\mathrm{R}}(x_t, \tau)$ is calculated by numerically integrating the lower bounded model-implied forward rates $\underline{\mathrm{f}}(x_t, \tau)$ as follows:

$$\underline{\mathrm{R}}\left(x_t, \tau\right) = \frac{1}{\tau} \int_0^{\tau} \underline{\mathrm{f}}\left(x_t, u\right) \,\mathrm{d}u \tag{B.8}$$

where $\underline{\mathrm{f}}(x_t, \tau)$ in turn uses the ANSM specifications for $\mathrm{f}(x_t, \tau)$ and $\omega\left(\tau\right)$ within equations B.2 and B.3 (u is a dummy integration variable for τ). We allow the lower bound setting r_{LB} to evolve over time in accordance with the market adapting to progressively lower settings of the ECB policy rate.[5] As implied in the notation and discussed in Priebsch (2013), $\mathbb{E}_t\left[\underline{\mathrm{R}}\left(x_{t+h}\right)\right]$ is obtained using projections of x_t under the physical $\mathbb{P}$ measure, with the horizons, maturities, and averages matching those of the survey (e.g. the 12-month forecast of the 3-month rate, or the 6-10-year forecast average of the 10-year rate). However, the objects on which the expectations are made are themselves under the risk-adjusted $\mathbb{Q}$ measure, so we allow for that in our model (which is particularly important for the expected 10-year rates).

The data we use are zero coupon interest rates with maturities of 0.25, 0.5, 1, 2, 3, 5, 7, 10 and 30 years. These are overnight indexed swap (OIS) rates, which are from derivative contracts that settle on the realized EONIA rate, from May 2008 (when a reliable full set of yield curve data is first available) to August 2015 (the latest observation at the time of the analysis). We use Bloomberg German government rates as a proxy for OIS rates from 31 January 1995 (the start of the Bloomberg data set) to April 2008, and prior to then we use German government rates from the Bundesbank.

Regarding the survey information, we use the monthly Consensus Economics interest rate surveys of the 3-month and 10-year government bond rates in three and twelve month's time, and the six-monthly (April and October) long-horizon surveys of the 10-year government bond rate. The latter are for the second to fifth calendar years relative to the year of the survey, and the average for the sixth to the tenth year relative to the year of the survey. We treat the long-horizon surveys outside April and October as missing observations.

We estimate the SLM using the iterated extended Kalman filter as detailed in Krippner (2015b). The iterated extended Kalman filter appropriately allows for the non-linearity of the measurement equation, which arises because $\underline{\mathrm{R}}(x_t, \tau)$ and $\mathbb{E}_t\left[\underline{\mathrm{R}}\left(x_{t+h}\right)\right]$ are non-linear function of the Level and Slope state variables (due to the normal probability functions).

The estimation obtains an estimated set of parameters for the model, and the time series of estimated Level, Slope, and Bow state variables L_t, S_t, and B_t. The SSR estimate for the K-ANSM(3), and also the K-ANSM(2) mentioned in the following section, is given by:

$$\mathrm{r}\left(t\right) = L_t + S_t \tag{B.9}$$

The ETZ estimate is obtained by calculating the horizon at which $\mathrm{f}(x_t, \tau)$ passes up through zero.[6] However, as discussed in section A.3, no ETZ estimate is available if all parts of the shadow forward rate curve are above zero.

The model-based EMS and the expected policy and risk premium components are obtained as discussed in section 4.2.2.

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[5] Kortela (2015) and Lemke and Vladu (2015) also use a time-varying lower bound for SLMs applied to the euro area.

[6] For three-factor models, as discussed in Krippner (2015b) with respect to the SSR path, the shadow forward rate curve can potentially initially pass down through zero before passing up at a longer horizon. We use the latter because it relates to the "lift-off" concept.

B.3 Alternative model estimations

To check the robustness, or otherwise, of monetary policy metrics from SLMs for the euro area, we have also estimated a variety of alternative SLM specifications with different datasets. Our alternatives include combinations of the following choices:

- To test the effect of changing the number of factors in the SLM, we estimate the K-ANSM(3) or the K-ANSM(2). The K-ANSM(2) has the same specification as the K-ANSM(3) from section B.2, except the Bow component is omitted, so just two factors (the Level and Slope components) are used to represent the yield curve data.
- To test the effect of changing the lower bound assumption, we estimate SLMs with lower bounds of 25, 0, -30 basis points, an estimated constant lower bound parameter, and an evolving lower bound.[7]
- To test the effect that different yield curve data can have on the results, we estimate SLMs using yield curve data out to 30 years or only out to 10 years time to maturity. The latter omits the 30-year maturity data mentioned in section B.2.
- To test the effect of incorporating survey data or not, we estimate SLMs that include or exclude the survey data mentioned in section B.2.

Appendices C, D, and E respectively plot the SSR, ETZ, and EMS results from our benchmark SLM estimation and the alternative estimates. We have also indicated major unconventional monetary policy easing events in those figures, to allow a visual inspection of whether the different monetary policy metrics generally respond consistently, or not, to the events. The indicated events are as follows:

- 13 May 2009: introduction of the 1-year Long-Term Refinancing Operation (LTRO) and the first Covered Bond Purchase Programme (CBPP1).
- 9 May 2010: introduction of the Securities Market Programme (SMP).
- 14-Dec-2011: introduction of the 3-year LTRO and CBPP2.
- 26-Jul-2012: introduction of the Outright Monetary Transactions (OMT) facility.
- 4-Jul-2013: forward guidance announcement (see footnote A.3).
- 4-Sep-2014: introduction of the Asset Backed Securities Purchase Programme (ABS-PP) and CBPP3.
- 22-Jan-2015: introduction of the Public sector purchase programme (PSPP), 22-Jan-2015.

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[7] The –30 bp value was chosen because that was the prevailing ECB deposit facility rate (set on 9 December 2015) at the time we undertook the estimations. The deposit facility rate is now –40 bps (set on 16 May 2016). Of course, a time-varying lower bound is most appropriate for the euro area. The point of using constant lower bounds for our alternative models is simply to test the effects that small changes in the lower bound setting can have on the results.

C Shadow Short Rate results

In this appendix, we present the results of SSR estimates for the euro area obtained using the shadow/lower-bound model (SLM) specifications and the data outlined in section B.3. Note that the figures focus on the SSR results for only the unconventional period, because the SSR estimates are typically close to the policy rate and/or short-maturity interest rates during the conventional period.

Figures C.2 and C.4 show that the K-ANSM(3) SSR estimates are very sensitive and sometimes adopt counterintuitive positive values in the lower bound environment. As fully illustrated and explained in Krippner (2015a), this sensitivity is essentially due to the flexibility of three factors overfitting the lower-bound constrained yield curve data in the unconventional period. Krippner (2015a) therefore concludes that SSR estimates from three-factor SLMs should not be used for monitoring or quantitative analysis, and we confirm that result for the euro area.

Figures C.1 and C.3 show that K-ANSM(2) SSR estimates have magnitudes that vary materially, but at least the profiles and dynamics between the difference applications are similar. Krippner (2015a) therefore refers to two-factor SSR estimates as relatively robust, and suggests that they are useful for monitoring purposes and quantitative analysis, but with appropriate robustness checks. We confirm that result for the euro area.

Given the variety of SSR results from the figures C.1 to C.4, figure C.5 summarizes for the full sample the maximum, minimum, and the representative two-factor SSR series that we have used in our robustness checks in section 8. The wide range of values in the unconventional monetary policy period indicates that the degree of easing and hence the results from econometric analysis can vary greatly simply due to the particular choice of specification and data used to obtain the SSR series.

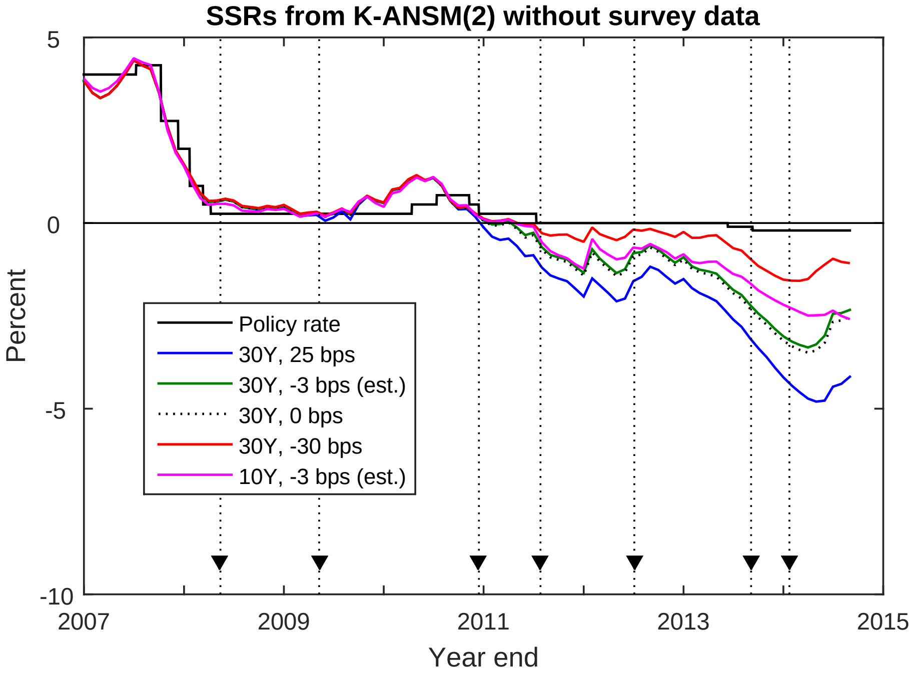

Figure C.1: K-ANSM(2) SSR estimates without survey data for different lower bounds.

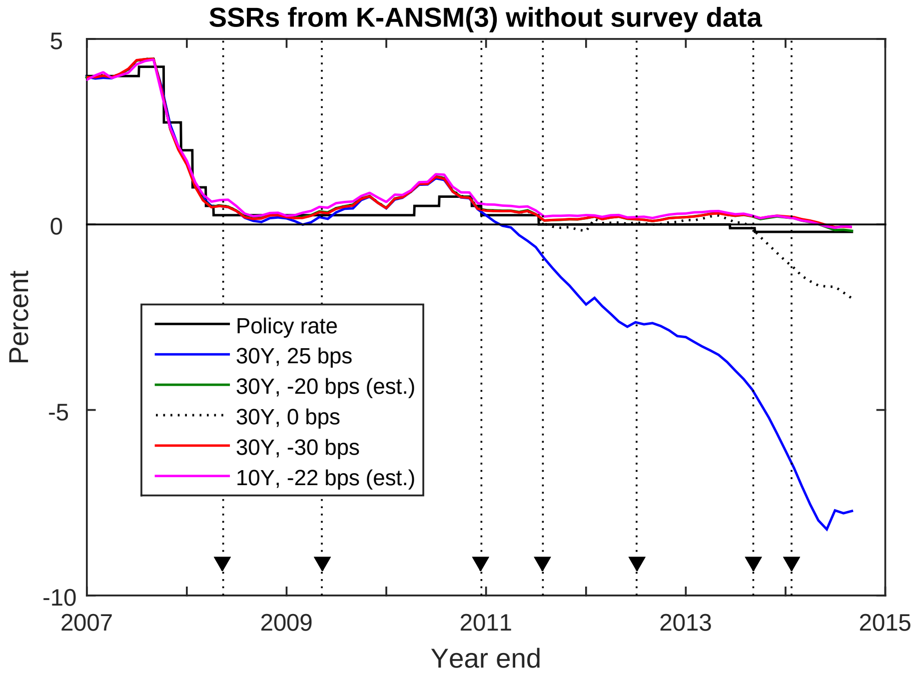

Figure C.2: K-ANSM(3) SSR estimates without survey data for different lower bounds.

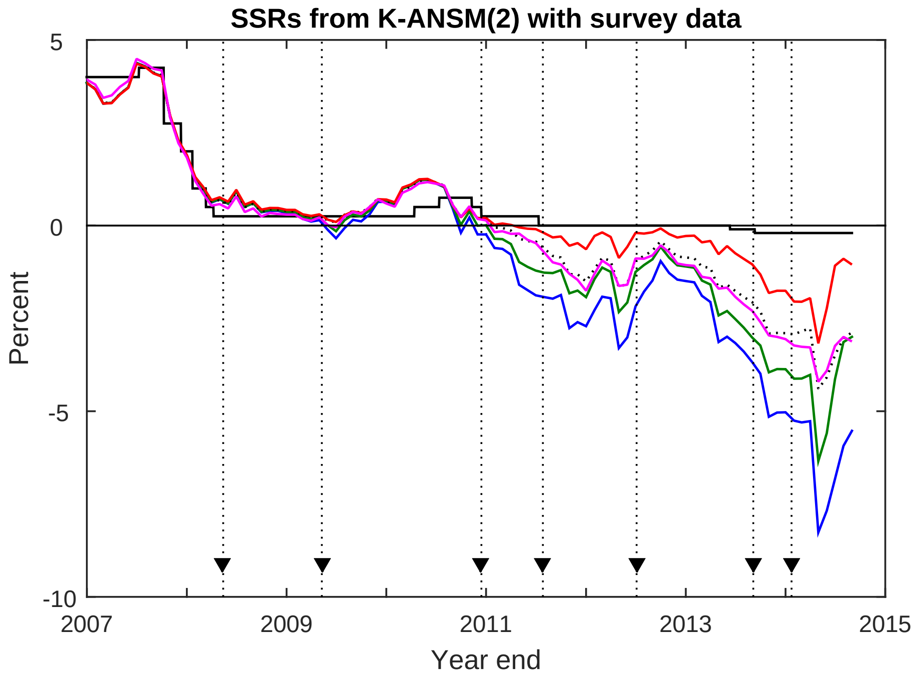

Figure C.3: K-ANSM(2) SSR estimates with survey data for different lower bounds.

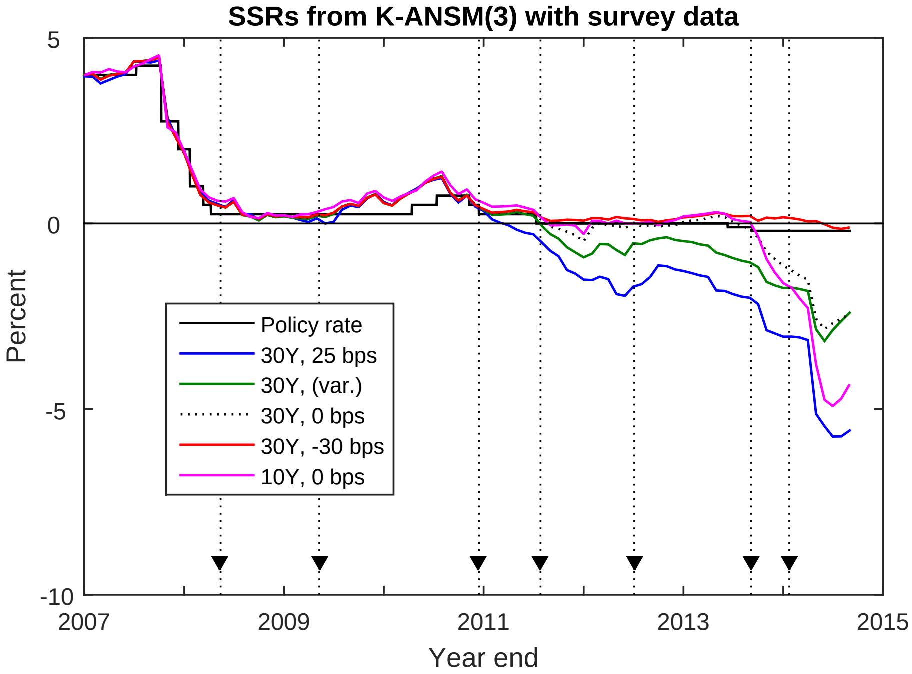

Figure C.4: K-ANSM(3) SSR estimates with survey data for different lower bounds.

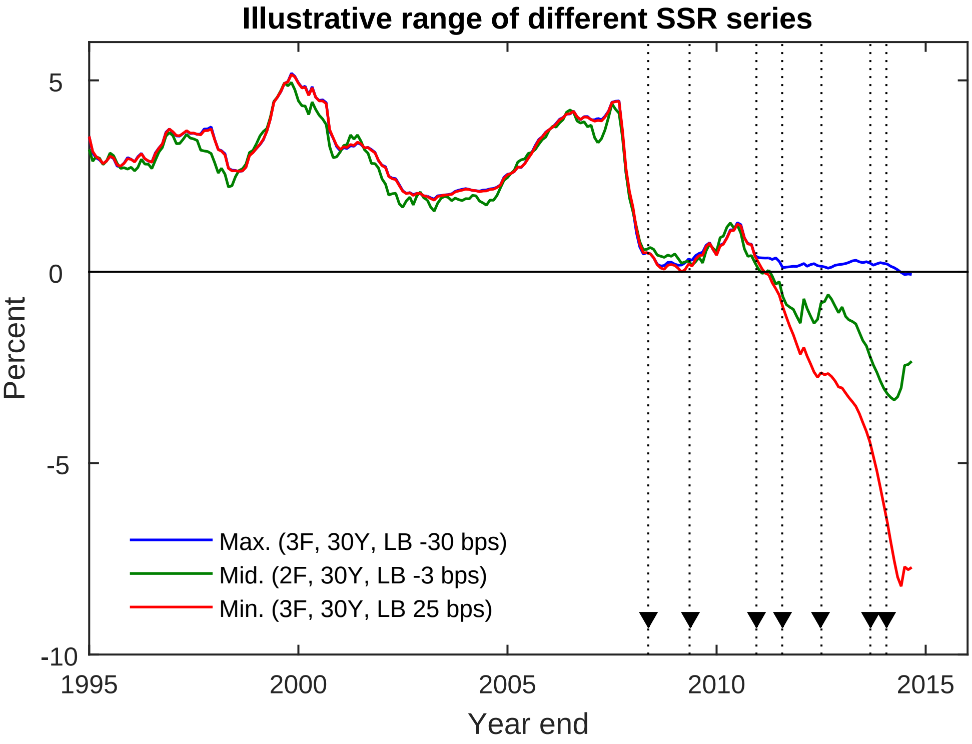

Figure C.5: Selected series of SSR estimated to illustrate the range of results when using alternative model specifications and data. The “Mid.” series is the representative two-factor SSR we have used in section 8 of the main text.

D Expected Time to Zero results

In this appendix, we present the results of ETZ estimates for the euro area obtained using the shadow/lower-bound model (SLM) specifications and the data outlined in section B.3. Note that the figures focus on the unconventional period only, because the ETZ are not defined in the earlier conventional monetary policy period. All of the ETZ estimates are plotted as negated values, so a decline (increase) represents a more (less) accommodative stance of monetary policy, as for the SSR and EMS estimates.

Figures D.1 to D.4 provide ETZ estimates as described in section A.2, i.e. based on the estimated forward rate curve. These ETZ estimates therefore include the effect of risk premiums. All of the figures show very similar profiles and dynamics, but the ETZ magnitudes vary materially between different estimations.

Figures D.5 and D.6 provide ETZ estimates based on the expected path of the short rate under the physical $\mathbb{P}$ measure, which are therefore on the same basis as analyst surveys for lift-off. The ETZ results under the $\mathbb{P}$ measure are only available for the estimations that use surveyed interest rate expectations data, because excluding that results in very imprecise estimates of the expected path of the short rate under the physical $\mathbb{P}$ measure.

Figure D.5 shows that $\mathbb{P}$-measure ETZ estimates from K-ANSM(2) SLMs have similar profiles and dynamics, but a material variation in magnitudes. Figure D.6 shows that $\mathbb{P}$-measure ETZ estimates from K-ANSM(3) SLMs also have similar profiles, but with more variation than the K-ANSM(2) results, and a material variation in magnitudes.

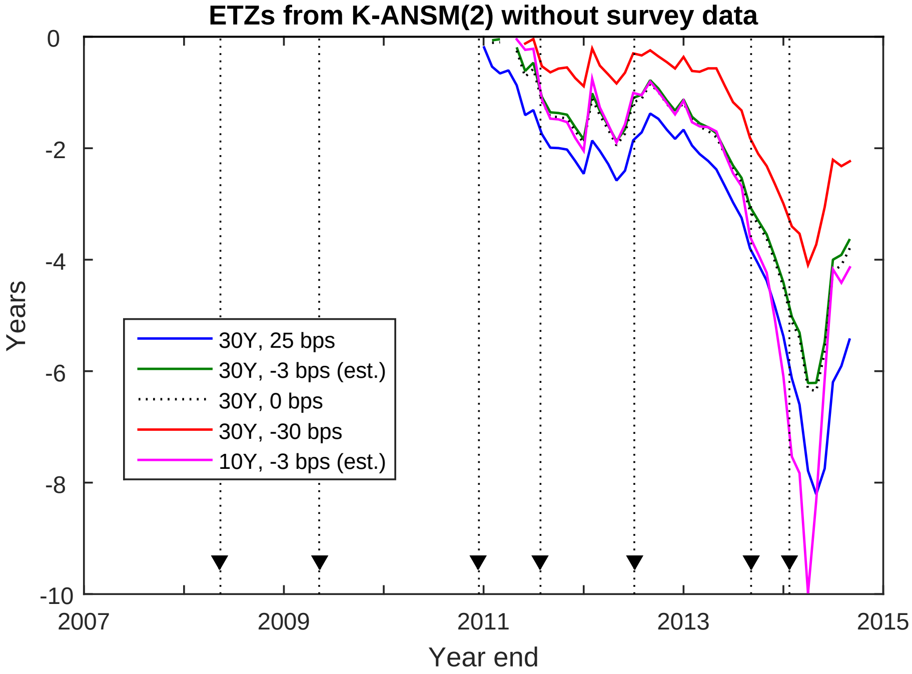

Figure D.1: K-ANSM(2) ETZ estimates without survey data for different lower bounds.

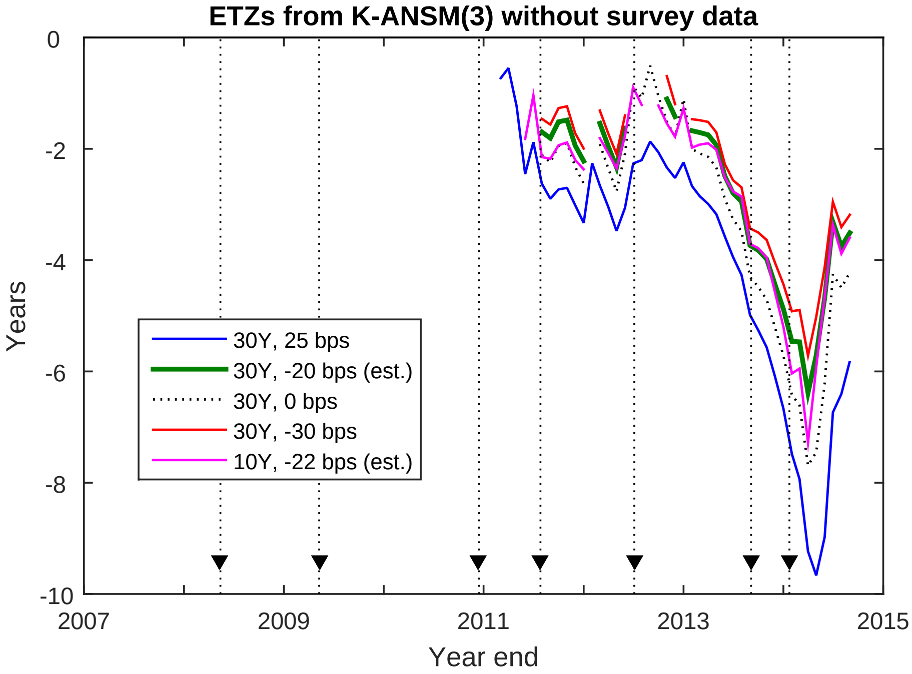

Figure D.2: K-ANSM(3) ETZ estimates without survey data for different lower bounds.

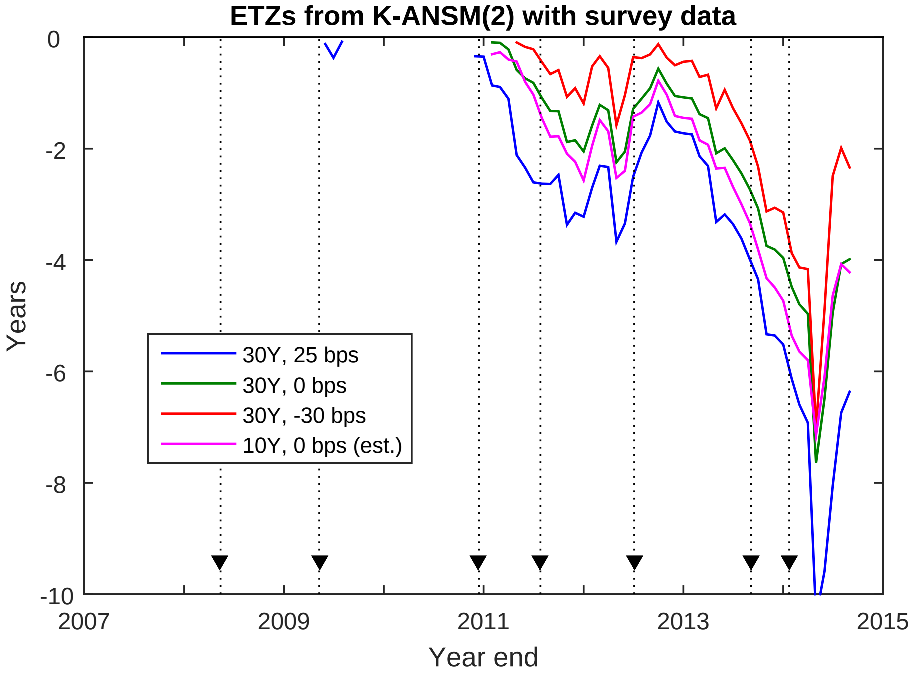

Figure D.3: K-ANSM(2) ETZ estimates with survey data for different lower bounds.

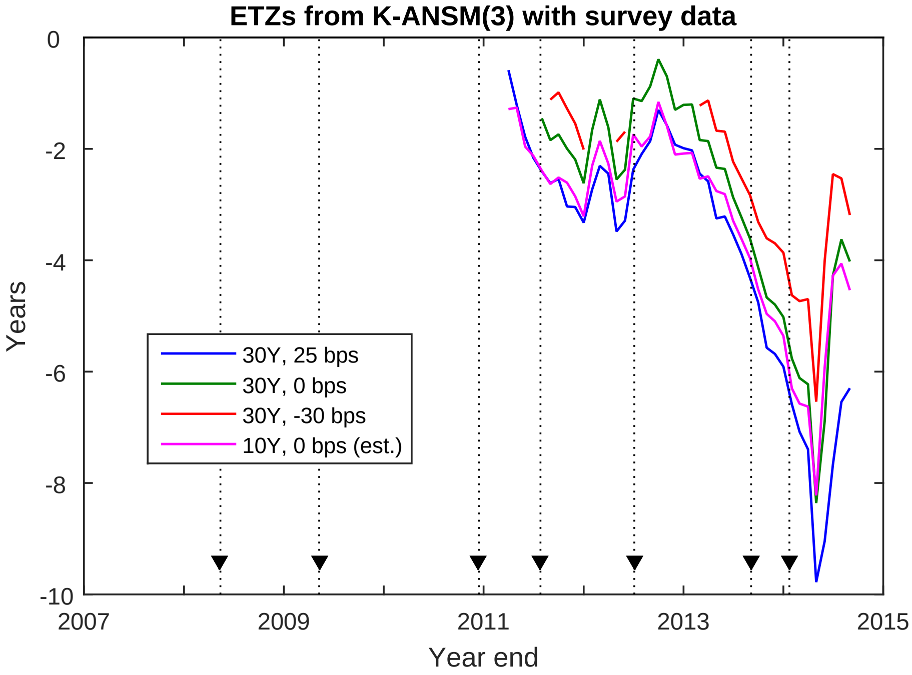

Figure D.4: K-ANSM(3) ETZ estimates with survey data for different lower bounds.

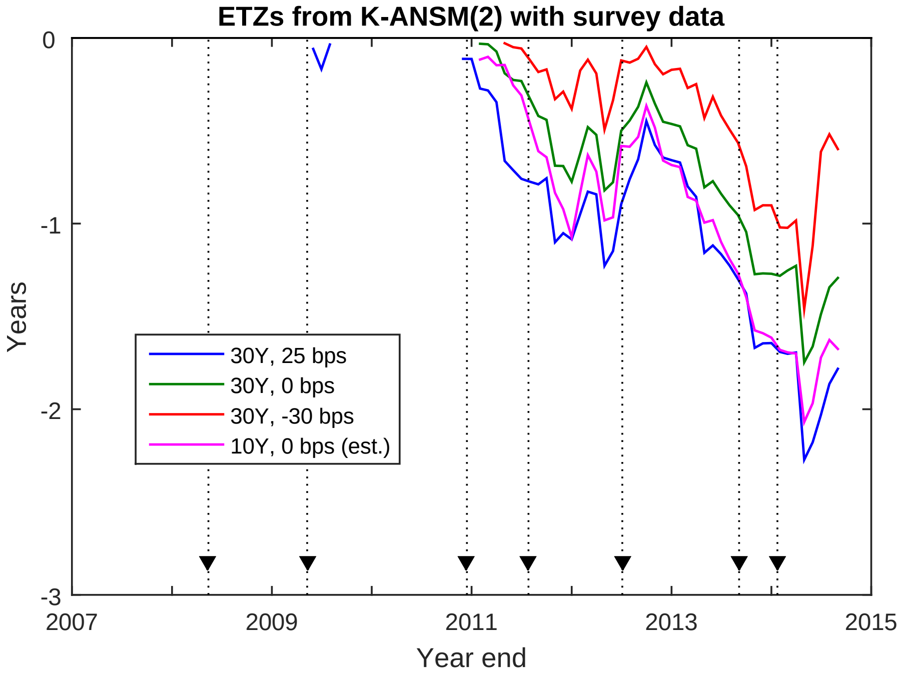

Figure D.5: K-ANSM(2) ETZ estimates under the physical measure for different lower bounds.

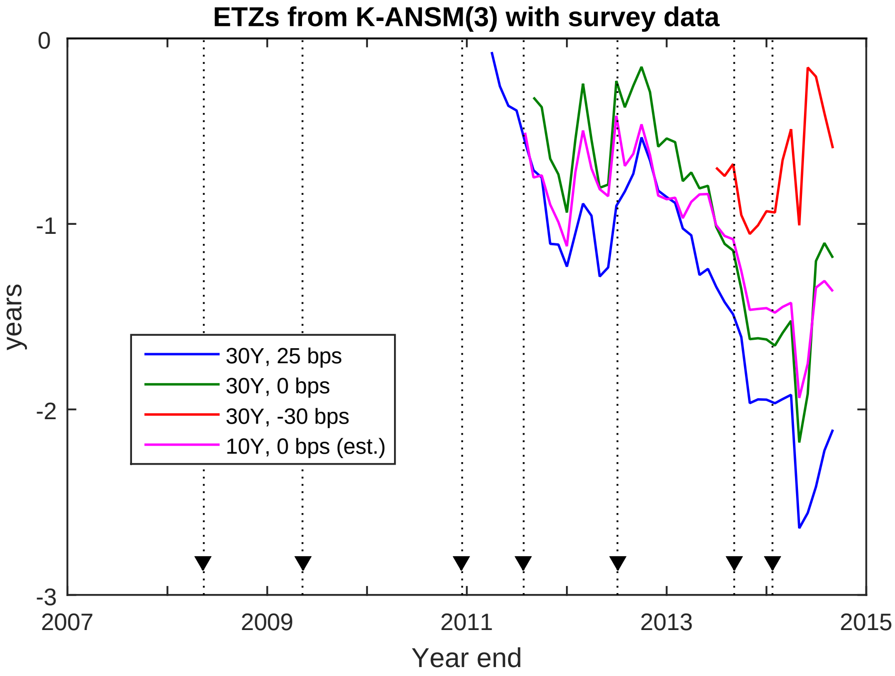

Figure D.6: K-ANSM(3) ETZ estimates under the physical measure for different lower bounds.

E Effective Monetary Stimulus results

In this appendix, we present further details and empirical results for the EMS. Section E.1 discusses the choice of horizon τ_{H}, and section E.2 provides the model-free EMS results for a range of different horizons. Section E.3 discusses the model-based EMS results obtained using the shadow/lower-bound model (SLM) specifications and the data outlined in section B.3.

E.1 Choice of horizon τ_{H}

The model-free EMS, $\mathrm{EMS}(t, \tau_{\mathrm{H}})$, and the model-based EMS along with its expected policy and risk premium components, i.e. $\mathrm{EMS}(x_t, \tau_{\mathrm{H}})$, $\mathrm{EMS}^{\mathrm{EP}}(x_t, \tau_{\mathrm{H}})$ and $\underline{\mathrm{R}}^{\mathrm{RP}}(x_t, \tau_{\mathrm{H}})$, can be mechanically calculated for any value of τ_{H}, and the calculations will differ between different τ_{H} values. That is, $\mathrm{LNIR}(t)$ is invariant to τ_{H}, so $\mathrm{EMS}(t, \tau_{\mathrm{H}})$ will depend on which observed interest rate $\underline{\mathrm{R}}(t, \tau_{\mathrm{H}})$ is used in equation 13. Similarly, $\mathrm{EMS}(x_t, \tau_{\mathrm{H}})$, $\mathrm{EMS}^{\mathrm{EP}}(x_t, \tau_{\mathrm{H}})$, and $\underline{\mathrm{R}}^{\mathrm{RP}}(x_t, \tau_{\mathrm{H}})$ will vary according to the model-estimated $\underline{\mathrm{R}}(x_t, \tau_{\mathrm{H}})$ and its components.

The concept of the EMS suggests using a value relevant to the planning horizon of economic agents. In section 4.2.2 from the main text, we mentioned our choice of the longest horizon possible from the standard yield curve data that is practically available, i.e. 30 years. This most closely corresponds to the infinite horizon for consumption utility optimization that underlies many standard macroeconomic models. As illustrated in figure A.1, the 30-year horizon is also well beyond the practical asymptotic value of the forward rate curve, so it fully captures the return to the time-varying equilibrium/steady-state values of the expected path of the short rate and the marginal risk premium. This is another reason why we prefer to use $\tau_{\mathrm{H}} = 30$ years.

However, we acknowledge that some may prefer a more practical planning horizon, such as one that covers the length of typical business cycles. That would suggest τ_{H} values of 7 or 10 years. That horizon is also on the fringe of the expected path of the short rate returning to it equilibrium/steady-state values. Others may prefer a horizon more closely linked to the planning horizon for monetary policy, which would suggest a τ_{H} value of 3 years. However, a value of 3 years is arguably too short from the perspective that the expected path of the short rate and marginal risk premiums would still be far from their time-varying equilibrium/steady-state values after that time has elapsed. In other words, one would have to justify why economic agents planned only on the basis of a three-year window of expectations and ignored expectations for longer horizons.

Empirical considerations also argue against choosing of a value of τ_{H} that is too short. In particular, if the interest rate for the time to maturity of τ_{H} becomes strongly constrained by the lower bound, then the associated EMS would only feature limited variation in such an environment. Therefore, further unconventional easing events from that point would not be reflected in the EMS, so it would no longer be suitable for representing the overall stimulus from monetary policy that the EMS is intended to capture. The 3-year interest rate became strongly constrained by the lower bound in the euro area from around 2012, which is reflected in the 3-year EMS in figure E.1 not showing much variation from that time. The empirical results for the 3-year EMS in table 1 also indicate that it is less plausible as a monetary policy metric in practice. Conversely, 7-, 10-, and 30-year interest rates were not strongly constrained by the lower bound, their associated EMS values continue to show variability similar to their own history and to each other, and our empirical results obtained with those EMS series are similar to each other and plausible as monetary policy metrics. That said, our choice of $\tau_H = 30$ years for our benchmark results is least subject to any empirical issues associated with a lower bound constraint on interest rates, which is another reason why we prefer to use it.

Given the discussion on the 3-year EMS above, from this point forward we will omit it from the further discussion. Our remaining comments on the range of EMS results should be taken as applying only to the 7-, 10-, and 30-year EMS results.

E.2 Model-free EMS

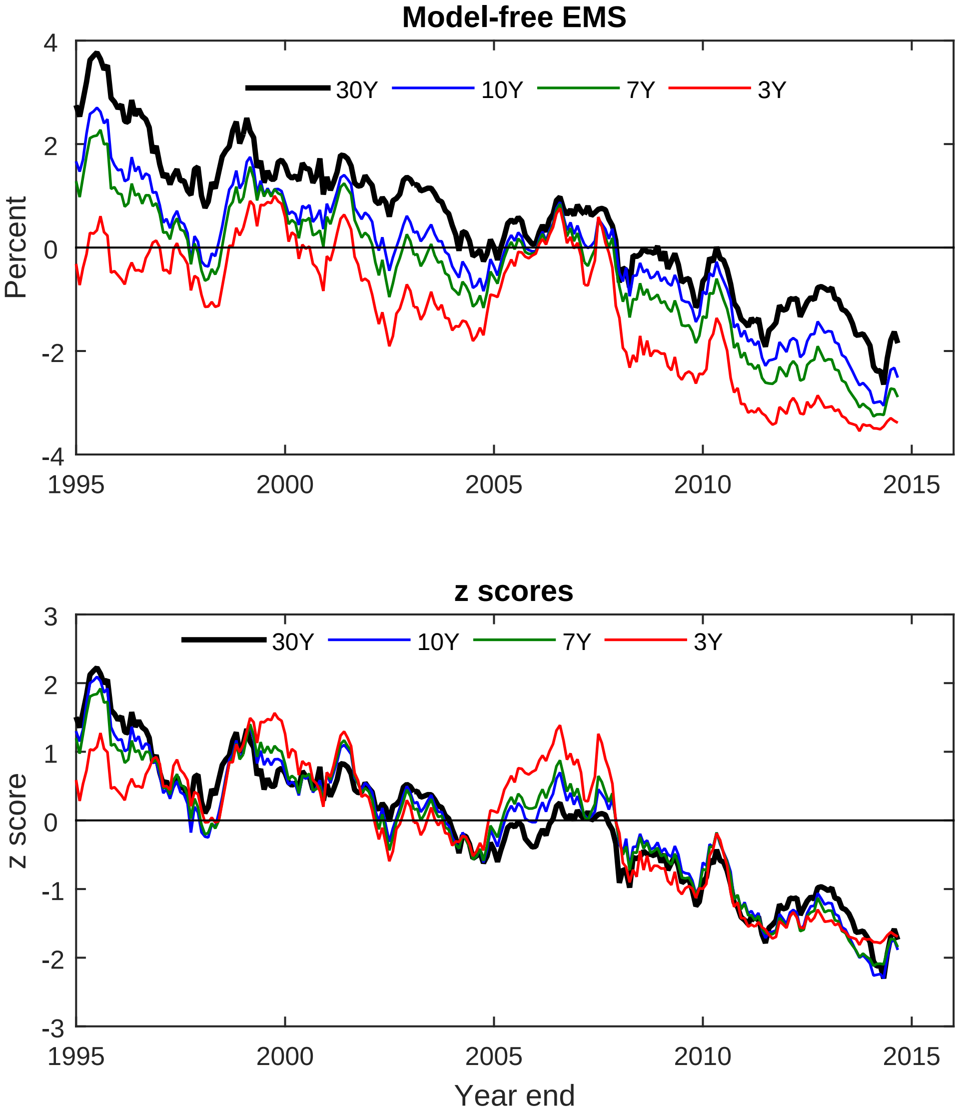

Figure E.1: Model-free EMS and z scores of model-free EMS with different horizons.

Panel 1 of figure E.1 plots the model-free EMS values over the full sample. The differences between the series reflects the different levels of the interest rates; the LNIR series is the same for each. Nevertheless, the EMS series move very similarly to each other over the entire period.

Panel 2 plots the z scores for the series in panel 1. The z scores show that the EMS results are all statistically similar to each other. Hence, using any of those EMS series in our macroeconomic application would obtain similar econometric results, which is what we find empirically.

E.3 Model-based EMS results

The choice of τ_{H} and the addition of the model-based EMS components adds two further dimensions to the modeling and data choices outlined in section B.3. To keep the number of figures in this remaining section manageable, we therefore provide a representative set of figures to illustrate the main points about the range of EMS results from the SLMs we estimated, but we can provide any other results on request.

Figure E.2 illustrates the most important point regarding model-based EMS estimates. That is, they are always very close to the model-free EMS values, which is because the models provide a close fit to the yield curve data. The fit is closer, as expected, when three-factor models are used (and would obviously get closer as further factors were added). However, it is worth noting that even two-factor models provide a close-enough representation of the yield curve data for the purposes of calculating model-based EMS series.

Panel 1 of figure E.3 shows that, for a given model specification and set of data, the model-based EMS results are essentially identical when alternative specifications for the lower bound are used. When viewed in conjunction with the results in figure E.2 (which use an evolving lower bound), panel 1 of figure E.3 therefore indicates that model-based EMS estimates are very robust to different model specifications (i.e. the number of factors and the lower bound setting), and the data (i.e. whether using yield curve data out to 10 or 30 years). Furthermore, when viewed in conjunction with the results from panel 2 of figure E.1, panel 1 of figure E.3 indicates that the z scores of the 30-, 10-, and 7-year model-based EMS estimates will be very similar to each other (even though the unscaled EMS estimates would differ materially, as in panel 1 of figure E.1).

In summary, model-based EMS estimates are essentially invariant to the choice of model, data, and the horizon τ_{H}. Therefore, any given model-based EMS series used in our macroeconomic application would obtain econometric results similar to those obtained with our benchmark model-based EMS estimates. Similarly, using the model-free EMS or any model-based EMS would obtain similar results.

Regarding the expected policy and risk premiums component estimates of the model-based EMS (i.e. EMS-EP and EMS-RP), panels 2 and 3 of figure E.3 respectively show that the lower bound setting only has a minor impact on their outright levels. Figure E.4 shows that most of that variation disappears when standardized as a z score, although some remaining variation is notable in the EMS-EP near the end of the sample.

Figure E.5 shows that there is some variation in the outright levels of the EMS-EP and EMS-RP estimates with respect to the number of factors in the SLM and the data used for the estimation. However, figure E.6 shows that the variation largely disappears when standardized as a z scores, but less so for the EMS-EP than the EMS-RP.

Figure E.7 illustrates that, as the horizon τ_{H} becomes larger, the outright levels of the EMS-EP become smaller while the outright levels of the EMS-RP remain similar in magnitude. The EMS-EP results reflect that the EMS-EP converges to zero as τ_{H} becomes larger, because the expected path of the short rate converges to the LNIR. The EMS-RP results reflect that the EMS-RP converges to the estimated long-horizon risk premium in the model, rather than to zero. Nevertheless, figure E.8 shows that the variation by horizon τ_{H} for both the EMS-EP and EMS-RP largely disappears when the results are standardized as a z scores. As discussed in section A.4, imposing an appropriate external proxy for a natural/steady state level risk premium in the model, like the LNIR for the EMS-EP, may allow the outright levels of the EMS-EP and the EMS-RP relative to the steady-state level to remain similar in magnitude for the longer horizons.

In summary, for the different SLMs we have estimated, the statistical properties of the estimated EMS-EP and EMS-RP components are very similar to each other. Therefore, any given set of EMS components used in our macroeconomic application would obtain econometric results similar to those obtained with our benchmark EMS components.

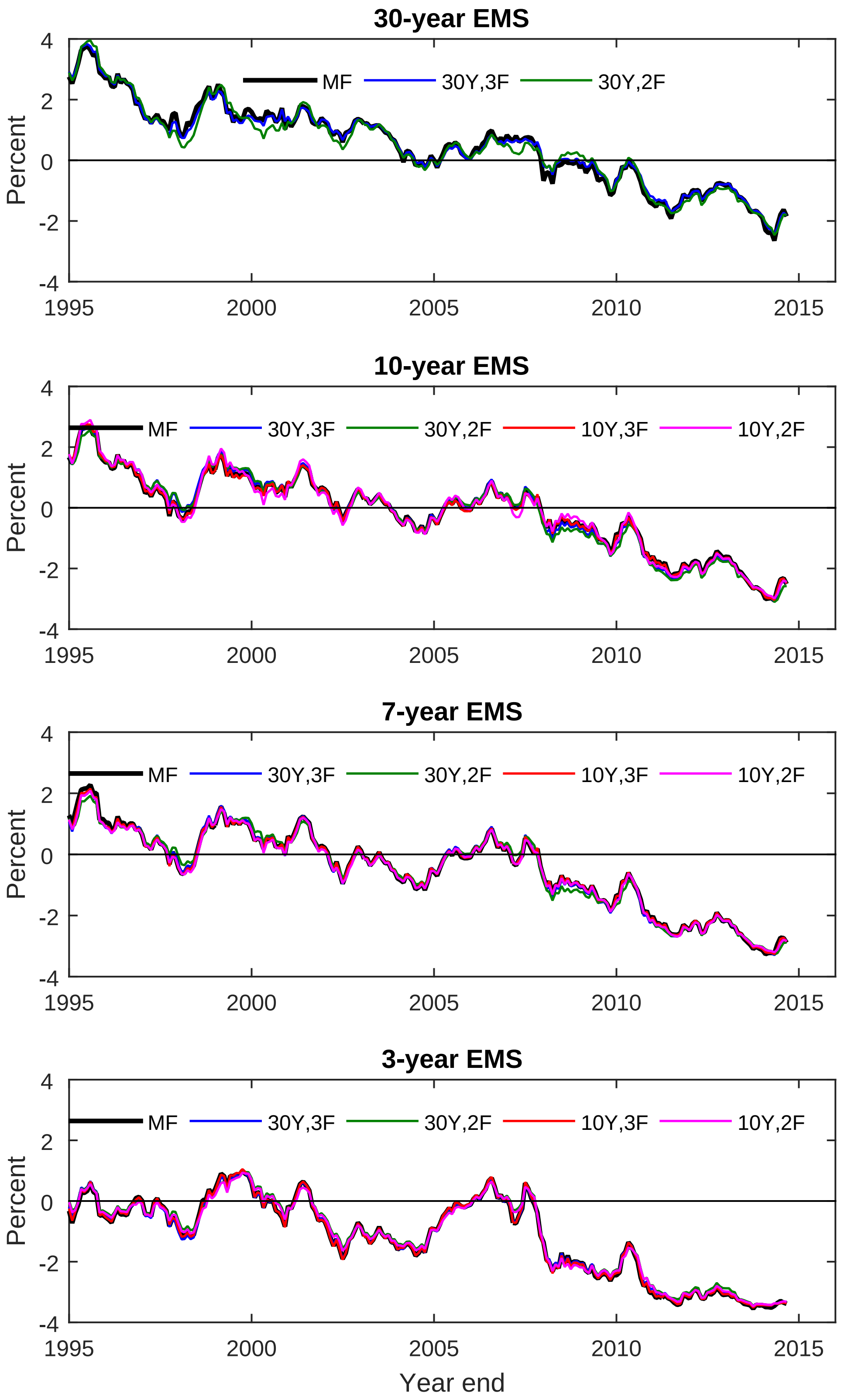

Figure E.2: Model-based EMS estimates for different horizons.

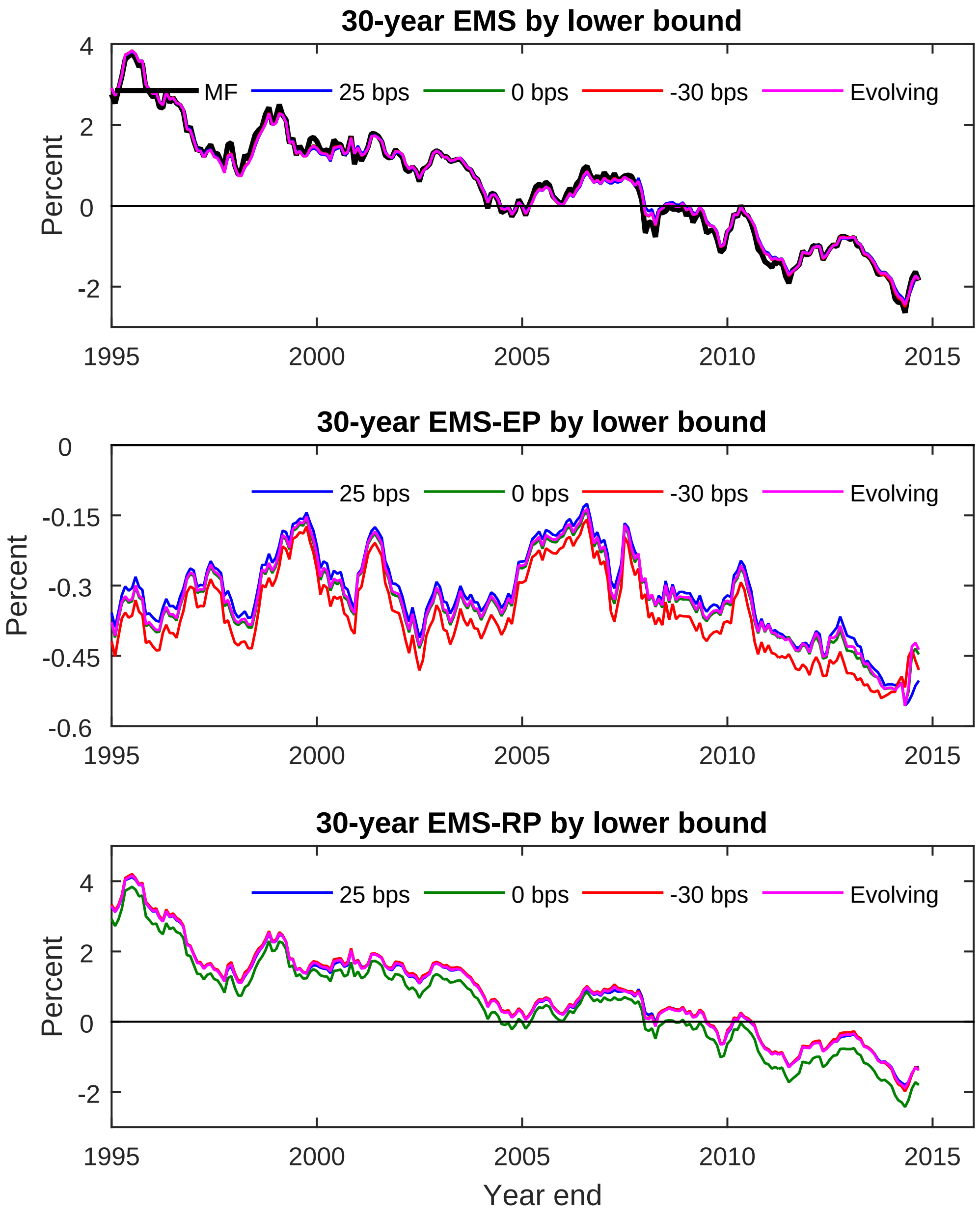

Figure E.3: Model-based 30-year EMS and component estimates with different lower bounds.

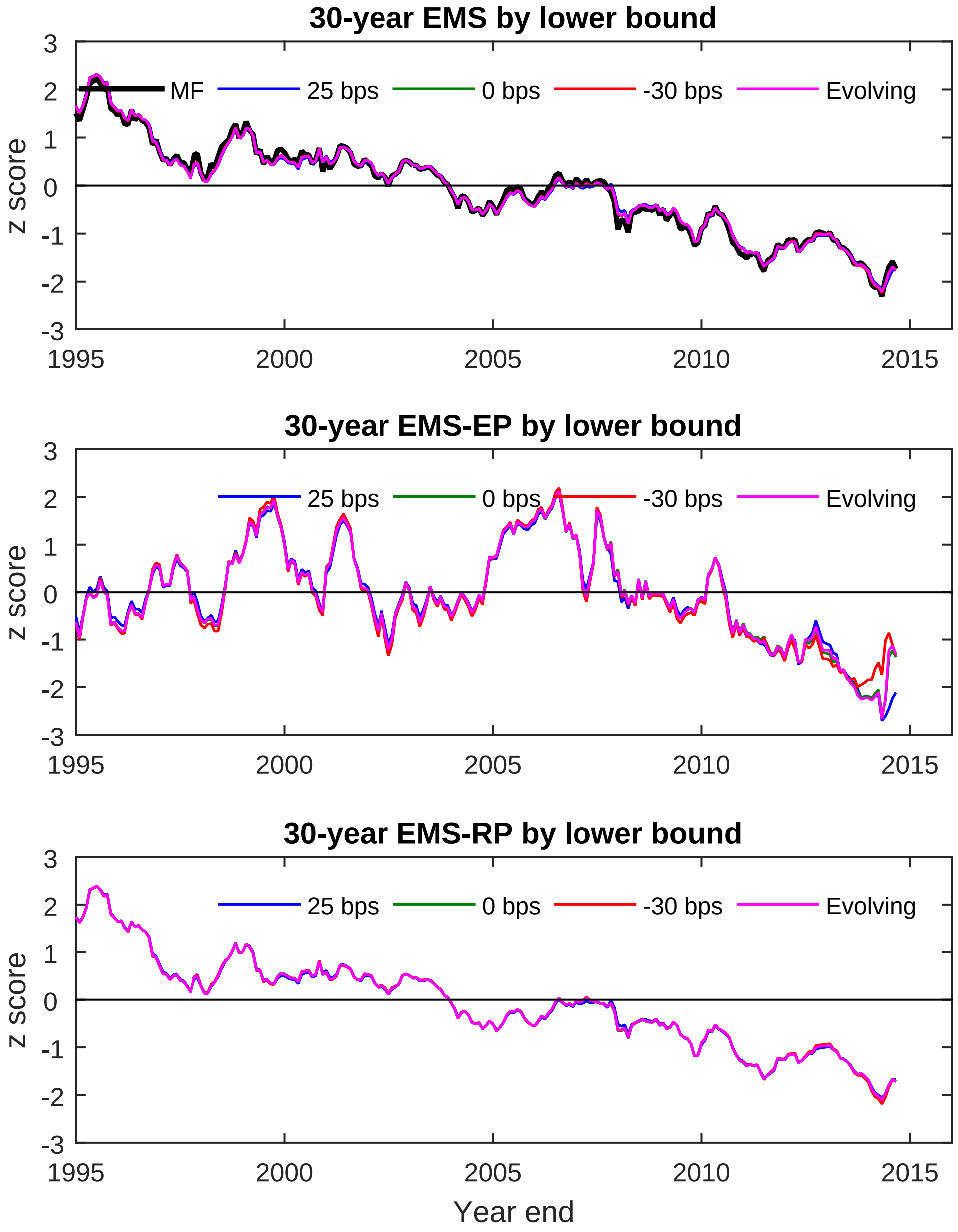

Figure E.4: z scores of model-based 30-year EMS and component estimates with different lower bounds.

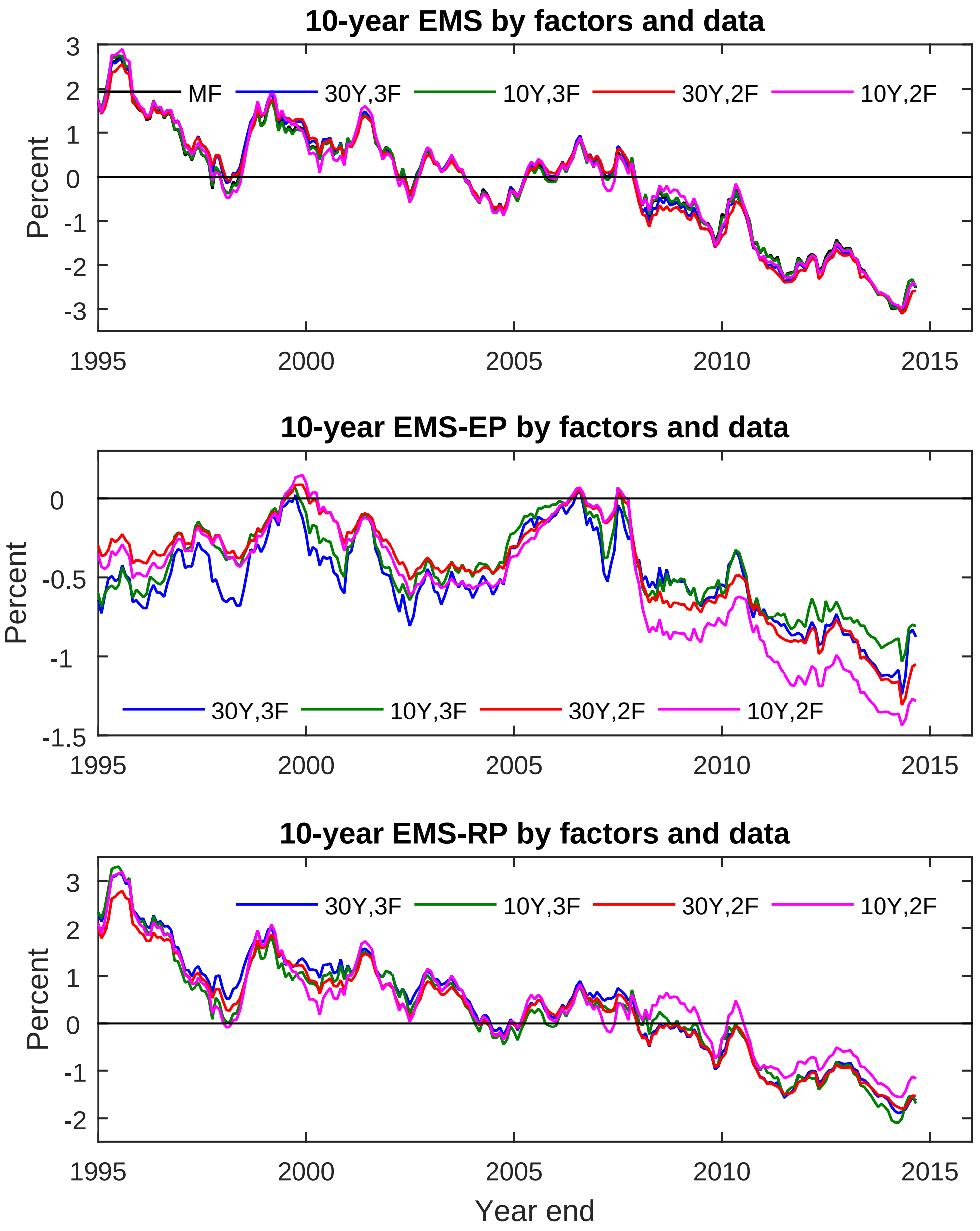

Figure E.5: Model-based 10-year EMS and component estimates using different model specifications and data.

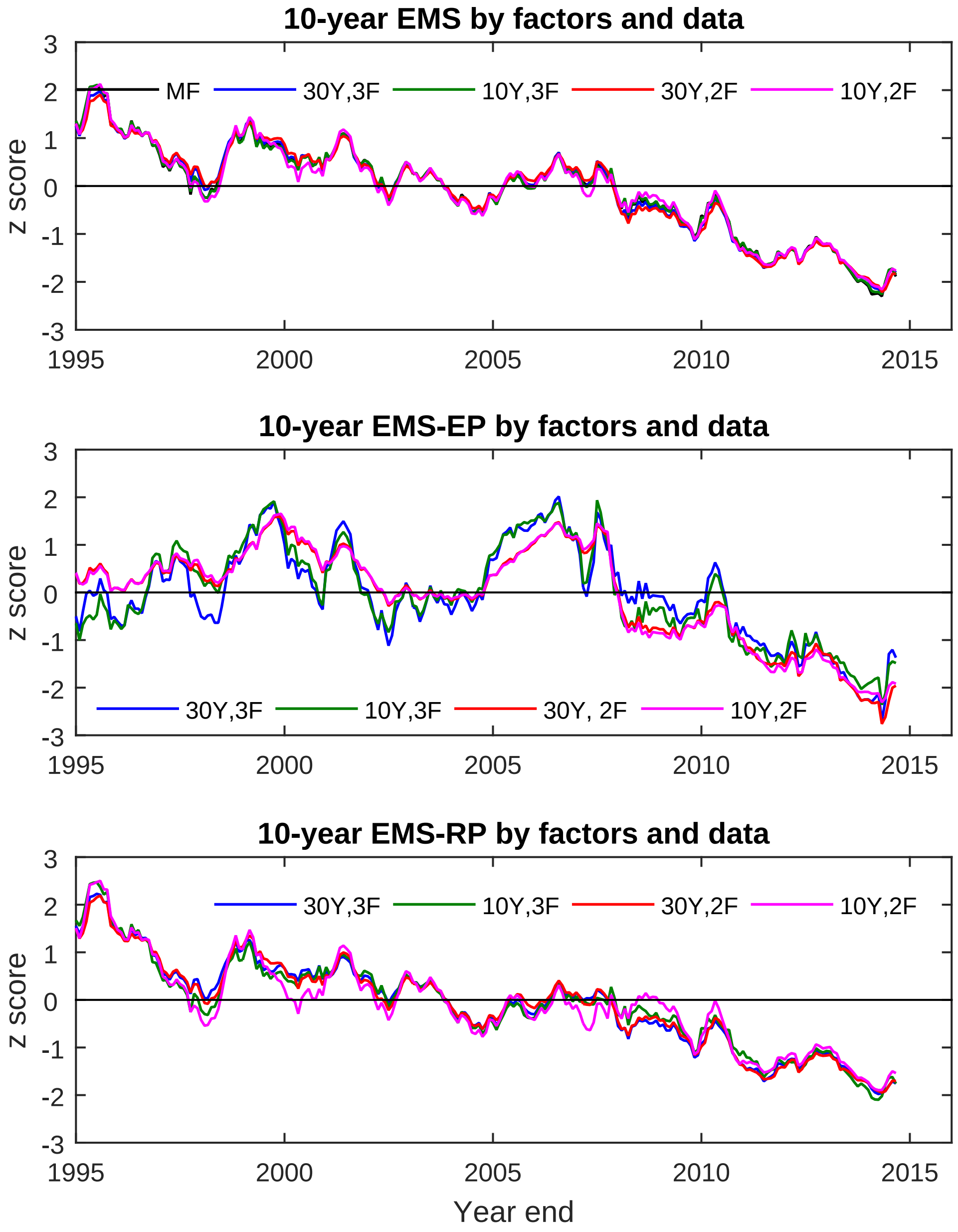

Figure E.6: z scores of model-based 10-year EMS and component estimates using different model specifications and data.

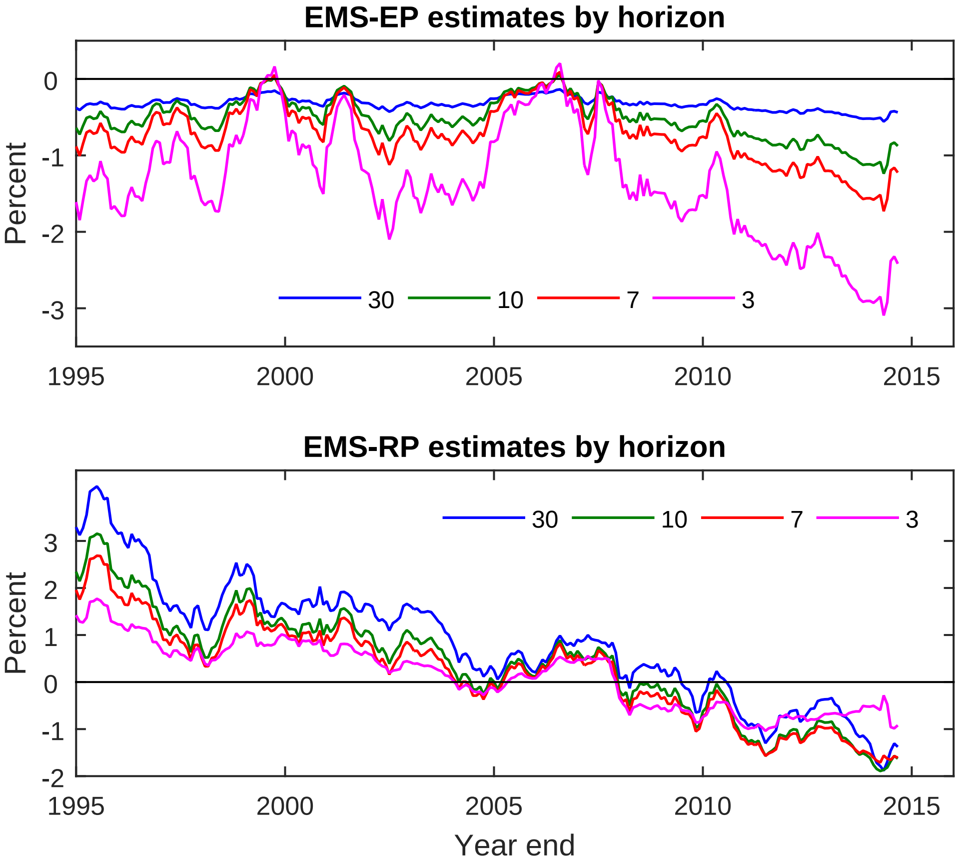

Figure E.7: EMS components by horizon.

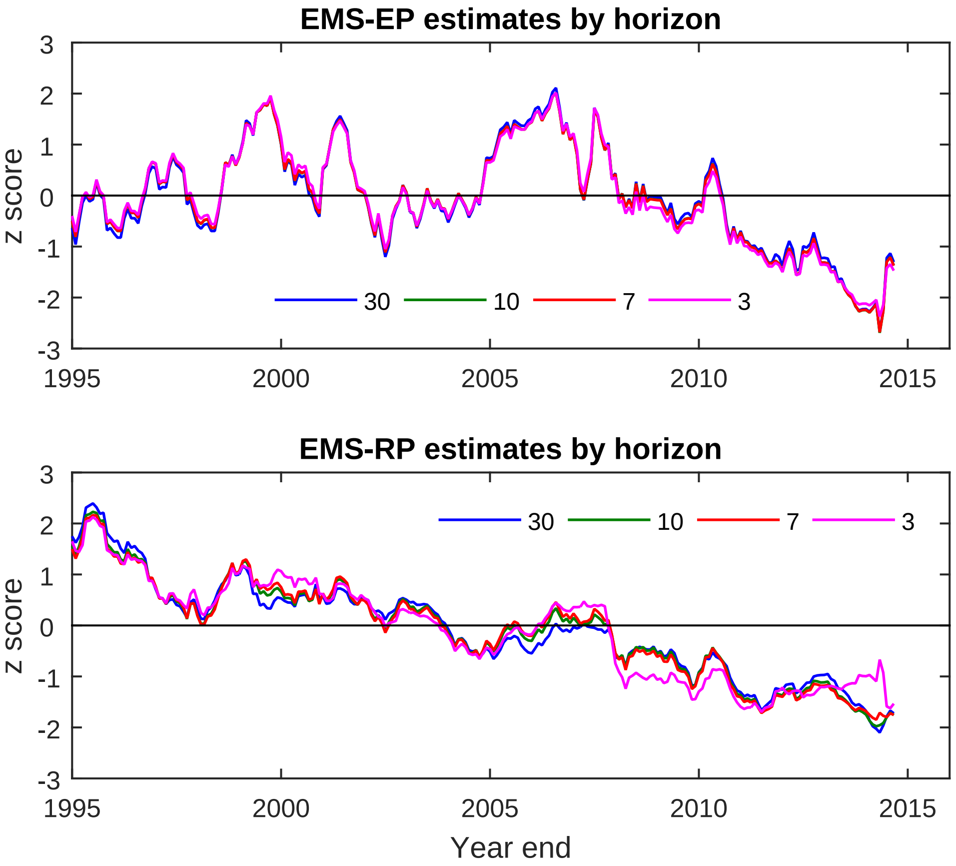

Figure E.8: z scores of EMS components by horizon.

F Impulse response from alternative models

This appendix provides the impulse response figures for the alternative models discussed in section 8. The letters after the figure numbers correspond to the columns in the summary table provided in section 8.

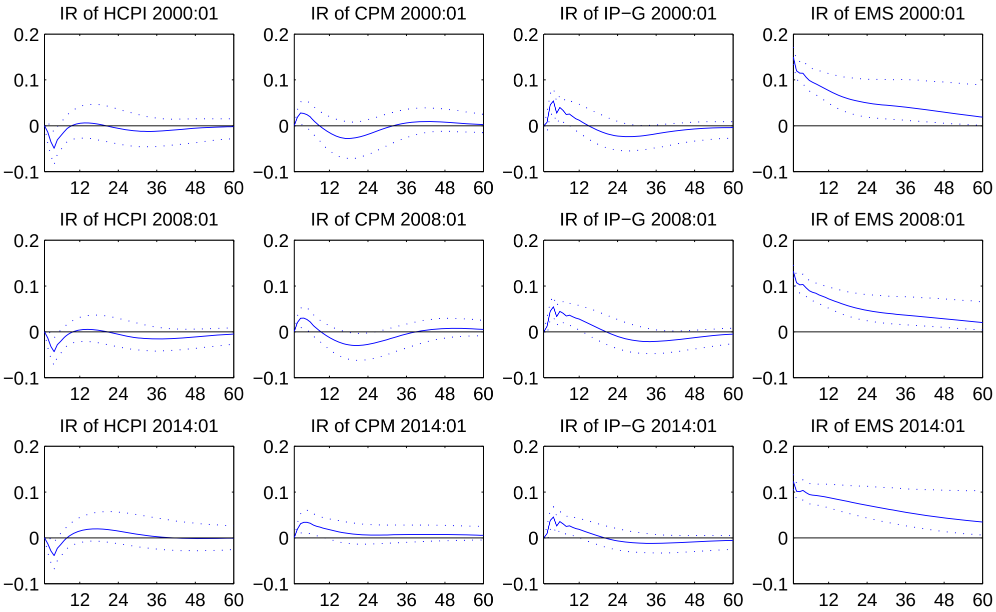

Figure F.1: (e) Impulse responses to an EMS(30) shock. Instead of PPI, HCPI is used as inflation measure. Dashed lines indicate 16% and 84% confidence intervals.

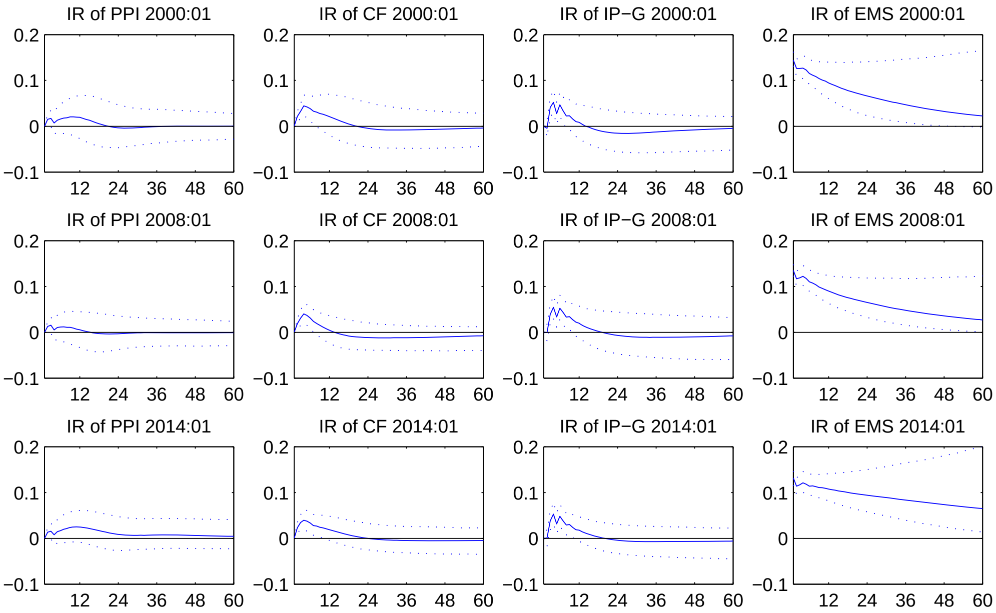

Figure F.2: (f) Impulse responses to an EMS(30) shock. Instead of CPM, inflation expectations from surveys are used as a measure for anticipated inflation. Dashed lines indicate 16% and 84% confidence intervals.

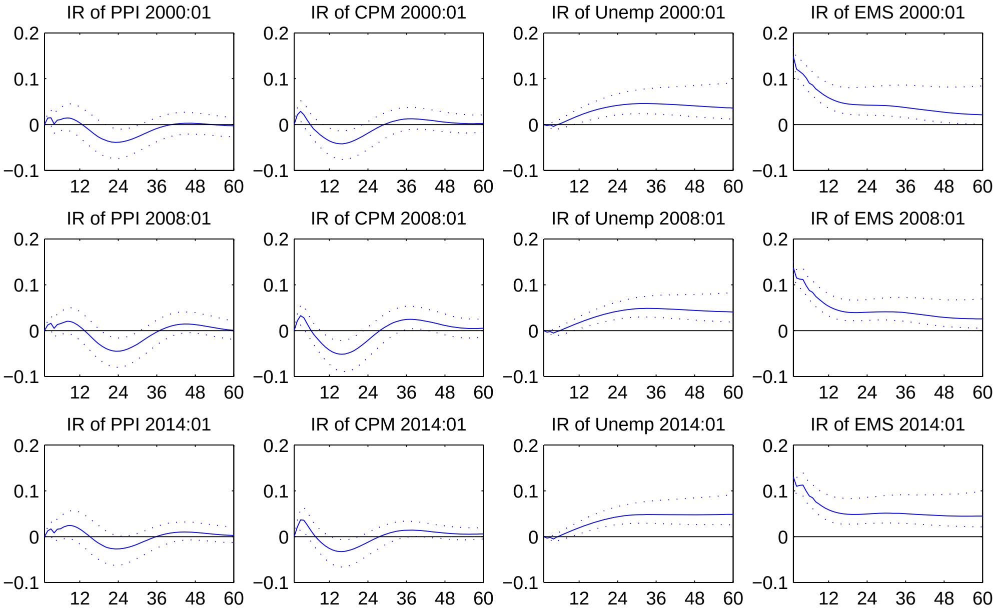

Figure F.3: (g) Impulse responses to an EMS(30) shock. Instead of the industrial production gap, the unemployment rate is used as an output measure. Dashed lines indicate 16% and 84% confidence intervals.

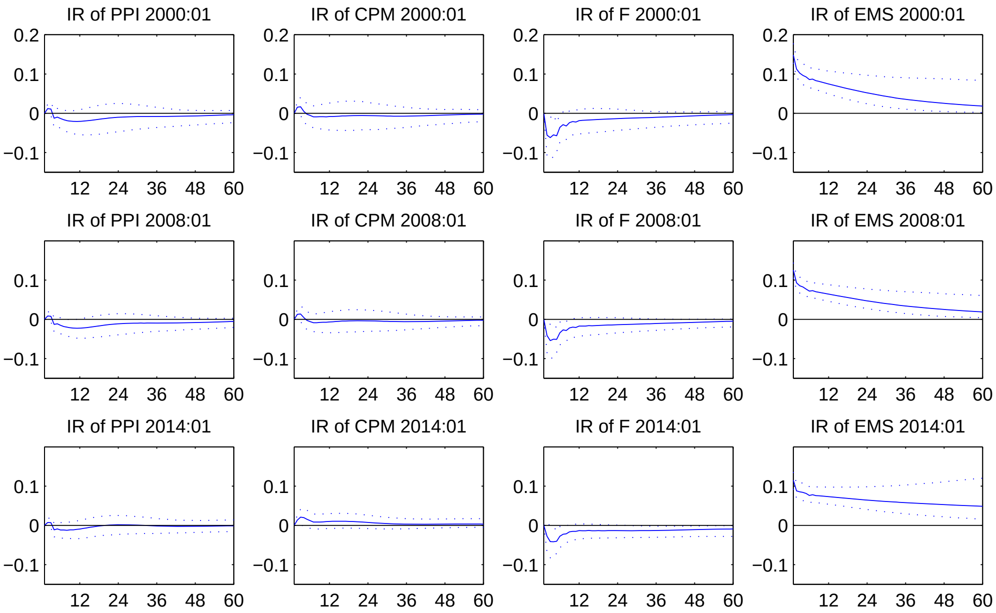

Figure F.4: (h) Impulse responses to an EMS(30) shock. Instead of the industrial production gap, a macroeconomic factor is used as an output measure. Dashed lines indicate 16% and 84% confidence intervals.

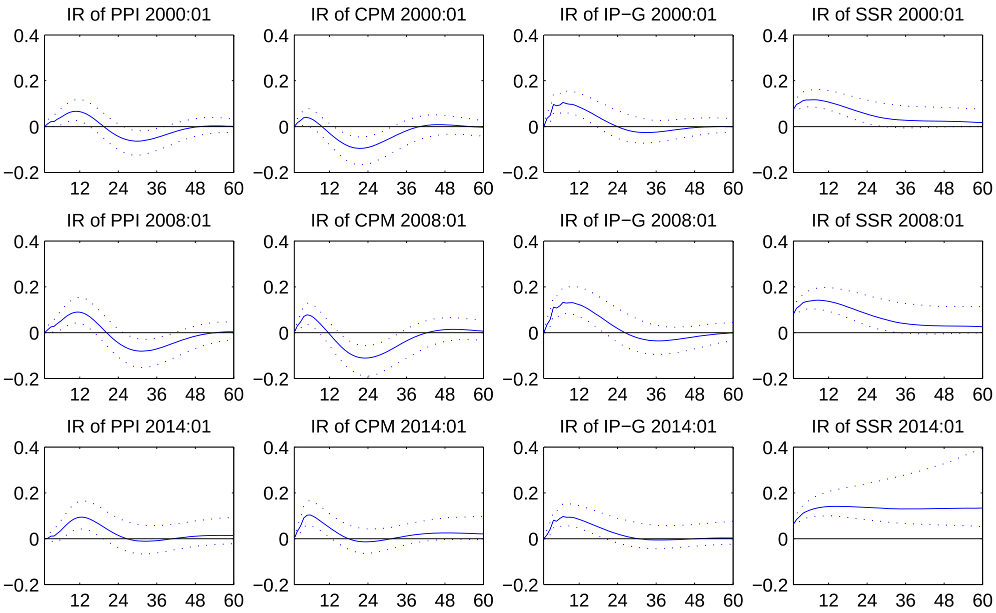

Figure F.5: (i) Impulse responses to a SSR shock. Dashed lines indicate 16% and 84% confidence intervals.

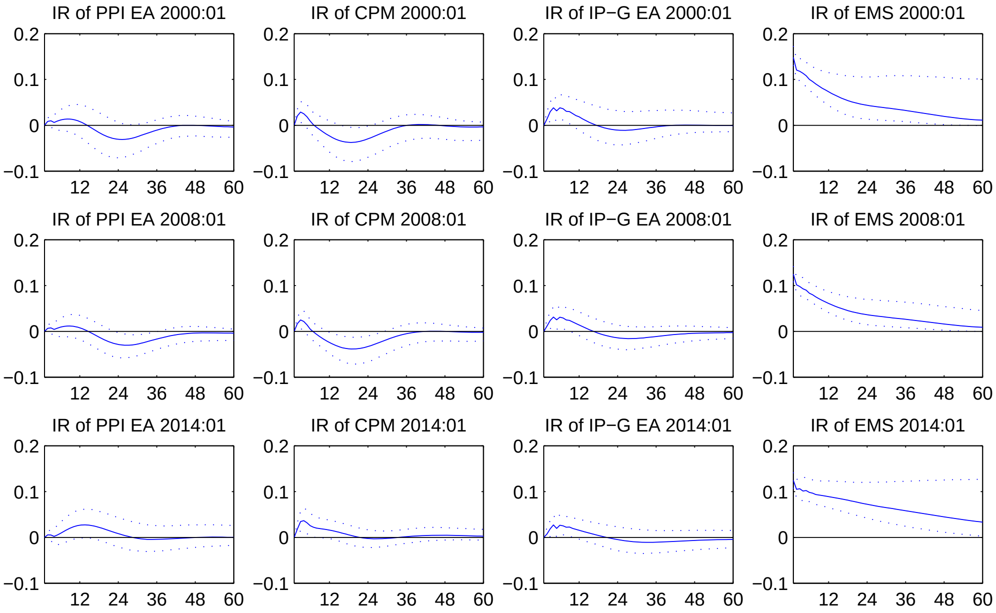

Figure F.6: (j) Impulse responses to an EMS(30) shock for an implementation with euro area data. Dashed lines indicate 16% and 84% confidence intervals.

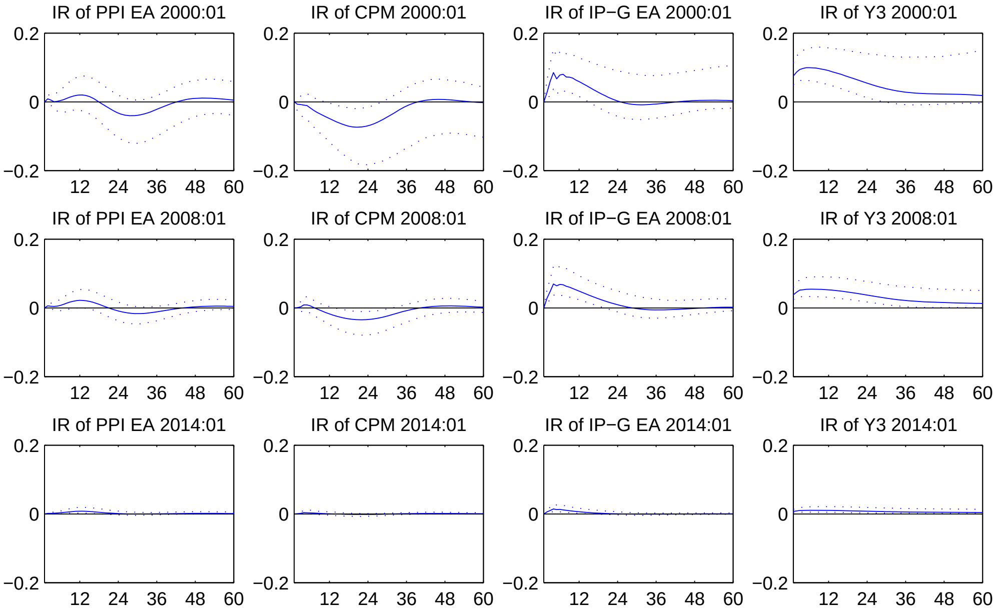

Figure F.7: (k) Impulse responses to a short rate shock for an implementation with euro area data. Dashed lines indicate 16% and 84% confidence intervals.

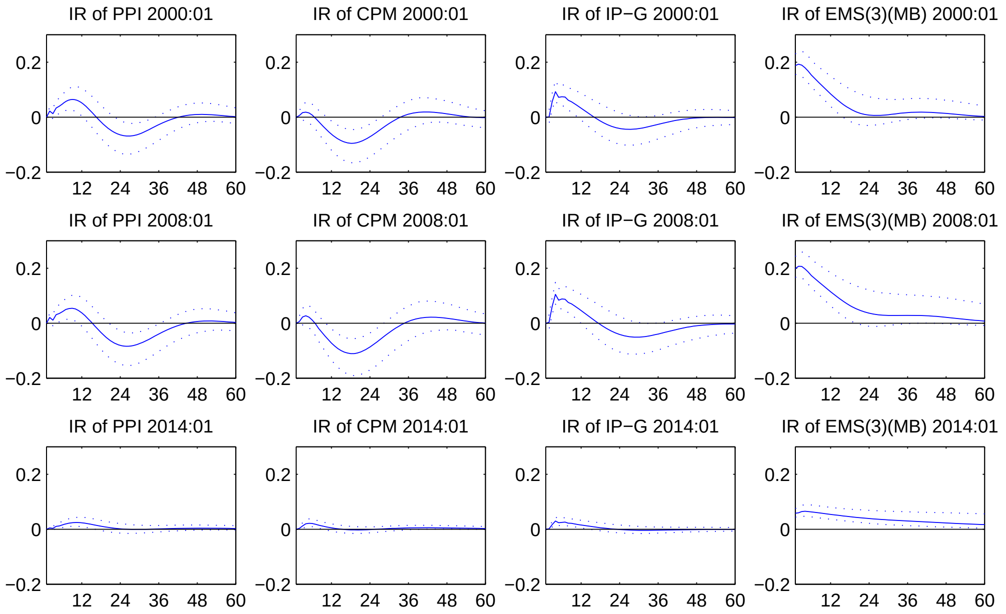

Figure F.8: (l) Impulse responses to an EMS(3)(MB) shock. Dashed lines indicate 16% and 84% confidence intervals.

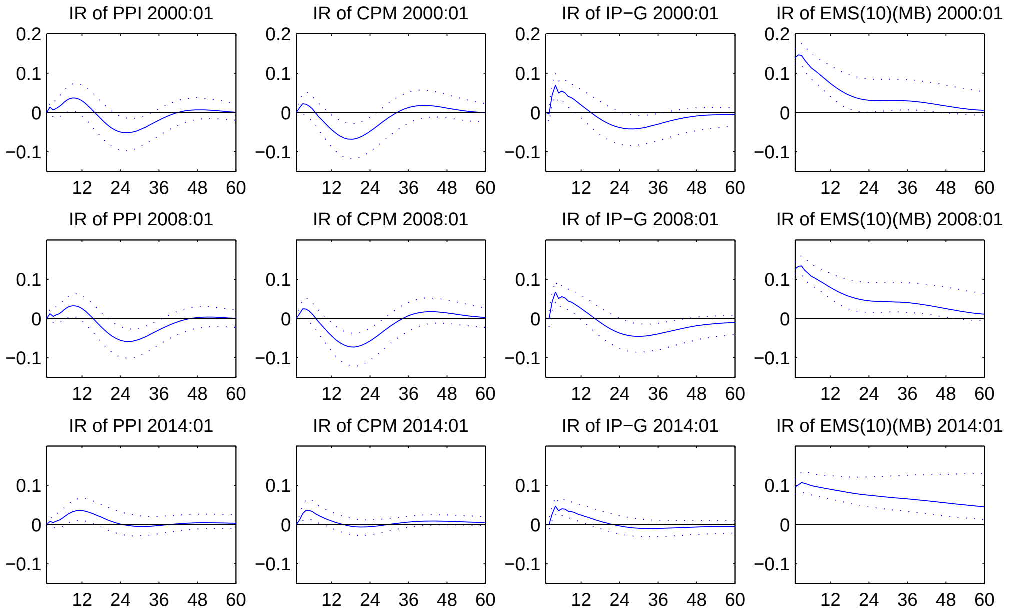

Figure F.9: (m) Impulse responses to an EMS(10)(MB) shock. Dashed lines indicate 16% and 84% confidence intervals.

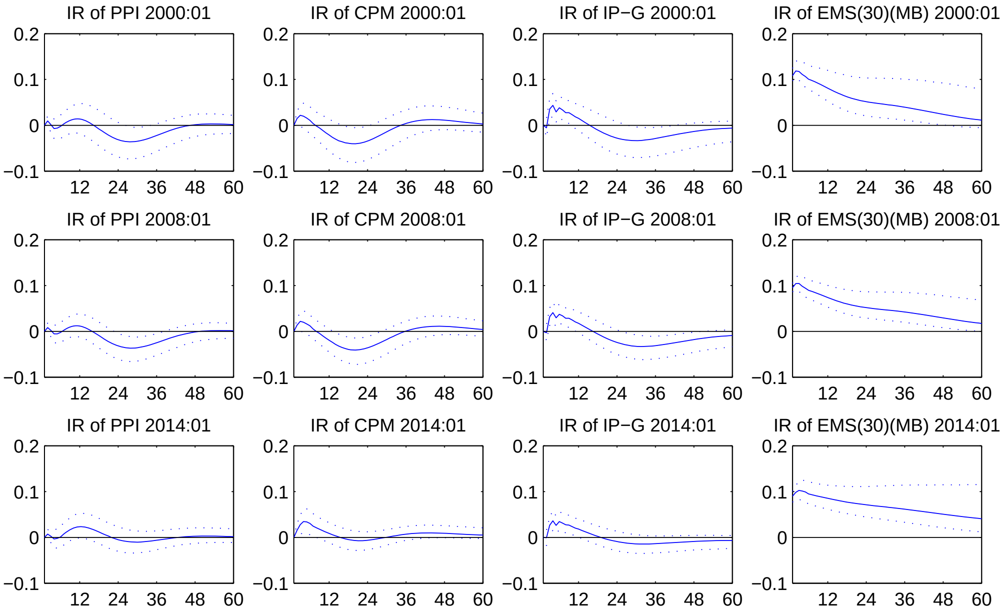

Figure F.10: (n) Impulse responses to an EMS(30)(MB) shock. Dashed lines indicate 16% and 84% confidence intervals.

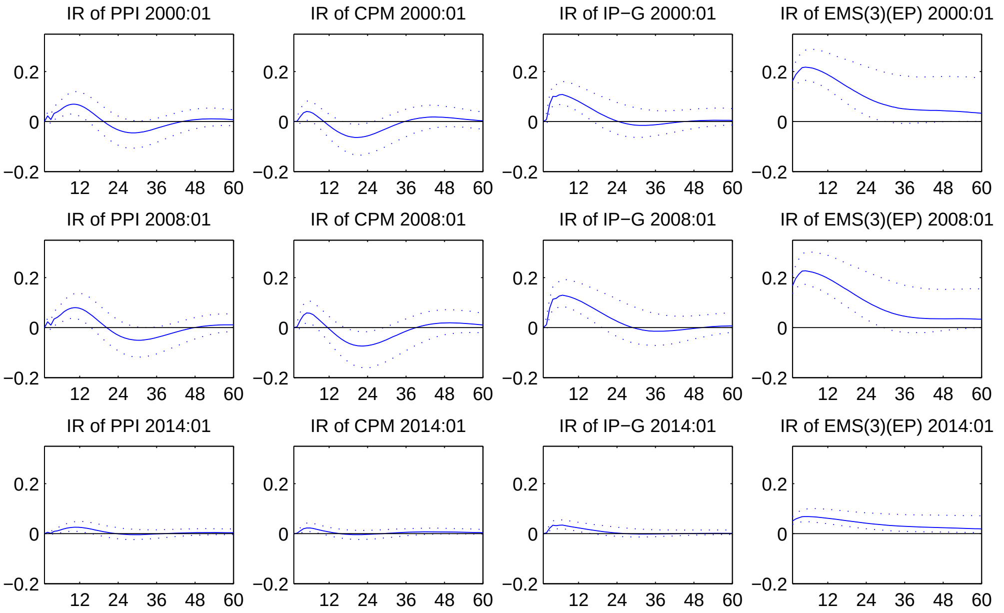

Figure F.11: (o) Impulse responses to an EMS(3)(EP) shock. Dashed lines indicate 16% and 84% confidence intervals.

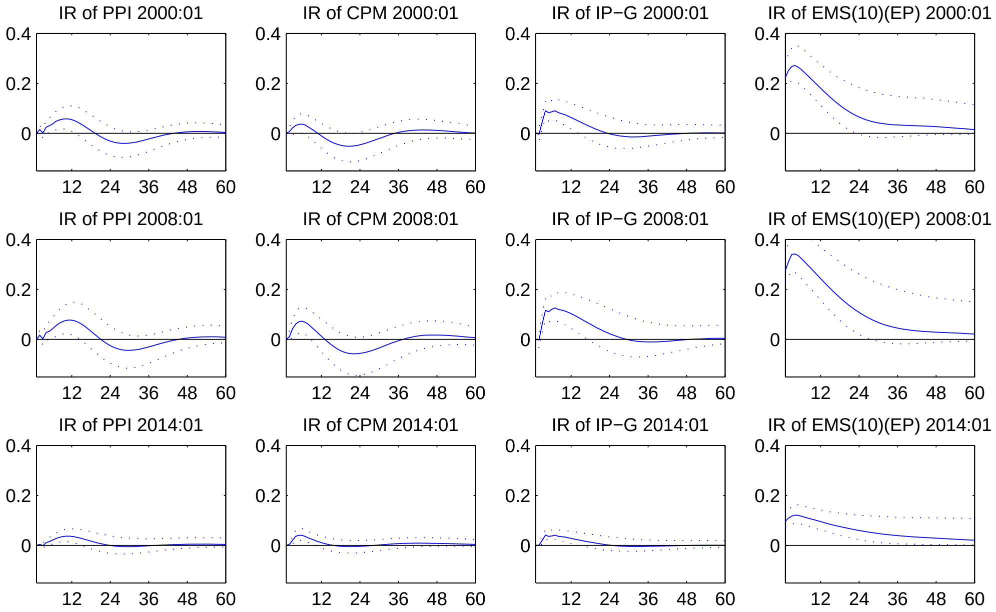

Figure F.12: (p) Impulse responses to an EMS(10)(EP) shock. Dashed lines indicate 16% and 84% confidence intervals.

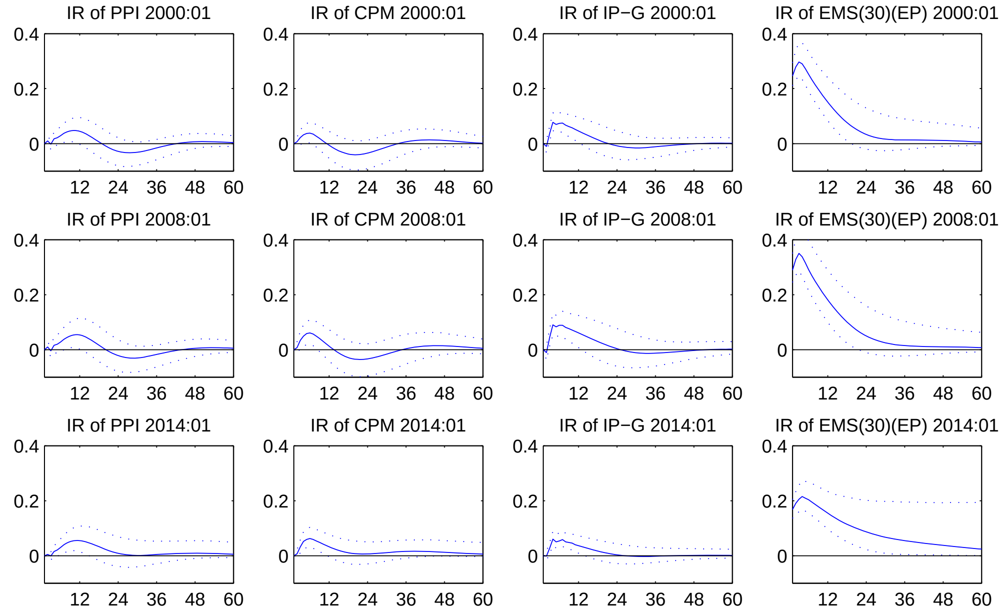

Figure F.13: (q) Impulse responses to an EMS(30)(EP) shock. Dashed lines indicate 16% and 84% confidence intervals.

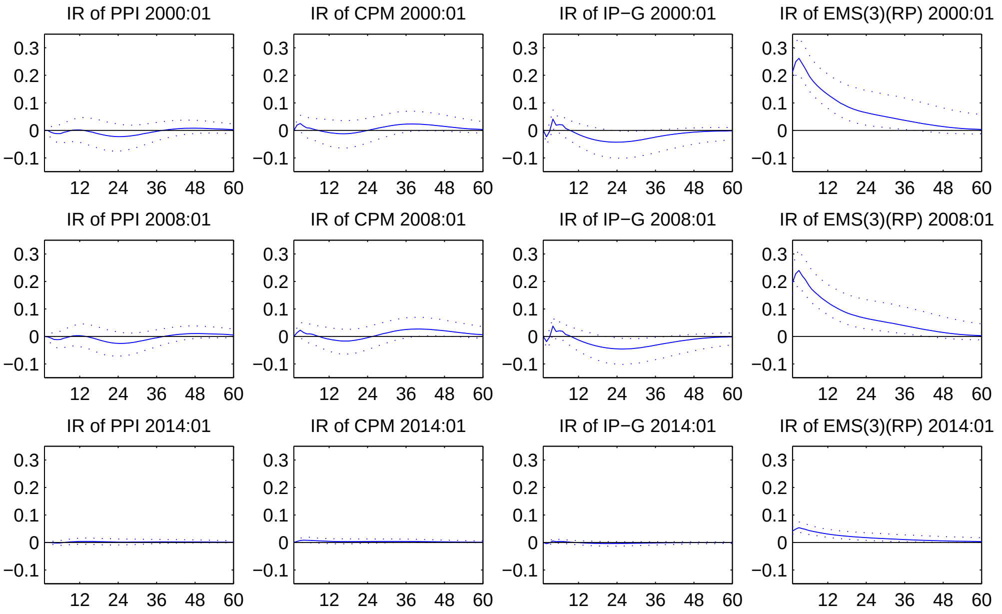

Figure F.14: (r) Impulse responses to an EMS(3)(RP) shock. Dashed lines indicate 16% and 84% confidence intervals.

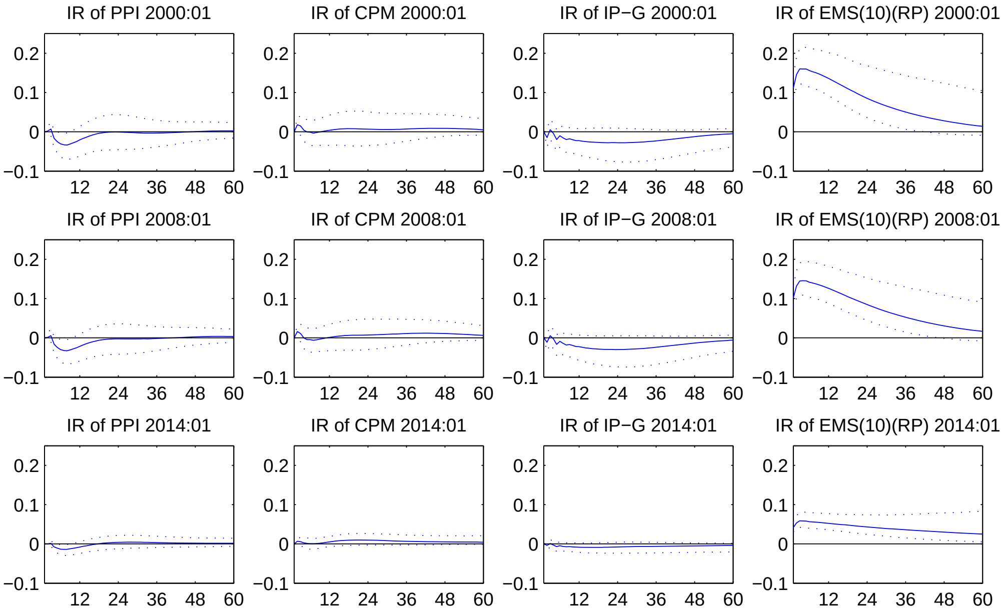

Figure F.15: (s) Impulse responses to an EMS(10)(RP) shock. Dashed lines indicate 16% and 84% confidence intervals.

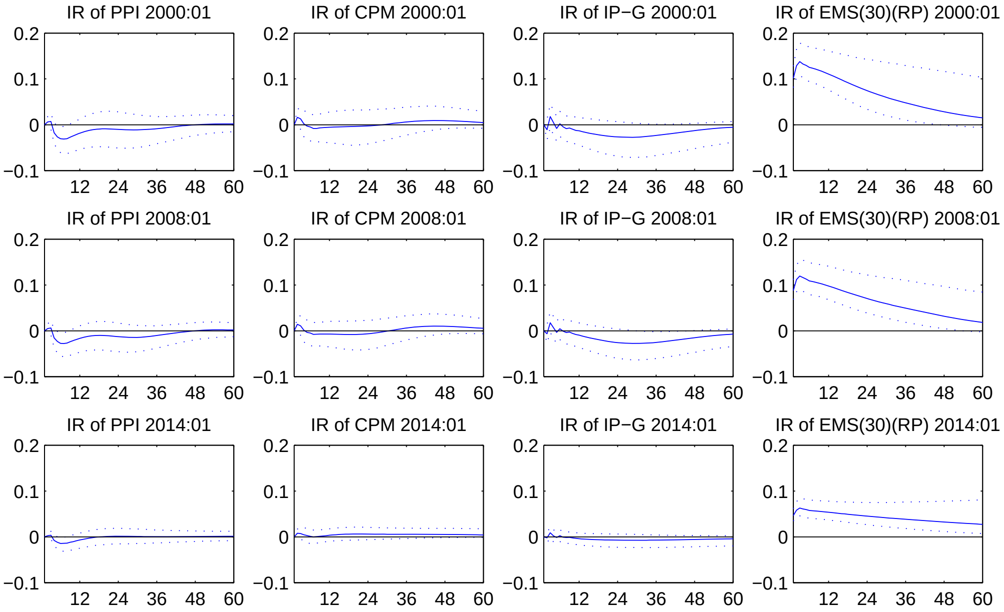

Figure F.16: (t) Impulse responses to an EMS(30)(RP) shock. Dashed lines indicate 16% and 84% confidence intervals.

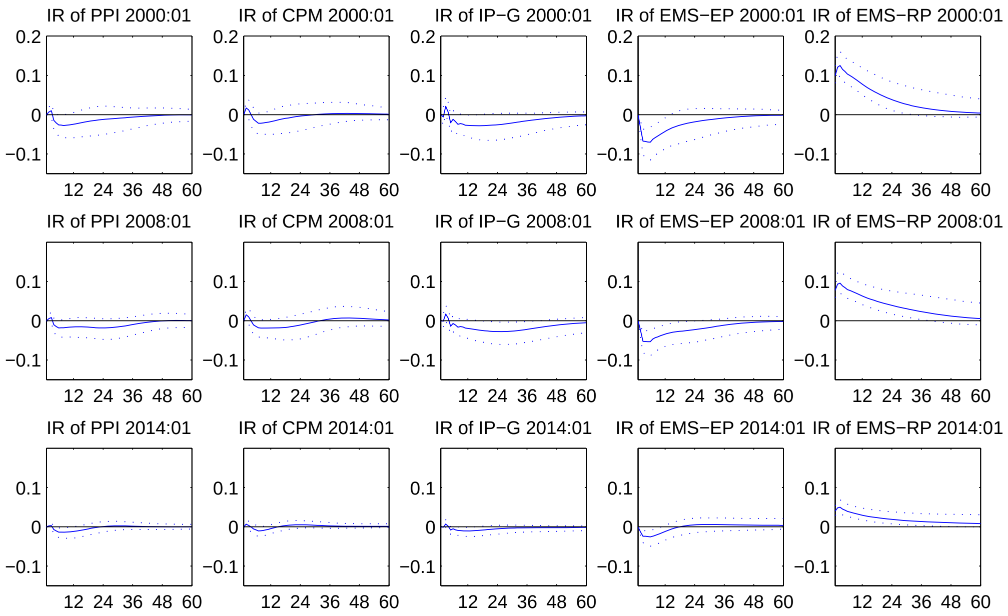

Figure F.17: (u) Impulse responses to an EMS(30)-RP shock. Dashed lines indicate 16% and 84% confidence intervals.

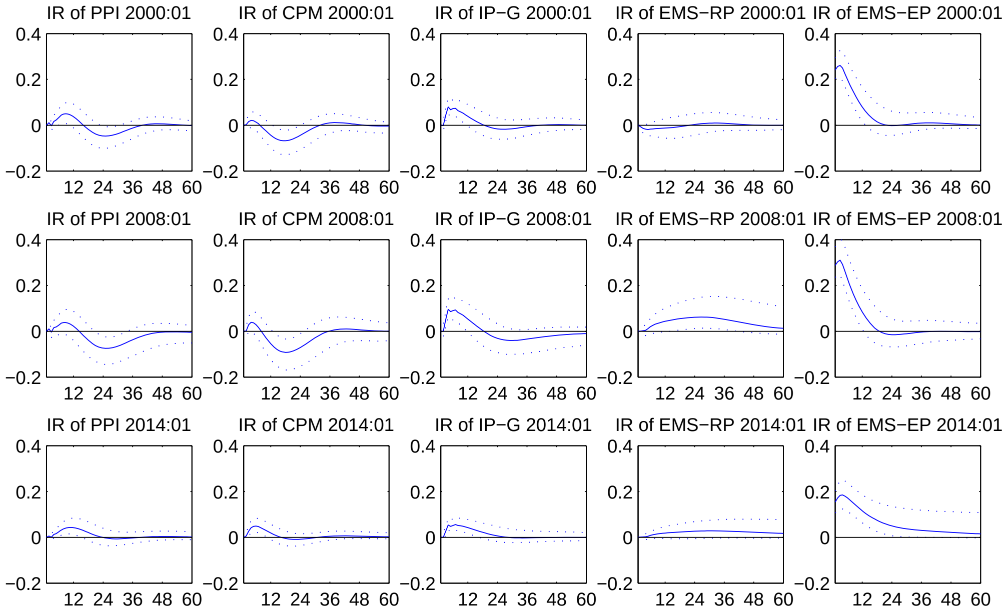

Figure F.18: (v) Impulse responses to an EMS(30)-EP shock. Dashed lines indicate 16% and 84% confidence intervals.

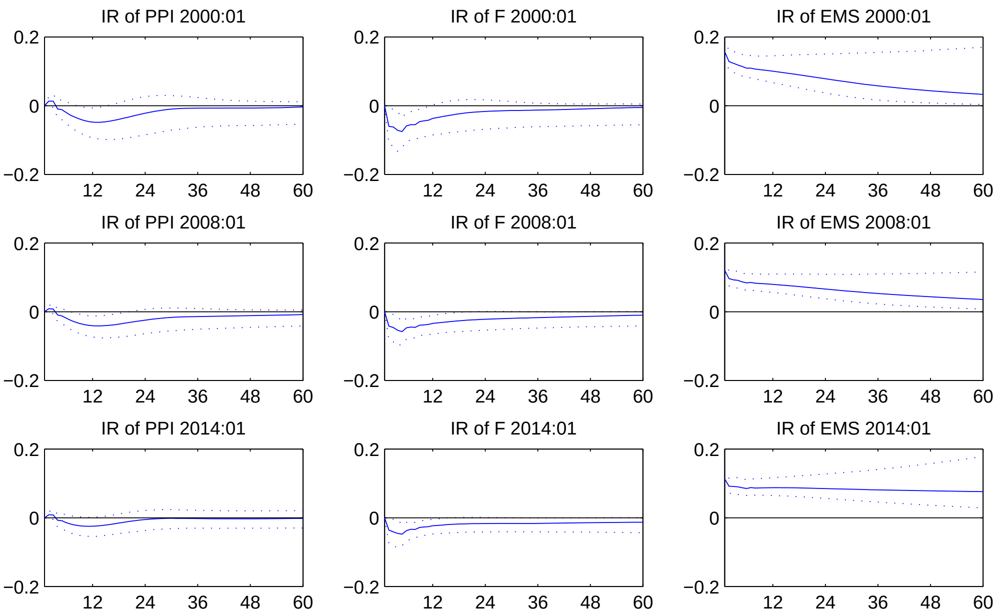

Figure F.19: (w) Impulse responses to an EMS(30) shock. Dashed lines indicate 16% and 84% confidence intervals.

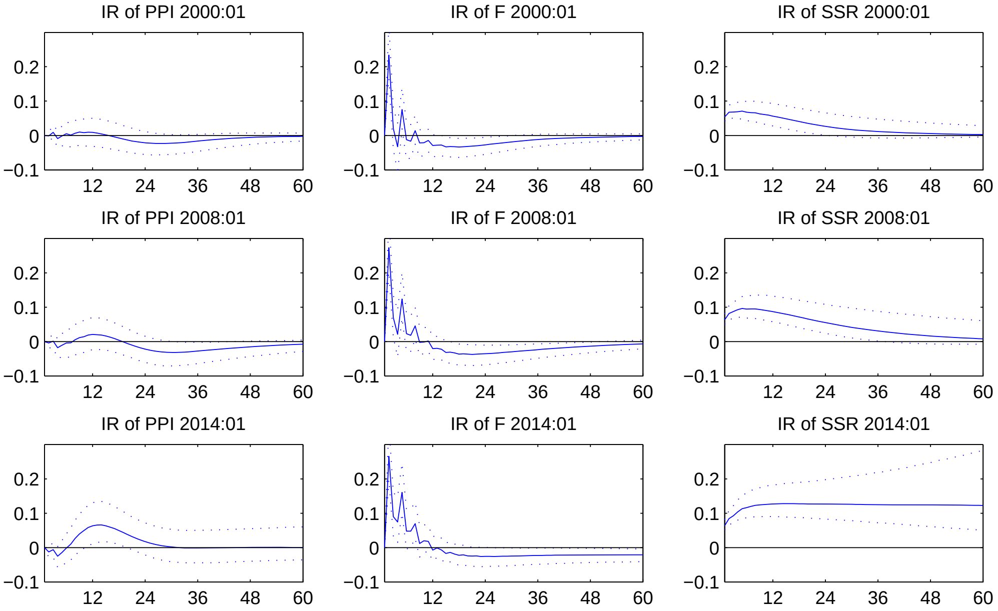

Figure F.20: (x) Impulse responses to a SSR shock. Dashed lines indicate 16% and 84% confidence intervals.

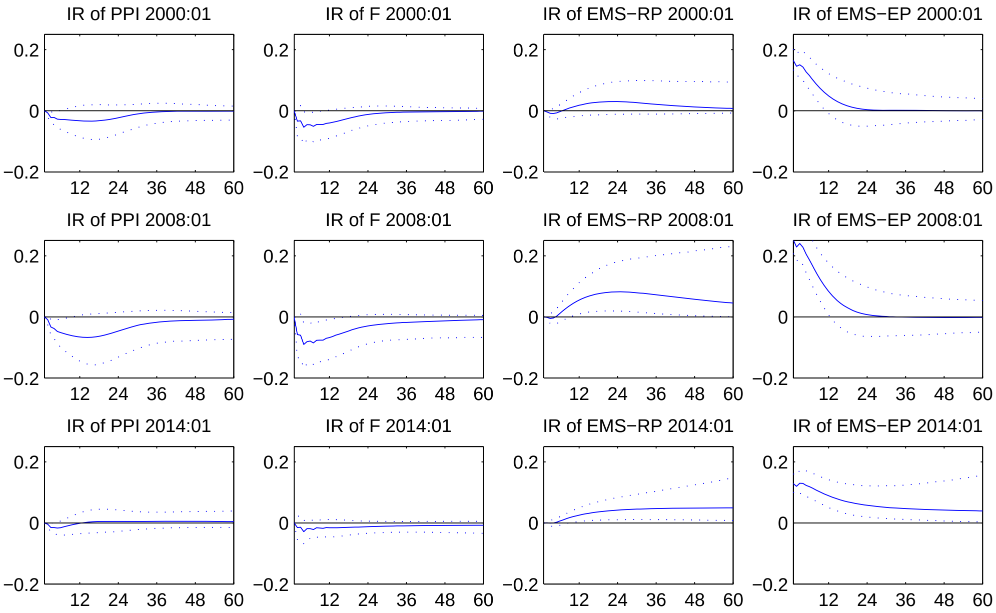

Figure F.21: Impulse responses to a shock on EMS(30)-EP. Dashed lines indicate 16% and 84% confidence intervals.

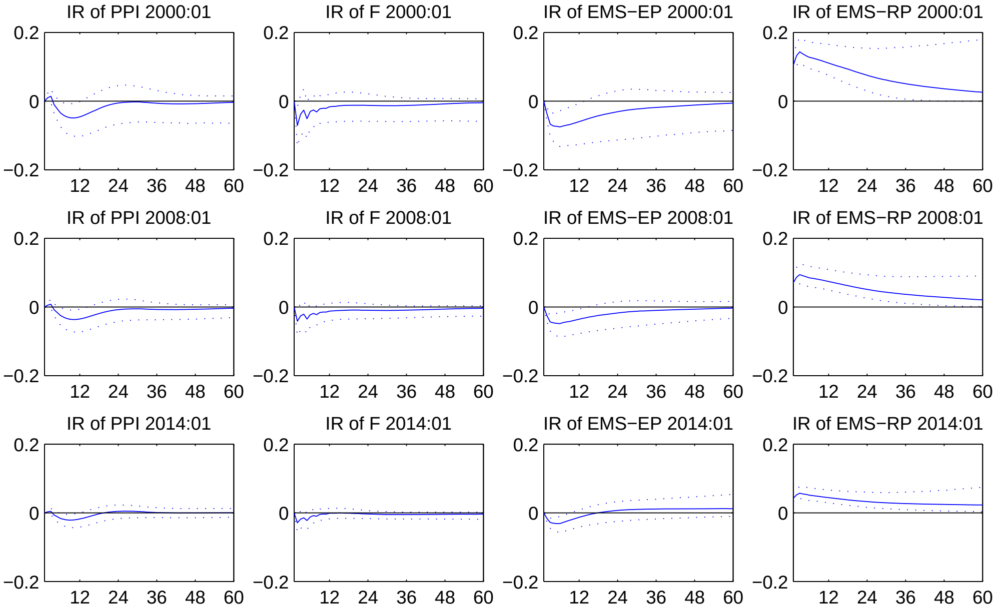

Figure F.22: Impulse responses to a shock on EMS(30)-RP. Dashed lines indicate 16% and 84% confidence intervals.