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The Impact of Monetary Policy on Corporate Bonds under Regime Shifts*

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Abstract

We study the effects of a conventional monetary expansion, quantitative easing, and of the maturity extension program on corporate bond yields using impulse response functions to shocks obtained from flexible models with regimes. We construct weekly bond portfolios sorting individual bond trades by rating and maturity from TRACE. A standard single-state VAR model is inadequate to capture the dynamics of the data. On the contrary, under a three-state Markov switching model with time-homogeneous VAR coefficients, we find that unconventional policies may have been generally expected to decrease corporate yields. However, even though the sign of the responses is the one expected by policy-makers, the size of the estimated effects depends on the assumptions regarding the decline in long-term Treasury yields caused by unconventional policies, on which considerable uncertainty remains.

Keywords: Unconventional monetary policy, corporate bonds, term structure of Treasury yields, impulse response function, Markov switching vector autoregression.

JEL codes: G12, E43, C32.

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1. Introduction

The financial crisis has offered unprecedented challenges to policy-makers worldwide (see, e.g., Joyce et al., 2012). In the U.S., the Federal Reserve was forced to reduce its target federal funds rate to zero and to massively increase the monetary base in an attempt to stabilize the financial system and stimulate the economy. In November 2008, the FOMC started a Large-Scale Asset Purchases (LSAP) program, consisting of purchases of large amounts of long-term assets, mainly agency bonds and MBS securities, initially up to $600 billion. In March 2009, the purchases were expanded to long-term Treasuries up to additional $600 billion. These policies, which imply the expansion of the high-powered monetary base (i.e., bank reserves and currency) through the direct purchase of long-term securities, are generally known as quantitative easing (QE) (see Bowdler and Radia, 2012). In addition, in September 2011 the FOMC launched the Maturity Extension Program (MEP), which consisted of purchases of $400 billion worth of long-term Treasury securities and contemporaneous sales of the identical amount of short-term notes. In contrast to QE, the MEP (also known as operation "twist"), keeps the monetary base constant, as proceeds from selling short-term Treasuries are used to buy long-term ones.

The purpose of these unconventional policies, as stated in the minutes of the FOMC meeting of December 16, 2008, was to "(...) support overall market functioning, financial intermediation and economic growth." In addition, the minutes suggest that the asset purchases were expected not only to reduce the yields on the instruments being purchased, but also to "reduce borrowing costs for a range of private borrowers", such as the yields of corporate notes and bonds—i.e., those debt instruments that are issued by firms to satisfy their financing needs. The first claim, i.e., that a reduction in the supply of long-term agency and Treasury bonds is able to reduce their yields, is supported by the theory, first proposed by Modigliani and Sutch (1966), that different classes of financial assets are not perfect substitutes in investors' portfolios. Consequently, changes in the supply of an asset to private investors produce effects on the prices, and thus the yields, of the asset itself (see Vayanos and Vila, 2009). The second claim, i.e., that the cost of borrowing of private corporations will decline as well, is supported by the idea that previous owners of the long-term Treasury bonds will have to rebalance their portfolios and will then buy corporate bonds of similar maturity, thus increasing their prices and reducing their yields (see, e.g., Bernanke, 2012). In light of the objectives stated in the FOMC minutes, as well as considering the importance of debt financing for U.S. firms, it is particularly relevant to understand the effects of monetary policies on the corporate bond market. In particular, the goal of this paper is to investigate the effects that conventional and unconventional monetary policies (namely, QE and MEP) may have been expected to produce on the yields of corporate bonds with different maturities and ratings.

The existing literature has investigated the effects of unconventional monetary policies on the securities that were directly purchased by the Fed, as well as the assets that were not purchased directly, such as MBS and corporate bonds. This strand of research includes, for instance (see also Table 3 for a summary), D'Amico and King (2013), Gagnon et al. (2011), and Krishnamurthy and Vissing-Jorgensen (2011). Our approach differs from these studies in that we do not propose an ex-post assessment, usually based on event studies, of unconventional monetary policies limited to the financial crisis period (see Martin and Milas, 2012), but rather an a-priori, full-sample investigation of the effects that these policies could be expected to produce at the time of implementation. Our analysis therefore uses longer time series drawn from a 2004-2012 sample that includes the financial crisis but is not limited to it. However, exactly because two of the three types of policies investigated are unconventional, they have been rarely used, so any unconditional historical evidence would be by necessity unreliable. Hence we opt to use modern, flexible dynamic time series models that allow for instabilities in the mechanism linking the riskless yield curve to the U.S. corporate bond market.[1] Markov switching (MS) models have recently become popular in the literature (see, e.g., Ang and Bekaert, 2002; Guidolin, 2012; Kapetanios et al., 2012), which can be attributed to the fact that financial time series are typically characterized by instability.[2] We therefore use estimated MS models to compute IRFs, and measure the effects of shocks to one or more policy variables on each of the series in the system. This approach has also another advantage compared to event-studies: whilst the latter have difficulties pinning down the persistence of the effects on corporate bond markets, our impulse-response functions are instead explicitly geared towards measuring such persistence properties.

The choice of how to simulate the three policies in a dynamic time series model for Treasury and corporate yields remains non-trivial. A conventional monetary expansion, which implies the injection of newly-created reserves into the system through the purchase of short-term Treasuries, may also be measured by changes in monetary aggregates. However, Bernanke and Mihov (1998) argue that this traditional approach fails to recognize that, in practice, the rate of growth of monetary aggregates depends also on the trend growth of the

[1] Cronin (2014) has used (generalized) variance decompositions to measure spillovers from both monetary base and M2 to the returns on four asset classes (stocks, commodities, currency index, and government bonds). QE is identified as a shock to the rate of growth of monetary aggregates.
[2] For instance, Williams (2012) studies monetary policy under two Markov regimes and points out that the optimal policy during the crisis state can be different from tranquil periods.

currency component of the money supply. Bernanke and Blinder (1992) suggest using innovations to the effective Federal Funds rate to capture monetary policy shocks.[3] Whereas the use of changes in monetary aggregates as a measure of conventional monetary policies may be questionable, this approach is impractical to simulate unconventional monetary policies and, in particular, operation twist because this policy does not imply the creation of monetary base but a change in the relative supply of long- and short-term Treasuries obtained through a change in the composition of the balance sheet of the Federal Reserve. For these reasons, we simulate monetary policy shocks through their effects on Treasury rates. This approach relies on two main assumptions: first, as far as conventional monetary policy is concerned, Fed funds rate and 1-month Treasury yield tend to co-move; second, as far as unconventional monetary policies are concerned, QE and MEP were at least able to lower Treasury yields, as theorized and auspicated by policy-makers. These assumptions are not unreasonable, as T-bill yield and Fed funds rates should be tightly linked by expectation theory; in addition, many studies have demonstrated that unconventional policies are able to affect Treasury yields, as will be extensively discussed in Subsection 4.2. However, in Section 4 we will relax these hypotheses and provide some robustness checks to our results, adopting alternative measures of monetary policies.

We simulate a conventional monetary expansion, which implies a shock to the short end of the yield curve, through a negative shock to the 1-month yield. In addition, in Subsection 4.1, we use shocks to Fed funds rate and Krippner's (2012) shadow short rate (SSR) as alternative measures of conventional policy. QE, which is implemented through the purchase of long-term securities is simulated as a negative shock to the 10-year yield, similarly to Kapetanios et al. (2012). Finally, MEP, which involves the sale of short-term Treasury notes and the contemporaneous purchase of longer-term Treasuries, is simulated as a negative shock to the 10-year Treasury yield accompanied by a simultaneous positive shock to the 1-month yield. In addition, in Subsection 4.3 we also use shocks to the size of the Fed balance sheet and its average duration to simulate QE and MEP, respectively. Finally, we also test the robustness of our baseline findings on unconventional policies using Krippner's (2012) Effective Monetary Stimulus (EMS) index.

Our results show that in the crisis regime, unconventional monetary policies are able to produce a general and persistent *decline* in corporate yields. As discussed above, this is in line with the objectives of the monetary authorities and it implies a reduction of the

[3] However, Rudebusch (1998) and Sims (1998) have debated whether and how VAR innovations to the effective Fed funds rate may represent monetary policy shocks. Christiano et al. (1999) provide a critical review of this debate. In this paper, we shall follow the view that VAR innovations to short-term rates may indeed help measuring policy shocks.

borrowing costs for bond issuers. In contrast, conventional monetary expansion policies tend to produce an increase in corporate yields and lead to higher borrowing costs perceived by firms, which may cause perverse effects on the level of real investments and, ultimately, on employment. Although clearly puzzling, this result is not completely surprising, especially if we consider that conventional monetary policy is no longer effective when the ZLB is reached.

To the best of our knowledge, the empirical findings and regime switching approach employed in our paper are new. However, a few earlier papers have obtained related results, mostly using event-study methods.[4] For instance, Krishnamurthy and Vissing-Jorgensen (2011) emphasize that LSAP produced a significant drop in the rates of long-term safe assets and barely affected risky assets such as Baa corporate bonds. Our findings show that some policies (MEP) may instead cause important and statistically significant effects, but in the crisis regime only. Wright (2012) has used a structural VAR to identify the effects of unconventional monetary policy on various long-term interest rates. He concludes that LSAP 1 and 2 had statistically significant effects on long-term Treasury and corporate yields, but these effects tended to reverse in subsequent months. Swanson (2011) investigates the implications of MEP using a high-frequency event study and concludes that this policy had smaller effects than LSAP: it lowered long-term Treasury yields by 15 bps while barely affecting the corporate yields. Our empirical views on the effectiveness of MEP are more benign, even though these implications are derived from a multi-state model and with reference to one regime only. More generally, the literature on unconventional policies suggests that, while there is consensus regarding the LSAP's and MEP's success in lowering long-term Treasury rates and the yields of the other assets being purchased, there is less evidence of their ability to lower the yields paid by the private sector (see Martin and Milas, 2012). This is exactly the question of our paper.

The paper is structured as follows. Section 2 presents the methodology and describes the data. Section 3 reports the results based on MSVAR model when monetary policies are simulated through shocks to Treasury yields. Section 4 provides a set of robustness checks, questioning the hypothesis that the shocks are transmitted with strength to the Treasuries;

[4] However Hamilton and Wu (2012) and Bauer and Rudebusch (2014) present time-series analyses assessing the effects of unconventional monetary policies using single-state models. Kontonikas, MacDonald, and Saggu (2013) show instead that a structural break took place during the financial crisis, altering the stock market response to policy rate shocks and denying conventional policies of their standard effects. This may be interpreted as the appearance of a new, third crisis regime that was not frequently experience before 2007-2009 and calls for the adoption of multi-regime models.

in addition, Section 4.4 assesses the extent to which the results depend on the ordering of the variables in a regime-specific Cholesky identification. Section 5 concludes.

2. Methodology and Data Construction

2.1. Markov switching VAR models

The notion that single-state vector autoregressive models may be insufficient to capture endogenous relationships among variables over time has recently become widespread in the empirical macroeconomics literature (see, e.g., Kapetanios et al., 2012), where the presence of instability and (often, recurring) change points has been often recognized and modelled. Because among the models employed to capture such time-varying relationships Markov switching models have played a key role (see, e.g., Hayashi and Koeda, 2013), in this paper we adopt a MSVAR approach.

A k-regime $MSVAR(p)$ process with heteroskedastic components, henceforth shortened as $MSIAH(k,p)$ (Markov switching intercept autoregressive heteroskedastic) as in Krolzig (1997), can be represented as

$$y_t = v_{S_t} + \sum_{j=1}^{p} A_{j,S_t} y_{t-j} + \Omega_{S_t}^{1/2} e_t \qquad e_t \sim NID(0, I_M), \tag{1}$$

where $S_t = 1,2 \ldots k$ indicates the regime at time *t*, *k* is the number of regimes, y_t is a $M \times 1$ vector of endogenous variables, v_{S_t} is a regime-dependent $M \times 1$ vector of intercepts, $A_{1,S_t}, \ldots, A_{j,S_t}$ are the regime-dependent $M \times M$ vector autoregressive coefficient matrices, and the lower triangular matrix $\Omega_{S_t}^{1/2}$ represents the regime S_t -specific factor in a regime-dependent Cholesky decomposition of the covariance matrix Ω_{S_t}. Because in general $\Omega_{S_t}^{1/2}$ is not diagonal, the variables in y_t will be simultaneously cross-correlated. Conditionally on the state S_t, the process described in equation (1) is identical to a standard Gaussian $VAR(p)$. In practice, however, because state S_t is unobservable and follows a k-state Markov chain process, the MSVAR process in (1) will be able to generate arbitrary non-normalities and represents a rather flexible dynamic time series process. In particular, we follow the literature (see Ang and Timmermann, 2011) and assume that the unobservable state S_t is generated by a discrete-state, homogeneous, irreducible and ergodic, first order Markov chain such that

$$\Pr(S_t = j | \{S_j\}_{j=1}^{t-1}, \{Y_\tau\}_{\tau=1}^{t-1}) = \Pr(S_t = i | S_{t-1} = j) = p_{i,j} \in (0,1), \tag{2}$$

where $p_{i,j}$ is the probability of switching from regime *j* to regime *i*. The transition matrix *P* that collects the probabilities $p_{1,1} \ldots p_{i,j}$ is called the transition matrix of the Markov chain process. For simplicity, in the following we assume that *P* is constant over time.

If M is large, this leads to the estimation of an extremely high number of parameters. As an alternative to a full $MSIAH(k,p)$, one can estimate a number of simpler models. For instance, in a $MSIH(k,p)$, $p > 0$, but the VAR matrices are state-independent:

$$y_t = v_{S_t} + \sum_{j=1}^{p} A_j y_{t-j} + \Omega_{S_t}^{1/2} e_t. \tag{3}$$

The $MSI(A)H(k,p)$ models in (1) and (3) may be estimated using maximum likelihood (ML) methods (see Hamilton, 1994, for a textbook treatment). Under conditions discussed in Krolzig (1997), consistency and asymptotic normality of the ML estimator for a MSIAH(k,p) may be shown to hold. As a consequence, standard inferential procedures can be used to test statistical hypotheses. For example, standard t-tests are used to assess the significance of estimated parameters.

Under the assumption of a single regime, k = 1, the MSIAH(k,p) model in (1) reduces to a standard VAR(p) model in its standard (or reduced) form,

$$y_t = v + \sum_{j=1}^{p} A_j y_{t-j} + \Omega^{1/2} e_t \qquad e_t \sim NID(0, I_M). \tag{4}$$

Because we are interested in understanding the effects of several types of monetary shocks on corporate yields and spreads, in this paper we compute impulse response functions (IRFs). An IRF traces the effects of a one-time shock to one (or more) of the innovations to either (1), (3), or (4) to the current and future values of the endogenous variables. In the case of the dynamic econometric models entertained in our paper, IRFs correspond to classical "counterfactual analyses" popular in the recent literature (see e.g., Chen et al., 2012) that assess what would have happened (in our case, to corporate yields) had a given policy not been undertaken, which we then compare with a baseline prediction which includes the policy.

To ensure that the correlations among the innovations to the variables included in the MSVAR are zero, we apply a standard Cholesky decomposition, that allows us to decompose the covariance matrix as $\Omega^{1/2}(\Omega^{1/2})' \equiv \Sigma = PP'$ to re-write the VAR such that the residuals of different equations are uncorrelated. As is well known, the drawback of this methodology is that, because it forces asymmetries in the system, the ordering of the variables assumes a potentially crucial importance that grows with the magnitude of the contemporaneous correlations of the innovations. Therefore, to avoid an undue influence of the ordering of the variables on our empirical findings, in Section 4 we will re-estimate our models using alternative orderings to assess the robustness of our results. As a general rule, our triangular factorizations follow two criteria: variables to be shocked are placed on top of the ordering, as in Wright (2012); the rest of the variables are ordered on the basis of their residual maturity, with Treasuries preceding corporate bonds.

Because impulse response functions are computed using estimated coefficients, they clearly also reflect estimation error. Accordingly, we construct confidence intervals for the impulse response functions using bootstrapping techniques. The bootstrap method produces confidence intervals that are more reliable and simpler to compute in practice than those based on asymptotic theory (see, e.g., Kilian, 1998). To implement the bootstrap method, each equation is estimated by OLS and a series $\{e_t\}$ of T errors (T being the sample size) is constructed by random sampling with replacement from the estimated residuals.[5] The series $\{e_t\}$ and the estimated coefficients are then used to construct $\{y_t^1\}$. Finally, the coefficients used to generate $\{y_t^1\}$ are discarded and new coefficients are estimated from $\{y_t^1\}$, obtaining a new time series of residuals $\{e_t^1\}$. The re-sampled impulse response function indexed as 1 is computed from the new estimated coefficients. At this point, starting from the $\{e_t^1\}$, the algorithm is re-started to construct $\{y_t^2\}$ to estimate new coefficients and obtain both new residuals $\{e_t^2\}$ and a re-sampled impulse response function indexed as 2. This process is iterated a total of M times. When this process is repeated for a sufficiently large number of times, the resulting set of M simulated impulse response functions can be used to construct the confidence intervals. For example, a 95% confidence interval is the one that excludes the highest and the lowest 2.5% of the bootstrapped, re-sampled IRFs. An impulse response function is considered statistically significant if zero is not included in the bootstrapped confidence interval.

It is possible to extend the concept of IRF to non-linear models by defining a generalized IRF (see, e.g., Koop et al., 1996), with reference to a MS framework. For concreteness, we focus on the estimation of IRFs for a $MSIH(k,p)$ model, where the coefficient matrix is not regime-dependent, because this type of MS models turns out to dominate all alternatives in the empirical results that follows in Section 3, while the $MSIH(k,p)$ case is relatively easy to deal with. In general, an h-step-ahead IRF is defined as

$$IR_{\Delta e}(h) = E[Y_{t+h}|y_t(\omega')] - E[Y_{t+h}|y_t(\omega)]\,, \tag{5}$$

where the sample path $y_t(\omega')$ is equal to the sample path $y_t(\omega)$ with the exception of the initial value of y_t, which has been perturbed by a shock Δe (see Potter, 2000). In practice, an IRF measures the difference between the conditional expectation of Y_{t+n} at time t in case y_t has been subject to a shock and the conditional expectations of Y_{t+n} at time t in case y_t has not been shocked. This definition can be generalized to fit a Markov switching framework. In practice, we can rewrite (5) as (see Hayashi and Koeda, 2013):

[5] When re-sampling the residuals, one has to take into account the fact that these in general will be correlated across different equations.

$$IR_{\Delta e} = E\left[Y_{t+h}\middle|\xi_{t,}e_t + \Delta e; Y_{t-1}\right] - E\left[Y_{t+h}\middle|\xi_{t,}e_t; Y_{t-1}\right]. \quad (6)$$

In a regime-switching framework an h-step-ahead IRF depends on the state prevailing at time t when the shock occurs. The problem in the computation of a Markov switching IRF is that the regimes are not observable. Noticeably, because we analyze $MSIH(k, p)$ models where the VAR matrix is not regime-dependent, we only need information about the state prevailing at the time the shock occurs. Even though other calculations are possible (Monte Carlo techniques to simulate the ergodic distribution of regimes, or assuming equal probabilities across regimes), in this paper we assume that the regime prevailing when the shock occurs is known. Despite the fact that it relies on one partially reasonable assumption (observable regimes), this methodology is useful to our analysis as it allows us to examine the effects of a shock conditioning upon the realization of a given state. The confidence intervals for the IRFs are computed with Monte Carlo simulation techniques exploiting the (asymptotic) normality of the ML estimators of conditional mean parameters in both the cases of k = 1 and k > 1. We sample randomly conditional mean parameters from this distribution a sufficiently large number of times (in the paper we set N = 10,000 throughout) and we compute IRFs.

To select the model structure—including the number of regimes and the number of lags in the case of (1), and the number of lags in the case of (4)—we conduct an extensive specification search using three information criteria: the Akaike information criterion, the Schwarz criterion and the Hannan-Quinn criterion, see Guidolin et al. (2015).

2.2. Data construction

One of the main difficulties that plague fixed income research, for instance in comparison to equity market research, is that bond markets are far more illiquid and less transparent. Bessembinder et al. (2009) report that the average bond trades only 52 days per year and, conditional on trading, approximately 4 times per day. Many existing studies rely on indices of corporate bond yields, such as those produced by Moody's or by Barclays (see, for example, Neal et al., 2000; Longstaff, 2010). Unfortunately, the use of those indices has several drawbacks, including the fact that they are generally constructed considering both callable and non-callable bonds.[6] Consequently, given the goals of our analysis, we place great emphasis on constructing our own corporate bond portfolios. Fortunately, the introduction of the Trade Reporting and Compliance Engine (TRACE) system by the National Association of Securities Dealers (NASD, currently known as the Financial Industry

[6] This option to be refunded in advance may have a significant impact on the behaviour of the bond yields, because the value of the embedded short call option increases when the price of the bond rises because when interest rates fall, financing can be obtained at a lower cost.

Regulatory Authority, FINRA) has significantly enhanced the transparency of the U.S. corporate bond market. Consequently, we rely on TRACE to construct from scratch our corporate yield time series. The data extrapolated from TRACE are passed through a careful cleaning procedure and merged with information, such as maturity and rating, retrieved from the CUSIP Service Bureau (see Guidolin et al., 2015, for details).

The dataset is used to construct four series of weekly yields. The observations are divided into portfolios according to their rating and maturity: (i) investment-grade short-term bonds (henceforth IGST), (ii) investment-grade long-term bonds (IGLT), (iii) non-investment-grade short-term bonds (NIGST), and (iv) non-investment-grade long-term bonds (NIGLT). [7] We limit ourselves to four corporate portfolios because the adoption of MSVAR methodologies implies considerable proliferation in the number of parameters. The weekly yield series for each of the four portfolios are constructed as follows. $YIELD_{t,j}$ is the average yield for all the bonds traded in week t and belonging to portfolio j. If there is more than one observation for a bond within the same week, only the last transaction in the week is taken into account to compute the average yield for the week. We thus obtain four weekly (Friday-to-Friday) yield series from October 8, 2004 to December 28, 2012.

The Treasury yield curve is summarized by the 1-month, 1-year, 5-year, and 10-year weekly (Friday-to-Friday) constant maturity Treasury yields from October 8, 2004 to December 28, 2012. Alternatively, to decompose the information embedded in the Treasury term structure, we also use the method suggested by Littermann and Scheinkman (1991). Littermann and Scheinkman observed that a three-factor model is able to explain most of the variability in the Treasury yield curve. To estimate our three-factor model we extract the first three principal components from the matrix containing the 1-, 3-, 6-month, 1-, 2-, 3-, 5-, 7-, and 10-year constant-maturity Treasury yields. As suggested by Littermann and Sckeinkman (1991), these three factors can be regarded as the level, the slope and the curvature of the Treasury term structure.

Finally, to conduct some robustness checks to our analysis we also employ alternative variables to measure monetary policies. First, we use the weekly shadow short rate produced by Krippner to measure conventional monetary policy. The SSR is essentially equal to the policy interest rate in non-ZLB/conventional monetary policy environments, but it can take on negatives values in ZLB/unconventional environments. This derives from

[7] A bond is classified as short-term if its remaining time to maturity is less than 5 years and long-term otherwise. For the sake of brevity, in this paper short-term is used to refer to both short- and medium-term bonds. Moreover, a bond is non-investment grade (NIG) if its rating is below BBB- (Standard & Poor's) or Baa (Moody's); otherwise a bond is of investment grade (IG).

a straightforward modification of a two-state variable Gaussian affine model based on Black's intuition that observed that physical currency provides an option against negative rates. Krippner's series are estimated using an extended Kalman filter on month-end US yield curve data from 1985 with maturities spanning from 3 months to 30 years.[8]

Second, we collect weekly data on the changes in the size of the Fed balance sheet and in its average duration. In particular, the former are computed as annualized percentage changes in the Total Assets as reported in the Federal Reserve's weekly H41 releases. The latter are computed as the absolute delta from one week to another in the average maturity of the Federal Reserve's portfolio of Treasuries. The average maturity is the average (expressed in weeks) of the midpoints of each time bracket weighted per Treasury holdings.[9] Finally, we represent unconventional monetary policy through the weekly Effective Monetary Stance (EMS), also computed by Krippner. This is a measure of monetary policy stimulus based on the comparison between the expected path of the effective policy rate and the long run expectation of its shadow rate.

3. Regime-Dependent Monetary Policy Transmission to Corporate Bonds

In this section we estimate a MSVAR model for the bond yield series. In particular, our model includes the four corporate series presented in section 2 (IG and NIG short- and long-term) and the four yield series chosen to represent the Treasury term structure. As discussed in Section 2, we consider non-linear Markov switching models to be more likely to represent the structure of the data than single-state VAR models, especially given that financial markets are characterized by well-known patterns of instability, structural breaks, regimes, etc. (see, e.g., Ang and Timmermann, 2011). For instance, Cronin (2014) finds considerable instability in his single-state VAR, especially with reference to the Great Financial Crisis when monetary aggregates impact asset prices much more than in "normal" times, but limits himself to a rolling-window analysis. Wright (2012) repeats his VAR analysis with reference to pre- and post-crisis periods and notices that monetary policy shocks operate on different points of the yield curve in the pre-crisis sample.

3.1 Model selection

[8] Wu and Xia (2014) represent an alternative to Krippner's shadow rate. They propose a simple analytical representation for bond prices in a multi-factor shadow rate term structure model that provides an excellent approximation and is extremely tractable for empirical implementation. However, their index is made available only on a monthly basis and starts off late in our sample.

[9] The six time brackets are: from 1 day to 15 days, from 16 days to 90 days, from 91 days to 1 year, form 1 year to 5 years, from 5 years to 10 years, over 10 years (the midpoint is equal to 15 years).

To specify a MS model one has to select not only the appropriate number of lags, but also the number of regimes. In addition, as illustrated in Section 2.1, a number of alternative models are possible, depending on which parameters are allowed to switch. We analyze three types of models: $MSI(k,p)$, where only the intercept terms are regime-dependent, $MSIH(k,p)$, where both the intercept terms and the covariance matrix are regime-dependent, and $MSIAH(k,p)$, where also the vector autoregressive parameters are regime-dependent. We consider a number of lags up to 2 and a number of regimes up to 3. The choice to not restrict *k=2* is consistent with the findings of Guidolin and Timmermann (2009) that at least a three-regime specification is needed when dealing with U.S. fixed income market. Moreover, a model with $k \geq 3$ would be too large to be estimated with a sample of 3,440 observations.

We use an adjusted (to protect against nuisance parameter problems, see Davies, 1977) likelihood ratio (LR) test to see whether a multi-state framework is appropriate. The LR test always rejects the null hypothesis of *k=1* at any conventional confidence level. Consequently, we conclude that $k > 1$ is appropriate. Furthermore, using Akaike, Schwartz and Hannan-Quinn criteria, we select a $MSIH(3,1)$ model.[10] Guidolin et al. (2015) show that the null of a single-state is rejected and provide VAR estimates.[11]

3.1. A three-state MSIH VAR(1)

The selected $MSIH(3,1)$ model of the form specified in equation (3) is estimated for the yield series. As described in Section 2.1, $MSIH(3,1)$ models have regime-dependent intercepts and covariance matrix, but regime-independent VAR matrix. In a MS model the variables affect one another through three channels: the dependence of each variable on lagged values of the others, the contemporaneous correlations, and the dependence of all the variables upon a unique Markov chain, as postulated in (3). However, because we estimate $MSIH(3,1)$ models which do not allow for regime-dependent autoregressive parameters, the linear relationships among the variables are stable over time.

The estimation results for the *yield*-$MSIH(3,1)$ model is reported in Table 1.[12] For each of the estimated coefficients we report in parenthesis the *p*-value of a *t*-test that the parameter is zero. It can be noted that approximately one half of the coefficients are significant for the

[10] The details of all tests performed for model selection are available upon request.
[11] Guidolin et al. (2014) perform simulated policy experiments similar to ours but using a simple, single-state VAR(1) framework. They find that no policies are ever effective in stimulating the economy through reductions in corporate yields.
[12] The tables also show the pseudo-R^2 computed as $R^2 = 1 - \left[\sum_{t=1}^{n}\sum_{i=1}^{3}(y_t - \hat{y}_{i,t})^2\hat{\xi}_{i,t}\right]/\left[\sum_{t=1}^{n}(y_t - \bar{y})^2\right]$, where the $\hat{\xi}_{i,t}$s are estimated filtered probabilities.

model. Importantly, the vast majority of the state-specific intercepts are significant at the 1% or at least 5% level. Moreover, the intercept is always significant in at least one of the regimes. Treasury yields show forecast power for each other and for both long-term yields. Corporate yields show predictive ability for Treasuries. In addition, the cross-linkages between the yields of bonds in the same rating classes but in different maturity clusters are always significant.

3.2. Economic Interpretation of the Regimes

In this subsection we provide an economic interpretation of the regimes, analyzing the $MSIH(3,1)$ estimated framework. Table 1 reports the transition matrices while Figure 1 shows smoothed probabilities. In addition, Table 1shows the regime-specific unconditional means of the variables. These means represent expected values under the assumption that regime i will prevail forever.[13] Together with regime-specific volatilities, these means are used to characterize the three regimes, which will be identified as *low rates*, *high rates* and *crisis* states.

Regime 1 is the most persistent of the states, as it has a "stayer" probability (i.e., the probability of remaining in the regime for an additional period) of 0.99. The average duration of the regime is approximately 22 months and its ergodic probability is 57%. This regime is characterized by low means for both corporate and Treasury yields. In addition, these means imply that both corporate and Treasury rates have an upward sloping term structure. All volatilities are low both for IG corporate and Treasury yields. For example, in regime 1 the 1-month Treasury yield has an annualized volatility of only 0.02%, in contrast to 0.12% in regime 2 and 0.33% in regime 3. On the contrary, the volatility of NIG yields is higher than in regime 2, albeit lower than in regime 3. For example, NIGST yields display an annualized volatility of 1.58% in regime 1, of 0.54% in regime 2 and of 4.37% in regime 3. The pairwise correlations of VAR innovations are in general quite low in this state. Consequently, we can consider regime 1 as a persistent and tranquil regime characterized by low yields and low volatilities.

Regime 2 is also rather persistent, even if less than regime 1 is: the "stayer" probability is 0.97. The average duration of the state is equal to approximately 7 months and its ergodic probability is 33%. This regime is characterized by high means on both corporate and Treasury yields. While the term structure of IG and Treasury yields is upward sloping, NIGST rates are on average higher than long-term ones, thus signalling an inversion of the yield curve. As hinted at above, volatilities are higher than in regime 1 for high-quality

[13] The regime-specific unconditional mean for regime S is computed as $\mu_S = (I_m - A_1)^{-1} \upsilon_S$.

assets, but lower for riskier assets (i.e., NIG bonds). Finally, pairwise correlations of innovations are slightly higher than in regime 1 and generally positive. Thus, this regime identifies a bond market characterized by high yields and high volatilities.

Finally, regime 3 is quite peculiar: mean corporate yields peak (reaching an annualized level of 29.02% in the case of NIGST, although this regime has the duration much lower than one year) while Treasury yields are extremely low or even negative (which has occurred during the 2008-2009 financial crisis). In addition, the term structure of NIG yields is inverted. The volatilities are very high and innovation correlations between Treasuries and corporates are generally negative. The average duration of this state is only 6 weeks and its ergodic probability is 10%. Clearly, this state is less persistent than the others: its "stayer" probability is 0.83. The peculiarities of this regime reveal that it can be interpreted as a state of *crisis*: during market crashes investors tend to "fly to quality", i.e., they transfer their wealth from high-risk/high-return assets to those that are considered "safe", such as Treasuries. For this reason, corporate yields, and in particular risky NIGs, skyrocket. In contrast, the yields of low-risk assets become low, which our model captures as short-lived, negative unconditional means. This is particularly true for Treasuries, which are generally considered the safest among all assets.[14]A scrutiny of the smoothed probabilities confirms this interpretation. Indeed, the smoothed probabilities of regime 3 peak in the period October 2008 - October 2009, which coincides with the outburst of the financial crisis. In the remainder of the paper we refer to regime 1 as *low rates* state, to regime 2 as *high rates* state and to regime 3 as *crisis* state.

Figures 2-4 report the IRFs for three types of shocks that we choose to represent a conventional expansion, QE and MEP, namely a negative shock to the 1-month Treasury yield, a negative shock to the ten-year Treasury yield and a combined shock to the 1-month Treasury yield and the ten-year Treasury yield. The graphs show the responses, along with 95% confidence bands, up to 26 weeks after policy shocks. These responses are calculated assuming that the initial regime is known, which implies that policymakers can detect with sufficient accuracy the nature of the current state. However, such an assumption seems to be comfortably supported by the shapes in Figure 1, where the regime probabilities seem to be usually close to 0 and 1, with rare cases of uncertainty.

3.3. Effects of conventional monetary policies

[14] Obviously, nominal yields are bounded below by zero. However, given that we compute the regime-specific means under the counterfactual assumption that a particular regime is going to prevail forever, it is possible to estimate negative Treasury yields.

We first study the effects of an expansionary monetary policy simulated as a one-standard-deviation negative shock to the 1-month T-bill rate. The analysis of the IRFs in the $MSIH(3,1)$ framework (Figure 2) indicates that the effects of a monetary expansion on yields depend on the regime that prevails at the time in which the policy is implemented. In particular, during a crisis, the effects of a rate-based policy tend to be more pronounced than in the other regimes for all corporate yields, especially the short-term ones. However, these effects go in a direction opposite to the one desired by the policymakers, i.e., to lower the borrowing costs for businesses and households. In fact, in times of crisis a conventional, expansionary policy causes an increase of about 51 bps in NIGST yields and of 13 bps in IGST ones. Although relatively smaller, the effect is positive also for long-term bonds: NIG yields increase by 11 bps and IG yields rise by 5 bps. Even though it tends to decline, the policy effect remains significant for at least one month following the shock. The response of short-term yields remains significant for more than 4 months.

In contrast, the effect of a monetary expansion in the *high rates* regime consists of a statistically significant reduction of corporate yields (although very small, in the order of 3-4 bps), with the important exception of NIGST yields. Thus, in this regime, monetary policy is successful at lowering the yields, with the exception of NIGST ones. Moreover, the beneficial effects are persistent, given that the responses converge to zero very slowly and remain significant for more than 4 months. Yet, the responses are very small, in the order of a handful of basis points at best. Finally, in the *low rates* state, the responses of corporate yields to an expansionary policy are close to zero and they are statistically significant only in the case of NIG short- and long-term yields. This means that in all three regimes, the effects of a conventional monetary expansion on corporate bond yields are modest, often carry the wrong sign (given the likely desiderata of policymakers) and are predominantly not statistically significant.

These weak and regime-dependent (hence, time-varying) effects are however not completely surprising. For instance, since Bernanke and Mihov (1998), we know that a rate-based expansionary policy has mainly two effects: it increases real output and it raises the price level. Because we know from Ang and Piazzesi (2003) that macroeconomic factors are able to explain the majority of the variability of bond yields—in particular, a higher inflation triggers an increase in bond yields, especially short-term ones—an expansion of the monetary base is likely to increase inflation and, consequently, corporate yields. Moreover, our results emphasize that the response of corporate yields to a monetary shock depends on the economic regime. This is again coherent with the findings of Bernanke and Mihov (1998) who have tested their results on different sample periods and noticed that the responses of macro factors to a monetary shock are time-varying. In particular, in our framework, in the *high rates* regime a monetary expansion triggers a reduction, albeit modest, of corporate yields instead of their increase. This is reasonable if one considers that an expansionary policy is likely to raise more concerns about future inflation when the rates are already low than when the level of interest rates is generally high. Finally, the crisis regime is the one that shows the most pronounced positive responses to a monetary expansion, which contrast with the desired objective of reducing the cost of borrowing. However, as we will discuss in Section 4, the *crisis* period was characterized by rates constrained by the zero lower bound, so that a conventional policy could hardly be expected to be effective when measured by the short-term rate. Moreover, these results are consistent with Kontonikas, MacDonald, and Saggu (2013) who report that while before the financial crisis the literature (see e.g., Basistha and Kurov, 2008) had documented that risky asset prices increased more strongly reacting to expansionary conventional monetary policy during recessions, the increased uncertainty experienced during the 2007-2009 financial crisis led to increasing risky yields while policy rates were being sharply cut.

3.4. Effects of quantitative easing-type policies

Figure 3 reports the effects on corporate yields of QE, which we simulate as a negative, one-standard-deviation shock to the 10-year Treasury. In particular, as unconventional monetary policies are more likely to be implemented in time of crises, in this section we particularly focus on the effects of QE in this regime. Indeed, in the other two regimes the responses are either close to zero or not statistically significant. Instead, in the *crisis* regime QE seems to generate a general and persistent reduction of the corporate yields, more pronounced for NIG ones. In particular, QE policy triggers an immediate reduction of 2 bps of the IGST yields and of 4 bps of IGLT ones. Albeit small, these responses are persistent and reach a peak around the fifth week after the shock (a reduction of 4 bps of IGST yields and of 6 bps of the IGLT ones). The effects are more significant for NIG short- and long-term rates. In particular, NIG short-term yields are immediately reduced by 80 bps after the shock. The effects sharply decline after the third week, but remain significant and negative during the whole observation period. NIG long-term yields decline by 10 bps after the shock, whit a peak of 15 bps after three weeks. Afterwards, the effects turn smaller, even if it remain significant during the entire observation period. These results are consistent with typical objectives of QE, triggering a reduction of borrowing costs.

These results are in line with previous direct evidence on the effects that QE would have produced on the yields of assets different from those purchased directly by the Fed. The vast majority of the papers have concluded that QE was effective mostly in reducing the yields of the assets being purchased (e.g., Krishnamurthy and Vissing-Jorgensen, 2011). D'Amico and King (2013) reach a similar conclusion that government purchases of Treasuries have been able to reduce Treasury yields, but have had a minimal effect on corporates. Although we fail to find first-order effects of QE on corporate bonds, our conclusions allow us to at least reject the Ricardian equivalence-type work by Eggertsson and Woodford (2003) and Cúrdia and Woodford (2011) who have argued that when the central bank replaces private-sector holdings of long-term bond securities with money, it does not change the risk characteristics of the private sectors' portfolios as a whole because households ultimately bear any risk taken on by the government through the tax burden that they will be susceptible to bear in the future.

3.5. Effects of maturity extension-type policies

Figure 4 reports the effects on corporate yields of MEP, which is simulated as a one-standard deviation negative shock to the 10-year Treasury yield accompanied by a positive one-standard-deviation shock to the 1-month T-bill rate. Similar to the other policies, the effects of MEP depend on the state that prevails when the policy is implemented. Indeed, as already observed for QE, the effects are in general close to zero or not significant for both the *low rates* and the *high rates* regimes. Instead, in the state of crisis the IRFs are significant and negative for all corporate yields. The effects generated by the MEP are similar to the ones produced by QE, but a bit more pronounced. In particular, MEP generate an immediate reduction of 14 bps of IGST yields and of 9 bps of IGLT ones. The effects tend to decline, but remain negative and significant for the entire IRF period. As observed for QE, the effects are more pronounced for NIG bonds. Indeed, in this case MEP produces a decline of 130 bps for short-term yields and of 30 bps for long-term ones. Also these effects are persistent, albeit declining, and are still observable at the end of the considered period. More in general, MEP seems to trigger the desired effect of reducing the cost of borrowing, lowering corporate yields and especially NIG ones.

Given that it consists in the contemporaneous purchase of long-term Treasuries and the sale of short-term ones, MEP policy is able to reduce the slope of the riskless yield curve without increasing the monetary base. Our results show that in times of crisis, the policy is able to lower yields of corporate bonds, producing a bigger reduction than QE. These results may be interpreted as a confirmation of the role of expected inflation in driving corporate rates. In fact, conventional expansionary monetary policy, which imply the expansion of the monetary base and thus are likely to increase inflation (see Bernanke and Mihov, 1998), triggers an increase in corporate yields. In addition, QE, which implies an expansion of the monetary base as well, is indeed less effective than MEP. On the contrary, MEP does not imply an expansion of the monetary base.

4. Discussion of the Results and Further Analysis

In this Section we discuss the economic foundations and robustness of the key empirical results reported in Section 3. We do that by subjecting our baseline estimation exercises to a range of variations concerning both the methods and the choices of the variables to be used in the analysis. Therefore, this Section is organized as a sequence of short subsections, each testing robustness using different approaches. In particular, Section 4.1 replaces the short-term rate used in Sections 3 (the 1-month T-bill) firstly with an actual short-term policy rate, the Federal Funds rate, and secondly with a shadow, estimated notion of short-term rate. Section 4.2 questions instead an important identification hypothesis that we have entertained in Section 3: that unconventional monetary policies were effective in reducing at least long-term Treasury yields (as well as increasing 1-year rates, in the case of the MEP). Section 4.3 tackles at its heart this very issue proposing to circumvent the intermediary role otherwise played by long-term Treasury rate as a mechanism to transmit the unconventional policies, by expanding our modelling effort to directly include variables (i.e., size, average maturity, and one synthetic indicator of the stance of monetary policy) that aim at directly measuring unconventional policies. Section 4.4 closes with a rather classical and yet always important set of experiments, by asking whether and how our findings in Section 3 could be sensitive to the specific Cholesky ordering.

4.1 Using alternative short-term rates

The importance of both very short term (e.g., one-month) T-bill and of the Federal Funds rates (henceforth, FFR) is widely recognized. The Fed implements monetary policy by targeting the effective FFR, while the 1-month T-bill rate is a commonly referenced default-risk-free rate in the US money market, and is often used by researchers to proxy the risk-free asset, so assumed to exist. Although a number of authors had assumed early on that the two rates would tightly move together as they are linked by the expectations hypothesis, a more recent literature (see, e.g., Nautz and Schmidt, 2009) has shown that the dynamic (error-correction) linkages between 1-month bill and FF rates are asymmetric and nonlinear to such an extent that in no way the two rates series may be taken as approximately identical over the short-term, especially in empirical work such as ours that admits the existence of regime shifts and hence nonlinearities. [15]

However, the Fed had lowered the FFR already during 2007, basically setting this rate to zero since 2008, and keeping this policy rate at this extremely accommodative level until the end of our sample. As a result, because it captures most the 2008-2012 sample, the crisis period is effectively characterized by an extremely low and stable FFR, so that any IRF-type policy experiment is clearly rather implausible, both in terms of the size of the shock impressed to the rate, as well as in terms of overall plausibility of a conventional policy being used exactly in this way.

We resort instead to a literature that has introduced ZLB constraints for nominal interest rates in otherwise standard no-arbitrage term structure model (e.g., Gaussian affine models) to derive indicators of the stance of monetary policy in the presence of the ZLB. In particular, we use Krippner's (2012) series on the US shadow short-term policy rate (SSR).

We proceed to estimate the same three-state MSIH(3,1) model proposed in Section 3, but in which the 1-month T-bill has been replaced by the SSR. The estimation outputs are reported in Table 2. For the sake of brevity, we shall limit our comments to the specific point estimates and their standard errors, apart from noting that the regimes have the same interpretation as in Table 1 and that most estimates are numerically similar to those reported and commented in Section 3. More importantly, Figure 5 shows that even when conventional, expansionary policy shocks are measured as shocks to SSR, in the crisis regime these produce short-to-medium term impacts on corporate yields that are perverse: for all horizons in the case of short-term corporates and for horizons up to 15-20 weeks in the case of long-term corporates, IRFs remain positive, an indication that reduction in policy rates increase corporate rates, often in a statistically significant manner. In the case of NIG, short-term corporates the effects are relatively large. This confirms and re-enforces our result in Section 3 that in the crisis state conventional policies have none of the desired expansionary effects (that is instead generally detectable in regimes 1 and 2).

4.2 An economic bootstrapping exercise

[15] Complete estimation results for the case in which the FFR is included in the analysis are available upon request. In general, the shocks to the FFR yield an impact on corporate rates that is only slightly more desirable to policy-makers than what we have found in the case of the 1-month T-bill rate, with reference to the crisis regime. In particular, IG yields (both short- and long-term) react with a limited (in both cases approximately by -3 bps) but statistically significant effect that however turns positive and insignificant by week 12.

In Section 3, we have assumed that the unconventional policies were effective in lowering at least the long-term Treasury yields during the 2008-2009 crisis. In practice, this meant that we had identified the policies through their (supposed) effects on Treasury yields, thus identifying Treasury bond as the transmission channel of unconventional shocks to corporate borrowing rates. This choice is coherent with the idea behind this policies (see Chen et al., 2012; Cúrdia et al., 2011). In particular, as discussed above, we simulate QE as a decline in long-term Treasury rates equal to one standard deviation in the crisis regime, and MEP as a contemporaneous decrease of one standard deviation in long-term Treasury yields and increase of one standard deviation increase in short-term yields. In practise, this consisted of an initially unanticipated long-term yield decline of 16 bps in the case of QE, and a decline of 16 bps accompanied by an increase of 18 bps in short rates, in the case of MEP. Such movements in Treasury rates are – at least at a weekly frequency – far from uncommon in US bond markets. Yet, assuming shocks of such a relatively large size on a weekly basis does mean to assume that both LSAP policies first, and then MEP policies were considerably successful in terms of their impact on the Treasury bond market. However, there is a recent literature that has questioned both the measurement and especially the statistical significance of the typical impacts reported in the event study literature (see e.g., International Monetary Fund, 2013, and Table 3, for a summary). For instance, Thornton (2013) performs event studies using standard methods and questions both the size of the effects for most QE and MEP announcements and especially, both their statistical and economic “significance”. The range of plausible and precisely estimated effects that he discusses tend to be considerably weaker than some of the impacts that have been occasionally discussed by policymakers (see, e.g., Bernanke, 2012; Stein, 2012).

To tackle these issues, we start by assembling a table that offers a summary of the effects that have been estimated by a number of papers that are commonly cited and used as a reference in the literature. In particular, and differently from similar efforts that have appeared in the literature (see, e.g., IMF, 2013), we focus on estimating and listing the weekly impact per a standardized 100-billion USD policy intervention of the type marked in Table 3. In this table, a range of rather heterogeneous effects appear. Occasionally, to establish a weekly standardized “per 100-billion USD” effect has been made complicated by the multiplicity of the announcement, not to mention the understandable tendency of many paper to report these results as part of a wider economic analysis and not as raw, distilled estimates. However, our final results seem not to depart too strongly from similar summaries that have appeared in the literature (see e.g., Chen et al. 2012; International Monetary Fund, 2013). The upshot of the table is that, once its overall size of 300 billion

USD is taken into account (but also entirely attributed to the first week of announcement/implementation) LSAP 1 (see the table for a formal definition of this operation) would have yielded a net effect on 10-year Treasuries ranging between a figure of approximately 10 bps up to a huge impact estimate of a 200 bps shock. Moreover, LSAP 2 (taking its 600 billion USD scale into account) would have yielded a net effect ranging between 25 and an unrealistic 300 bps. Considering both 200 and 300 bps an order of magnitude that has not been noticed in financial markets at the time, in Figure 6 we perform afresh the QE exercise of Section 3, when the initial shock ranges between a minimum of 15 bps (obtained as an average between 10 and 25 bps) and 100 bps. Because 15 bps is only slightly lower to the 10-year rate Treasury shock already considered, what is informative here is mostly the upper bound of our exercise. Although this is easily performed because we are conditioning on knowledge of the initial regime, in Figure 6 we also indicate the range of possible effects by filling out all potential responses included between the lower and upper bounds. The message of the picture is that if the initial impact is further reduced vs. what we had assumed in Section 3, the effect on short-term IG and long-term NIG bonds practically disappears in an economic sense, consisting at most in a few dozen bps that were hardly enough to justify the policies enacted. However, if one eye-balls the high end of the range of the effects of LSAP on 10-year Treasury rates, then large impacts, easily exceeding 200 bps at horizons of 1-6 weeks are estimated, especially as far as NIGs and long-term IG bonds are concerned. Yet, a weekly, initial (and unexpected, see the discussion in Thornton, 2013) impact of 100 bps is huge in economic terms, it has been reported by a handful of authors at best while – if one takes the average of the impacts concerning LSAP in Table 3 as best representative of reality – such a policy would have required more concentrated (in time) interventions of 2-3 times the size effectively deployed between 2009 and 2010 (i.e., easily in the range of one trillion dollars) to yield effects of 150-400 bps in the corporate bond markets, i.e., first-order magnitude effects with an implicit multiplier included between 1.5 and 4. Moreover, Figure 6 shows that any such effect, albeit estimated to be sizeable in the short run, all converge in 6 months to an impact of approximately 200 bps for NIG corporates, and less than 100 bps for IG ones, i.e., a large portion would remain rather temporary even considering horizons that account for the entire duration of the crisis state.

Figure 7 performs the same "economic bootstrap" experiment with reference to the MEP. In this case, our review of the literature summarized in Table 3 reveals estimated impact effect, standardized to a 100 billion policy that fall between a few bps only and as much as 20 bps. Moreover, as in most of the literature, such effects have been estimated as a pure effect on long-term Treasury rates. This reflects not only a practical necessity and a need to compare results to those concerning LSAP 1 and 2, but also the obvious fact that with the FFR (and for most of the crisis sample, 1-month T-bill rates) kept at zero by policy interventions, the only possible impact could have manifested itself through a decline in long-term government bond rates. Therefore Figure 7 is estimated assuming a lower bound impact of 10 bps and an upper bound of 30 bps, once the 400 billion USD size of the MEP has been taken into account. The figure shows that if one considers the lower bound, then MEP had also ex-ante, as always in depths of a crisis, little chance to produce effects. These are at best of a few bps in the case of IG corporates and exceed 100 bps (but only initially, as they converge quickly to medium-run effects of 20 bps at most) in the case of short-term NIG corporate rates. Interestingly, however, more generous impact effects of 30 bps do generate rather persistent and non-completely negligible reduction of IG rates of 25-30 bps and especially of NIG rates in excess of 50-60 bps also in the case of long-term bonds, which might have been encouraging in cases experiments similar to ours had been performed during 2011, before MEP was launched.

4.3 Expanding the analysis to direct measurement of unconventional policies

Most of the empirical analysis presented thus far suffers from an obvious limitation: we aim at investigating how and whether unconventional monetary policies may be transmitted to the cost of (debt) capital faced by firms and yet we have deployed no measures of such policies. Both in Sections 3 and 4.2, we have contented ourselves with a range of alternative assumptions concerning the shock that would affect long-term Treasury rates when an unconventional policy is implemented, and relied at first on empirical estimates of the entity of such a shock during the crisis state, and then on the typical initial impact reported in the literature to perform a sort of bootstrapping exercise. In this Section, we exploit instead the additional variables collected and discussed in Section 2 and concerning the size, average maturity of the Fed's balance sheet, and on one indicator of "effective monetary stance", to try and sidestep the problem of the very effectiveness of LSAP and MEP measures on the Treasury market.

In a first exercise, we measure QE as a shock to the size of the Fed's balance sheet. In this exercise, the set of four Treasury rates have been replaced by their first principal component introduced in Section 2, which as it is standard in the literature, happens to well capture a *level factor* across different maturities. This may be interpreted as a further robustness check in itself, to answer the question: does the characterization of the regimes continue to hold when Treasuries are replaced by the implied level (as well as slope and curvature) factors? Second, the MSIH(3,1) has been expanded to now include the variable measuring the weekly change in the average maturity of the Fed's balance sheet. The latter measures obviously capture the effects of implementing MEP, because longer-term bonds are purchased and shorter-term sold, thus increasing the balance sheet maturity. The New York Fed database provides SOMA holdings from 2003 to the present, divided in rough maturity breakdowns (less than 15 days, 16-90 days, 91 days to 1 year, over 1 year to 5 years, over 5 years to 10 years, and over10 years). We use these data to calculate the average maturity of the Fed's Treasuries portfolio for each end of month.[16]

The estimation of the resulting six-variable MSIH(3,1) yields a general characterization of the regimes that remains perfectly compatible with Tables 1 and 2.[17] Figure 8 only weakens but does not erase our conclusions on the effectiveness of the MEP. Visibly, the previously weak and often imprecisely estimated effects on IG corporate rates disappear when MEP is measured as a shock to the average maturity of the Fed's balance sheet. IG rates slightly increase, even though over a 6-month horizon such an effect is limited to a few basis points. On the contrary, in the case of the NIG rates (both short- and long-term) the initial effects are strong (approximately 45 bps and 100 bps, for short- and long-term rates, respectively), they go in the desired direction, and are precisely estimated. However, such effects rapidly decline towards zero or even turn negligibly positive as the horizon of the experiment expands. All in all, considering that certainly we are only accounting the effects of an unexpected increase of only 2 weeks in the overall maturity of the Fed's balance sheet, while announcements effects are much more likely to prove informative, these results provide some support to the notion that MEP may be effective.

We have tried a similar estimation strategy with reference to the size of the Fed's balance sheet. Although estimation of a model expanded to include a level factor did give results generally consistent with our findings in Section 3, an unreported figure (available upon request) similar to Figure 8 did give disappointing indications. Also because regimes failed to be as sharply identified as in Tables 1 and 2, the IRFs showed very weak, almost negligible reactions, of corporate rates to shocks to size of the Fed's balance sheet. Of course, one ought to also take into account that, especially when it comes to size, this reflect with a lag and considerable inertia the announcement and market implementation of LSAP-type

[16] Moreover, to cover the entire sample, we derive the data from January 1982 to December 2002 using the average maturity of the Fed's Treasury holdings as calculated by Kuttner (2006) (available at http://econ.williams.edu/people/knk1/research.). Visual inspection of the resulting series confirms that this variable has been strongly affected by the Fed unconventional policies. Indeed, the average maturity doubled in 2008, under the LSAP 1 program and it especially picked up from September 2011, after the MEP was launched.

[17] The corresponding table is not reported to save space but it may be obtained from the Authors.

policies and a finding of weak or even contradictory IRFs may be considered normal (if so, this casts in even brighter light the interesting findings in Figure 8).

Exactly to remedy to the sluggishness with which the size of the Fed's balance sheet is likely to react, we have also performed a further estimation exercise, similar to the one involving the average duration of the Fed's balance sheet, but instead based on Krippner's (2012) Effective Monetary Stimulus (EMS) index. As described in Section 2, the EMS summarizes the current and expected path of the actual or ZLB-constrained short rate relative to an estimate of the neutral interest rate and as such it is forward-looking. Even though formally EMS only pertains to the future expected path of SSR and FFR, Krippner has shown that EMS reacts to a range of monetary policy measures, including QE measures and their anticipated effects. An unreported set of IRFs (available upon request) shows that a one-standard deviation shock to EMS yields effects that corroborate the hypothesis that in general monetary stimuli tend to affect corporate rates in ways desirable to policymakers. Over short horizons, all types of corporates rates decline as a result of a shock to EMS, even though the largest effects concern NIG bonds, with declines 100 and 50 bps, for short- and long-term bonds, respectively. IG rates react less, even though for the shortest maturities the initial decline of approximately 10 bps tends to be precisely estimated. We take this as evidence that forward-looking, omnibus indices of the stance of monetary policy that are not orthogonal to strategies involving the size of the Fed's balance sheet do give indications of some effectiveness of the mechanism transmitting shocks to the corporate bond market.[18]

4.4 Experimenting with alternative identification orderings

As it is well known (see Christiano et al., 1999), one undesirable feature of a Cholesky identification is that IRF results may strongly depend on the exact ordering implied by the triangularization employed. Moreover, a literature exists that has debated whether Cholesky's schemes may make any sense when applied to systems of interest rates only, as in our case (see e.g., Mönch, 2012, and references therein).[19] It is therefore important to test whether our earlier results are robust to alternative orderings of the variables, as it is typical of the literature (see Bekaert, et al., 2013).

[18] Of course, it remains difficult to map a specific type of monetary policy action or strategy into an appropriately sized shock to EMS. Wu and Xia (2014) have used VARs to examine the effects of policies based on "forward guidance" and hence impacting on expectations on Treasury rates.

[19] All variables that obey the efficient markets hypothesis should be placed but last in a Cholesky ordering because placing it elsewhere would imply that this very variable would fail to reflect all available information. However, the shorter the period over which interest rates are averaged, the less likely it is that all rates will reflect all information.

Figures 9 and 10 (for QE and MEP shocks, respectively) show the results obtained under four orderings alternative to the one already used in Section 3. To save space, the two figures only show results for the two portfolios for which results were weaker and more erratic on the basis of the analysis above, long-term corporate bonds, both of investment and non-investment grade quality. In both figures, the first row corresponds to a sensible ordering in which we place the Treasury yields that we have assumed to be the intermediate channels of monetary policy impulses on top (i.e., 1-month and 10-year) followed by all corporate bond rates and 1- and 5-year Treasury rates at the bottom. While the sign of the reaction of long-term IG rates is always correct, in the case of QE shocks estimation is slightly imprecise and in the case of NIG rates we obtain a short-run increase that however quickly disappears to become a medium-to-long horizon negative response compatible with the policy-makers goals. The second and third row of plots of the figures concern objective orderings that place portfolios in order of increasing average maturity. The idea is that according to a mechanism similar to the expectations hypothesis, shocks would propagate from short-term bonds to long-term ones. The second (third) row is then estimated when corporates are placed before (after) Treasuries in the Cholesky ordering. Both rows display results that coherent with the main thrust of our findings in Section 3 and that appear to be coherent with the goals of unconventional monetary policies. However, results for IG long-term corporate rates are weaker and less precisely estimated in the case of the second ordering. Yet, in a maturity-sorted ordering, it makes more sense for Treasuries to precede corporates, which is indeed our third ordering. Finally, the fourth ordering is picked purposefully to lack any sensible meaning: all corporates are placed before Treasuries and in particular the assumption is that movements in Treasury rates would be caused by shocks to NIG rates, which ignores their tendency to be illiquid and sluggish in responding to economic conditions. Moreover, such an ordering is contradiction to our willingness to interpret our IRFs as simulated policy experiments. The results in the fourth of row of Figures 9 and 10 turn somewhat disappointing: although the impact of QE still has the expected sign, it is insignificant; in the case of MEP the effects are small and the sign incorrect. Not surprisingly, orderings which make little sense and contradict the very notion of the possibility of policy shocks, yield corporate bond reactions that – albeit not radically opposite to Section 3 – are generally confused and imprecisely estimated. However, when the orderings are chosen to reflect sensible hypotheses regarding the transmission mechanism of the shock, the results do not contrast the findings in Section 3.

4.6 Effects on credit spreads

In addition to these corporate yield series described in Section 2, we also construct the corresponding credit spread series. For each trade in the sample, the associated spread is calculated as the difference between the yield of the bond and the yield of a Treasury with a maturity which (approximately) matches the remaining life of the corporate bond. Importantly, this is done on a trade-by-trade basis to minimize the risk of missing out on important fluctuations in the Treasury series. $SPREAD_{t,j}$ is then the average spread for all the bonds traded in week t and belonging to portfolio j. It is worth noting that this methodology to calculate spreads is more accurate than simply taking the difference between corporate yield averages and Treasury rate (see Lin and Curtillet, 2007, for a related discussion).

Similarly to the MSIH(3,1) model for yields described above, we have also estimated a MS model for spreads, similarly to recent work by Maalaoui Chun, Dionne, and Francois (2014).[20] Because regime 1 is characterized by generally low Treasury yields, while regime 2 is characterized by high Treasury yields, corporate spreads tend to be higher in regime 2 than in regime 1. For example, the mean of NIGST spreads is equal to 8.53% in regime 1 and to 7.45% in regime 2. On the contrary, the mean of 1-month T-bill rates equals 1.76% in regime 1 and 2.02% in regime 2. Regime 1 exhibits higher volatilities and higher innovation correlations than regime 2 does. For example, NIGST spreads have a volatility of 2.15% in regime 1, but of only 0.91% in regime 2. In addition, the correlation between the innovations to NIGST spreads and 1-month T-bills equals -0.11 in regime 1, whereas it is only -0.07 in regime 2. Finally, regime 3 is characterized by high means, high volatilities and high correlations. This is particularly evident for NIG corporate bonds. Indeed, the mean of NIGST spreads reaches an annualized level of 12.42% and their volatility is equal to 3.74%. Regime 2 is by far the most persistent of the three states: its "stayer" probability is 0.96. In addition, it has an average duration of approximately 5.5 months and an ergodic probability of 68%. Regimes 1 and 3 are instead less persistent, as their "stayer" probabilities are equal to 0.88 and 0.85, respectively. Furthermore, they have an average duration of 8.59 and 6.87 weeks and an ergodic probability of 17% and 15%, respectively.

Thus, regime 1 is characterized by low rates and high spreads, while regime 2 exhibits high rates and low spreads. The existence of an inverse relationship between credit spreads and Treasury yields is well documented in the literature (e.g., Duffee, 1998, and Lin and Curtillet, 2007) and it is also consistent with the findings presented in Section 3. Moreover, many authors who have employed MS models document the presence of a highly persistent regime in which

[20] In a model with endogenous regimes for US credit spreads (computed from transaction data for corporate bonds collected by the National Association of Insurance Commissioners) or with monetary regimes, they find that market, default, and liquidity factors have superior explanatory power because of their interaction with regimes.

rates are stable and characterized by low means and low volatilities and one in which the opposite is true (see Guidolin, 2012). The behavior of the spreads, instead, is similar to the one that has been empirically observed for stock risk premia: volatility tends to be high when means are low. Finally, regime 3 exhibits peculiar characteristics, such as flight-to-quality and a peak in volatilities and correlations, which are typical in times of crisis (see, for example, Longstaff, 2010).

We next estimate IRFs for the three types of shocks that we have already used in Section 3 to represent a conventional expansion, QE and MEP, respectively. Figures 11 through 13 show IRFs for the MSIH(3,1) model applied to spreads. The graphs show the responses, along with 95% confidence bands, up to 26 weeks after policy shocks. In Figure 11, the effects of an expansionary policy on credit spreads also vary according to the assumptions on the initial regime. However, conventional policies remain generally ineffective. In the *high rates/low spreads* state, the effects of an expansionary conventional policy are close to zero for both IG and NIG spreads. In particular, the responses of IG spreads are not statistically significant and do not even reach 1 bp; the responses of NIGs are statistically significant only in the week subsequent to the policy shock. NIGST spreads increase by about 3 bps, whereas the long-term ones decrease by about 2 bps. In contrast, the effects on corporate spreads are significant and persistent in the *low rates/high spreads* state. In this regime, IG and especially NIG spreads increase as a result of a shock. In particular, IGST spreads *increase* by 14 bps, while the long-term ones *increase* by 4 bps. The *positive*, counter-intuitive effects on NIG spreads are even more pronounced. For NIGST spreads, the effects peak (at approximately 46 bps) after a month and then start to slowly decay. NIGLT spreads, instead, *increase* by 14 bps. All the responses tend to remain significant for about 7-9 weeks with the exception of IGST bonds, which becomes statistically insignificant after just 2 weeks. These effects contradict the classical goals of the monetary authorities because an *increment* in credit spreads is a sign of an increase in the perceived risk of corporate bonds and is likely to hamper investments and hence real growth.

In the crisis state, the effects differ on the basis of whether we consider short or long-term bonds, irrespective of their IG or NIG nature: the response to an expansionary policy is not statistically significant for IGLT and even negative for NIGLT spreads. The latter decrease—which is the first instance consistent with objectives of an expansionary policy—by 18 bps, even though the effect levels off quickly and the response is statistically significant only for up to 3 weeks. In contrast, short-term spreads *increase* by about 6 bps for IG bonds and by 20 bps for the NIG ones. In both cases, the responses are significant for one month.

Also in this case, a literature exists that can be used to provide some foundations to our empirical results. For instance, Wu and Zhang (2008) have studied the effects that a shock to some macroeconomic factors, such as real output, inflation and market volatility, produce on corporate spreads. Their results suggest that a positive shock to inflation generates an increase in corporate spreads. These results are coherent with our findings, which show that an expansionary policy tends to increase spreads. Moreover, similarly to what happens to yields, the empirical responses were particularly pronounced in the crisis regime, especially for short-term spreads. This is consistent with the idea that corporate spreads not only incorporate the risk of default of the firm, but also a bond risk premium, similar to the equity risk premium. Gourio (2013) suggests that this risk premium compensates the investors for bearing "tail risk", i.e., the risk of low probability events with disastrous consequences, such as the collapse of the financial system.

Similarly to the results for yields, many of the responses of IG spreads to the implementation of QE in Figure 12 are not statistically significant. In contrast, the effects of the policy on NIG spreads depend on the nature of the regime. In a state of *crisis,* the policy produces an increase of 22 bps in NIGST spreads and of about 44 bps in long-term ones. In both cases the responses tend to die away quickly and are statistically significant for less than 1 month. In the *low rates/high spreads* regime, QE produces a reduction of both NIGST and long-term spreads. In particular, the former *decrease* by about 33 bps, while the latter fall by approximately 15 bps. These responses tend to level off in 5-6 weeks and they remain statistically significant only for 3 weeks. Although they are not particularly persistent, these effects conform to the likely intended effects of the monetary policies. In contrast, in the *high rates/low spreads* regime the responses are by far less pronounced. In particular, the response of NIGLT spreads is not statistically significant. NIGST spreads, instead, are subject to a *decrease* of about 7 bps, but the effect is statistically significant only for up to two weeks.

All in all, the effects of QE on the spreads are similar to the ones that have been observed for the yields. Indeed, many of the responses are not significant, especially for IG bonds. Furthermore, in the crisis regime QE produces an increase of both short- and long-term spreads. These results are compatible with the fact that QE implies the creation of monetary base, which increases inflation (see Bernanke and Mihov, 1998). As explained in Section 3, a positive shock to expected inflation may then trigger an increase in corporate yields and spreads, according to Krishnamurthy and Vissing-Jorgensen's (2011) inflation expectations channel.

The effects of MEP on corporate spreads in Figure 13 are in general more pronounced for NIG bonds. In the crisis state, for example, the responses of IG spreads to the implementation of the policy are statistically insignificant. NIGST and NIGLT spreads, instead, increase by about 10 bps and 63 bps, respectively. For NIGST spreads the response is significant only over the week following a shock. For NIGLT spreads the response is statistically significant up to 3 weeks. In the *low rates/high spreads* regime, MEP produces negative responses for all spreads except IGLT ones. In fact, for the latter the response is not statistically significant. Instead, IGST spreads decrease by about 10 bps. The effects are more pronounced for short- and long-term NIG bonds: indeed, their spreads drop by about 70 and 30 bps, respectively. Although decreasing, their responses remain statistically significant for more than 1 month after the implementation of the policy, which represents a considerable effect. In contrast to the crisis regime, in this state the overall effects of MEP are in line with the objectives of the monetary authorities. Finally, in the *high rates/low spreads* state the responses of corporate spreads to the policy are in general not statistically significant. The only exception concerns NIGLT spreads, which slightly increase (3 bps). However, the effects are statistically significant only during the first week after the implementation of the policy.

Thus, while in the *low rates/high spreads* regime the relationship between corporate spreads and Treasury yields is generally positive (i.e., a reduction in the slope is associated with a reduction in the spreads), in the crisis regime this relationship becomes negative, in line with the findings of Duffee (1998). This is coherent with the well-documented idea that the slope of the Treasury yield curve is a leading indicator of the business cycle. In particular, a reduction of the slope is interpreted as a signal of an imminent recession. Clearly, this is especially true in a crisis regime when a recession is impending. Consequently, a negative shock to the slope is likely to increase the risk premium component of the spreads, as suggested by Gourio (2013). Thus, in the crisis regime, MEP can be expected to lower yields, as it is a non-inflationary policy, but it increases spreads, because of the signals that it sends to the market about the conditions of the economy.

4.7 Other robustness checks

We have also re-estimated the *MSIH(3,1)* model (also for spreads) with the Treasury yield factors—i.e., level, slope and curvature—in place of the Treasury yield series. Our robustness checks confirm most of our reported results. In particular, this exercise allows us to verify that our interpretation of the regimes holds in this alternative framework. This matters because incorrect definitions of the states would affect the interpretation of the economic consequences of different types of monetary policies.[21] In particular, Figure 14 shows that MEP, modelled as a change in the slope factor, causes large, persistent, and statistically significant declines in yields, especially in short-term corporate rates, both NIGST and IGST; the effects are weaker and their sign shifts over time in the case of long-term corporate rates. The bottom panel of Figure 14 shows that roughly two-thirds of the

[21] Complete results of all robustness checks are available from the author(s) upon request.

effects derive from a decline in risk premia. However, these effects manifest themselves only in the crisis regime and not in the two remaining states, similarly to the evidence above.

5. Conclusions

We have investigated the effects on corporate yields of three different types of policies: a conventional monetary expansion, quantitative easing, and the maturity extension program. We have simulated the three policies both through shocks to the Treasury yields that simply assume their effectiveness, and by adopting strategies that measure in a more direct ways shocks to size and composition of the Fed's balance sheet. This approach is different from the one that has been adopted by previous studies (e.g., Gagnon et al., 2010; Krishnamurthy and Vissing-Jorgensen, 2011; Joyce et al., 2011) that have tried to measure the effects of unconventional monetary policies during the recent financial crisis using ex-post data on resulting changes in yields and economic performance, mostly through event studies. Indeed, our goal is not to provide an ex-post evaluation of the policies, but rather to understand what are the general responses one would have expected at the time the of the interventions on the basis of relatively long time series of data.

Our results show that the responses of corporate bonds to the simulated policies are statistically significant and large only in the crisis state. Considering that this regime is the most relevant to our analysis because we focus on the policies that the Fed carried out during the 2008-2009 financial turmoil and ensuing recession, it is worthwhile to summarize here our key results. In the crisis regime a conventional monetary policy based on short-term rates (to include implicit, shadow measures that may take negative values, as recently popularized in the literature), tends to lead to weak effects or even to an increase in corporate yields. As in Kontonikas, MacDonald, and Saggu (2013), with nominal interest rates approaching the zero lower bound and the macro-financial environment sharply deteriorating, conventional rate cuts signal worsening future conditions, consistently with the Keynesian liquidity trap theory. QE, is generally able to decrease corporate yields, even if these effects are smaller compared to the ones that can be attributed to MEP. However, even though the sign of the responses is the one expected by the policy-makers, the size of effects presented in Section 3 depends on the specific assumptions we make on the decline in long-term Treasury yields caused by QE vs. MEP.

Finally, the MEP, which is instead a non-inflationary monetary policy, is able to decrease all yields. This result that the MEP can be expected to lower yields, especially for NIG bonds, in line with Swanson's (2011) findings that the earlier historical "operation twist" episode in the U.S. led to similarly sized, hence effective, announcement effects on Treasury yields and Hamilton and Wu's (2012) positive results on the effectiveness of MEP. Equivalently, our paper can be interpreted as providing evidence on the ex-ante effectiveness of an aggregate duration channel of unconventional policy pursued through MEP. If investors dislike interest rate (duration) risk, when the central bank purchases long-duration assets it reduces the aggregate amount of duration risk that remains in the market and needs to be borne by the private sector. As a result, the compensation required by investors to hold all remaining bonds carrying duration risk falls, putting downward pressure on yields.

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Table 1: Estimation results: MSIH(3,1)-yields

	Investment Grade ST	Investment Grade LT	Non-Investment Grade ST	Non-Investment Grade LT	1 m Treasury yield	1 y Treasury yield	5 y Treasury yield	10 y Treasury yield
1. Intercept term								
Regime 1	**-0.365*** **	**0.152** **	**0.376*** **	**0.975*** **	**-0.070*** **	-0.014	**-0.101* **	-0.069
(Low rates/High spreads)	**(0.000)**	**(0.049)**	**(0.008)**	**(0.000)**	**(0.005)**	(0.489)	**(0.069)**	(0.229)
Regime 2	0.193	**0.227** **	**1.166*** **	**1.892*** **	**-0.148*** **	**-0.073** **	**-0.198*** **	**-0.140** **
(High rates/Low spreads)	(0.147)	**(0.013)**	**(0.000)**	**(0.000)**	**(0.006)**	**(0.027)**	**(0.002)**	**(0.032)**
Regime 3	0.035	**0.196*** **	-0.003	0.017	**-0.103** **	0.015	-0.077	-0.057
(Crisis)	(0.689)	**(0.010)**	(0.986)	(0.854)	**(0.02)**	(0.564)	(0.187)	(0.328)
2. VAR(1) Matrix								
Investment Grade ST	**0.693*** **	**0.066** **	0.270	**0.201** **	**-0.056*** **	-0.003	0.005	-0.008
(t-1)	**(0.000)**	**(0.016)**	(0.125)	**(0.04)**	**(0.000)**	(0.729)	(0.763)	(0.631)
Investment Grade LT	**0.228*** **	**0.87*** **	0.092	0.127	**0.039*** **	0.006	**0.043** **	**0.068*** **
(t-1)	**(0.000)**	**(0.000)**	(0.716)	(0.352)	**(0.003)**	(0.545)	**(0.047)**	**(0.002)**
Non-Investment Grade ST	**0.009*** **	0.004	**0.823*** **	**0.062*** **	0.000	-0.002	**-0.007*** **	**-0.009*** **
(t-1)	**(0.004)**	(0.173)	**(0.000)**	**(0.000)**	(0.767)	(0.015)	**(0.001)**	**(0.000)**
Non-Investment Grade LT	-0.009	-0.001	**0.153*** **	**0.601*** **	0.001	0.001	0.006	**0.006* **
(t-1)	(0.110)	(0.815)	**(0.005)**	**(0.000)**	(0.31)	(0.483)	(0.108)	**(0.100)**
1 m Treasury yield	0.053	0.032	-0.244	**0.193** **	**0.785*** **	**-0.053*** **	-0.035	-0.008
(t-1)	(0.202)	(0.236)	(0.169)	**(0.045)**	**(0.000)**	**(0.000)**	(0.141)	(0.726)
1 y Treasury yield	0.042	-0.028	0.067	**-0.357* **	**0.278*** **	**1.058*** **	0.043	-0.008
(t-1)	(0.483)	(0.528)	(0.846)	**(0.074)**	**(0.000)**	**(0.000)**	(0.252)	(0.813)
5 y Treasury yield	0.004	-0.161	0.701	-0.325	-0.033	-0.02	**0.981*** **	0.090
(t-1)	(0.954)	(0.023)	(0.288)	(0.379)	(0.108)	(0.232)	**(0.000)**	(0.112)
10 y Treasury yield	-0.039	**0.191*** **	-0.843	**0.605* **	-0.006	0.007	-0.029	**0.872*** **
(t-1)	(0.577)	**(0.005)**	(0.164)	**(0.068)**	(0.761)	(0.648)	(0.548)	**(0.000)**
R-squared	0.964	0.976	0.932	0.881	0.995	0.995	0.999	0.990
3.Unconditional mean								
Regime 1 (Low rates/High spreads)	1.349	3.585	6.866	7.106	0.183	0.220	0.562	1.546
Regime 2 (High rates/Low spreads)	5.456	6.024	8.992	7.773	4.388	4.644	4.840	5.047
Regime 3 (Crisis)	4.453	6.861	29.016	17.022	-5.343	-3.793	-0.352	1.489

Table 1 (Continued)

	Investment Grade ST	Investment Grade LT	Non-Investment Grade ST	Non-Investment Grade LT	1 m Treasury yield	1 y Treasury yield	5 y Treasury yield	10 y Treasury yield
4. Correlations/Volatilities								
Regime 1								
Investment Grade ST	0.095							
Investment Grade LT	0.519	0.103						
Non-Investment Grade ST	0.060	0.115	1.586					
Non-Investment Grade LT	-0.114	0.019	0.150	1.065				
1 m Treasury yield	-0.062	-0.044	-0.037	0.059	0.023			
1 y Treasury yield	0.029	-0.019	0.019	-0.075	0.249	0.021		
5 y Treasury yield	-0.059	-0.083	-0.050	-0.083	-0.115	0.627	0.095	
10 y Treasury yield	-0.103	-0.071	-0.051	-0.070	-0.087	0.507	0.910	0.101
Regime 2								
Investment Grade ST	0.144							
Investment Grade LT	0.465	0.083						
Non-Investment Grade ST	0.071	0.150	0.537					
Non-Investment Grade LT	0.199	0.150	0.206	0.270				
1 m Treasury yield	0.179	0.238	-0.029	0.075	0.123			
1 y Treasury yield	0.102	0.030	0.022	-0.086	0.199	0.059		
5 y Treasury yield	0.084	0.039	0.095	-0.103	0.003	0.847	0.087	
10 y Treasury yield	0.061	0.041	0.088	-0.121	-0.061	0.746	0.954	0.076
Regime 3								
Investment Grade ST	0.927							
Investment Grade LT	0.632	0.390						
Non-Investment Grade ST	0.557	0.547	4.374					
Non-Investment Grade LT	0.315	0.111	0.421	3.118				
1 m Treasury yield	-0.216	-0.106	-0.107	-0.023	0.327			
1 y Treasury yield	-0.122	0.079	-0.006	-0.091	0.637	0.180		
5 y Treasury yield	-0.139	0.146	0.006	-0.263	0.229	0.583	0.163	
10 y Treasury yield	-0.115	0.155	0.113	-0.247	0.100	0.342	0.865	0.155

5.Transition Matrix	Regime 1	Regime 2	Regime 3
Regime 1 (Low rates/High spreads)	0.99	0.00	0.01
Regime 2 (High rates/Low spreads)	0.00	0.97	0.03
Regime 3 (Crisis)	0.06	0.11	0.83

*significat at 10% level, **significant at 5% level, ***significant at 1% level

Table 2: Estimation results: MSIH(3,1) model when the short-term rate is the shadow short policy rate

	Investment Grade ST	Investment Grade LT	Non-Investment Grade ST	Non-Investment Grade LT	*Shadow* Fed Funds Rate	1 y Treasury yield	5 y Treasury yield	10 y Treasury yield
1. Intercept term								
Regime 1	**-0.269*****	**0.178****	0.141	**0.972*****	**0.408*****	**0.066*****	**0.201*****	**0.205*****
(Low rates/high spreads)	**(0.002)**	**(0.022)**	(0.212)	**(0.000)**	**(0.000)**	**(0.005)**	**(0.000)**	**(0.000)**
Regime 2	**0.255****	**0.241*****	**1.136*****	**1.847*****	**0.439*****	0.030	**0.126****	**0.138****
(High rates/low spreads)	**(0.045)**	**(0.005)**	**(0.000)**	**(0.000)**	**(0.000)**	(0.367)	**(0.030)**	**(0.019)**
Regime 3	0.085	**0.220*****	(0.070)	-0.072	**0.465*****	**0.102*****	**0.165*****	**0.153*****
(Crisis)	(0.309)	**(0.002)**	(0.630)	(0.571)	**(0.000)**	**(0.000)**	**(0.001)**	**(0.003)**
2. VAR(1) Matrix								
Investment Grade ST	**0.686*****	0.039	0.294	**0.177***	0.013	-0.006	-0.015	**-0.032****
(t-1)	**(0.000)**	(0.111)	(0.118)	**(0.089)**	(0.639)	(0.518)	(0.326)	**(0.038)**
Investment Grade LT	**0.217*****	**0.905*****	0.106	0.141	**-0.060***	(0.011)	**0.059*****	**0.089*****
(t-1)	**(0.000)**	**(0.000)**	(0.662)	(0.287)	**(0.094)**	(0.258)	**(0.002)**	**(0.000)**
Non-Investment Grade ST	**0.009*****	0.002	**0.832*****	**0.049*****	**0.009****	**-0.002****	**-0.007*****	**-0.009*****
(t-1)	**(0.002)**	(0.436)	**(0.000)**	**(0.002)**	**(0.037)**	**(0.033)**	**(0.001)**	**(0.000)**
Non-Investment Grade LT	-0.007	0.001	**0.127****	**0.631*****	**-0.015****	-0.001	0.001	0.002
(t-1)	(0.151)	(0.769)	**(0.014)**	**(0.000)**	**(0.031)**	(0.536)	(0.822)	(0.508)
1 m Treasury yield	0.003	0.006	-0.117	0.055	**1.004*****	**0.013*****	**0.059*****	**0.060*****
(t-1)	(0.756)	(0.545)	(0.194)	(0.289)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
1 y Treasury yield	**0.108*****	0.006	**-0.363****	-0.054	**-0.061****	**0.992*****	0.012	0.002
(t-1)	**(0.000)**	(0.764)	**(0.021)**	(0.529)	**(0.034)**	**(0.000)**	(0.383)	(0.902)
5 y Treasury yield	0.025	**-0.112***	**1.368****	**-0.661****	0.135	**-0.033****	**0.830*****	**-0.086***
(t-1)	(0.714)	**(0.087)**	**(0.020)**	**(0.034)**	(0.191)	**(0.047)**	**(0.000)**	**(0.080)**
10 y Treasury yield	-0.070	**0.117****	**-1.217****	**0.765*****	-0.112	0.002	0.015	**0.931*****
(t-1)	(0.264)	**(0.048)**	**(0.019)**	**(0.006)**	(0.196)	(0.873)	(0.719)	**(0.000)**
3. Unconditional Mean								
Regime 1 (Low rates/high spreads)	1.663	4.067	6.897	8.028	-2.862	0.491	1.468	2.535
Regime 2 (high rates/low spreads)	5.175	5.510	9.143	6.639	2.695	4.384	3.683	3.789
Regime 3 (Crisis)	4.714	8.123	28.869	20.095	0.362	-3.668	2.363	4.598
R-squared	0.963	0.976	0.932	0.884	0.997	0.998	0.995	0.990

Table 2 (continued)

	Investment Grade ST	Investment Grade LT	Non-Investment Grade ST	Non-Investment Grade LT	*Shadow* Fed Funds Rate	1 y Treasury yield	5 y Treasury yield	10 y Treasury yield
4. Correlations/Volatilities								
Regime 1								
Investment Grade ST	0.085							
Investment Grade LT	0.464	0.101						
Non-Investment Grade ST	0.044	0.107	1.572					
Non-Investment Grade LT	-0.059	0.112	0.119	0.980				
1 m Treasury yield	0.295	0.296	-0.045	0.041	0.203			
1 y Treasury yield	0.001	-0.046	0.010	-0.086	0.094	0.019		
5 y Treasury yield	-0.094	-0.101	-0.053	-0.119	0.080	0.586	0.084	
10 y Treasury yield	-0.139	-0.082	-0.044	-0.102	0.081	0.457	0.897	0.092
Regime 2								
Investment Grade ST	0.144							
Investment Grade LT	0.471	0.087						
Non-Investment Grade ST	0.083	0.180	0.548					
Non-Investment Grade LT	0.172	0.131	0.246	0.283				
1 m Treasury yield	0.218	0.167	-0.042	-0.265	0.125			
1 y Treasury yield	0.033	-0.097	0.088	-0.070	0.004	0.065		
5 y Treasury yield	0.015	-0.099	0.150	-0.108	0.070	0.852	0.085	
10 y Treasury yield	0.004	-0.071	0.141	-0.123	0.105	0.720	0.941	0.073
Regime 3								
Investment Grade ST	0.918							
Investment Grade LT	0.647	0.374						
Non-Investment Grade ST	0.548	0.550	4.265					
Non-Investment Grade LT	0.289	0.100	0.431	3.105				
1 m Treasury yield	-0.050	-0.136	-0.069	0.005	0.228			
1 y Treasury yield	-0.153	0.051	-0.010	-0.093	0.023	0.172		
5 y Treasury yield	-0.240	0.059	0.001	-0.247	0.026	0.559	0.171	
10 y Treasury yield	-0.201	0.073	0.100	-0.215	0.003	0.347	0.881	0.166

5. Transition Matrix	Regime 1	Regime 2	Regime 3
Regime 1 (Low rates/high spreads)	0.983	0.000	0.017
Regime 2 (high rates/low spreads)	0.000	0.963	0.037
Regime 3 (Crisis)	0.076	0.116	0.809

*significat at 10% level, **significant at 5% level, ***significant at 1% level

Table 3: Summary of standardized (per-100 billion dollars) weekly impacts from different unconventional monetary policy measures

The table summarizes standardized, weekly impacts on 10-year Treasury rates estimated under a variety of methods and assumptions in the papers listed in the leftmost column. In the table, LSAP I refers to the FOMC announcements and operations consisting of the purchase of long-term Treasury securities for US$300 billion over the following six months as expressed on March 18, 2009. LSAP II refers to the November 3, 2010 announcements of the intention to purchase a further US$600 billion of longer term Treasury securities by the end of the second quarter of 2011. LSAP II was then extended and IMF (2013) does distinguish it from an LSAP III operation. MEP consist of a plan first announced on September 21, 2011 to purchase, by the end of June 2012, US$400 billion of Treasury securities with remaining maturities of six years to 30 years and to sell an equal amount of Treasury securities with remaining maturities of three years or less.

	Operation	Type of analysis	Frequency of data	Impact of 100 billion per week
Bauer and Rudebusch (2011)	LSAP I	Event study	Daily	- 5.1 bps
D'Amico and King (2010)	LSAP I	Event study	Daily	-70 bps
D'Amico et al. (2011)	LSAP I	Regression/model-based	Weekly	-11.67 bps
Doh (2010)	LSAP I	Event study	Weekly	-4 bps
Krishnamurthy and Vissing-Jorgensen (2011)	LSAP I	Event study	Daily	-6.11 bps
Neely (2011)	LSAP I	Event study	Daily	- 6 bps
Gagnon et al. (2011)	LSAP I	Event study	Daily	-5 bps
Hamilton and Wu (2011)	LSAP I	Regression/model-based	Weekly	-3.5 bps
D'Amico et al. (2011)	LSAP II	Regression/model-based	Weekly	-9 bps
Krishnamurthy and Vissing-Jorgensen (2011)	LSAP II	Event study	Daily	-4.55 bps
Meaning and Zhu (2011)	LSAP II	Regression/model-based	Daily	-47 bps
Swanson (2011)	MEP	Event study	Daily	-15 bps (not per 100 billion)
Hamilton and Wu (2010)	MEP	Regression/model-based	Weekly	- 3 bps
Meaning and Zhu (2011)	MEP	Event study	Daily	-4.25 bps

Figure 1: MSIH(3,1) model: Smoothed probabilities

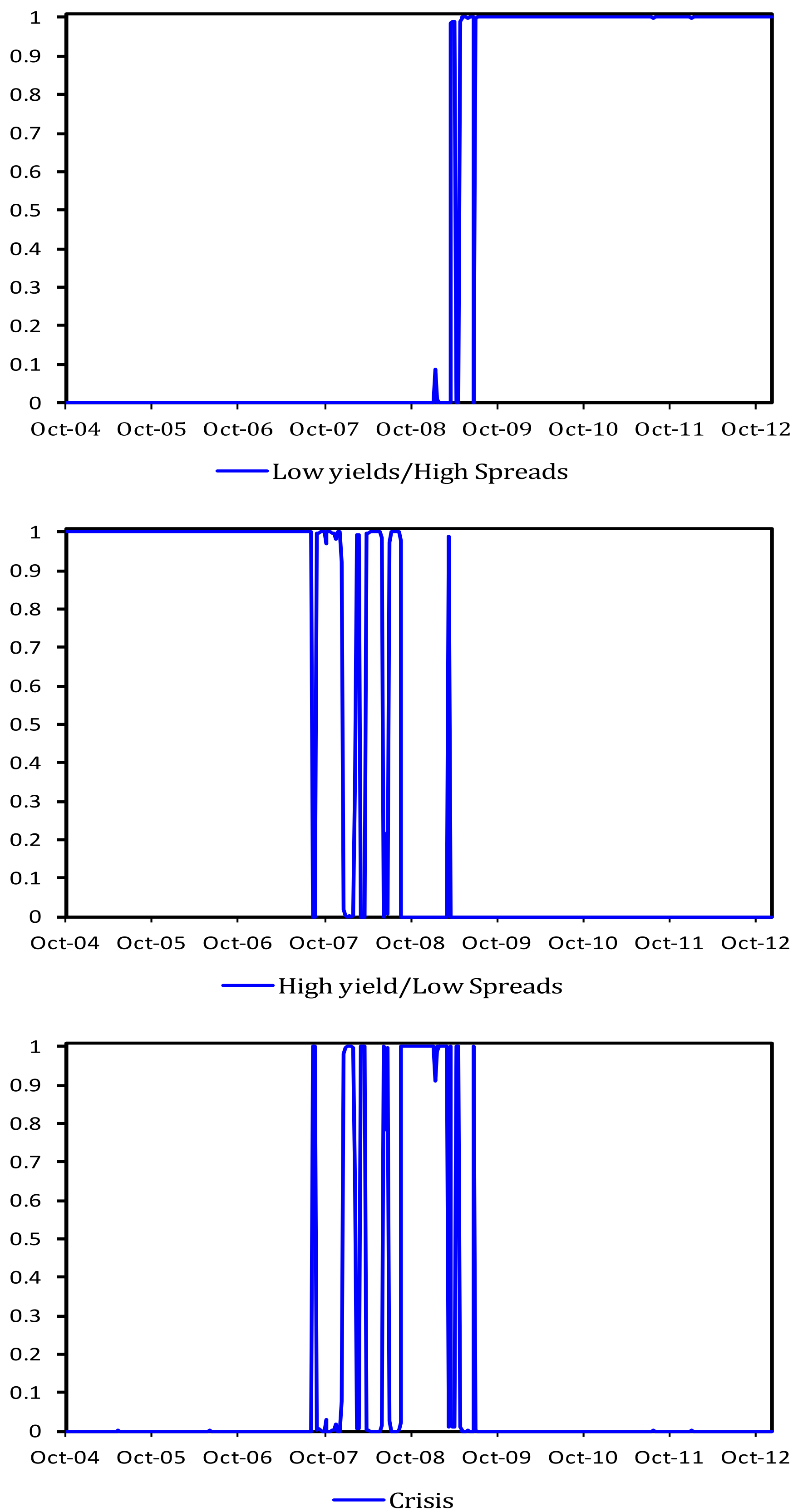

Figure 2: MSIH (3,1) model: Impulse responses to conventional monetary policy

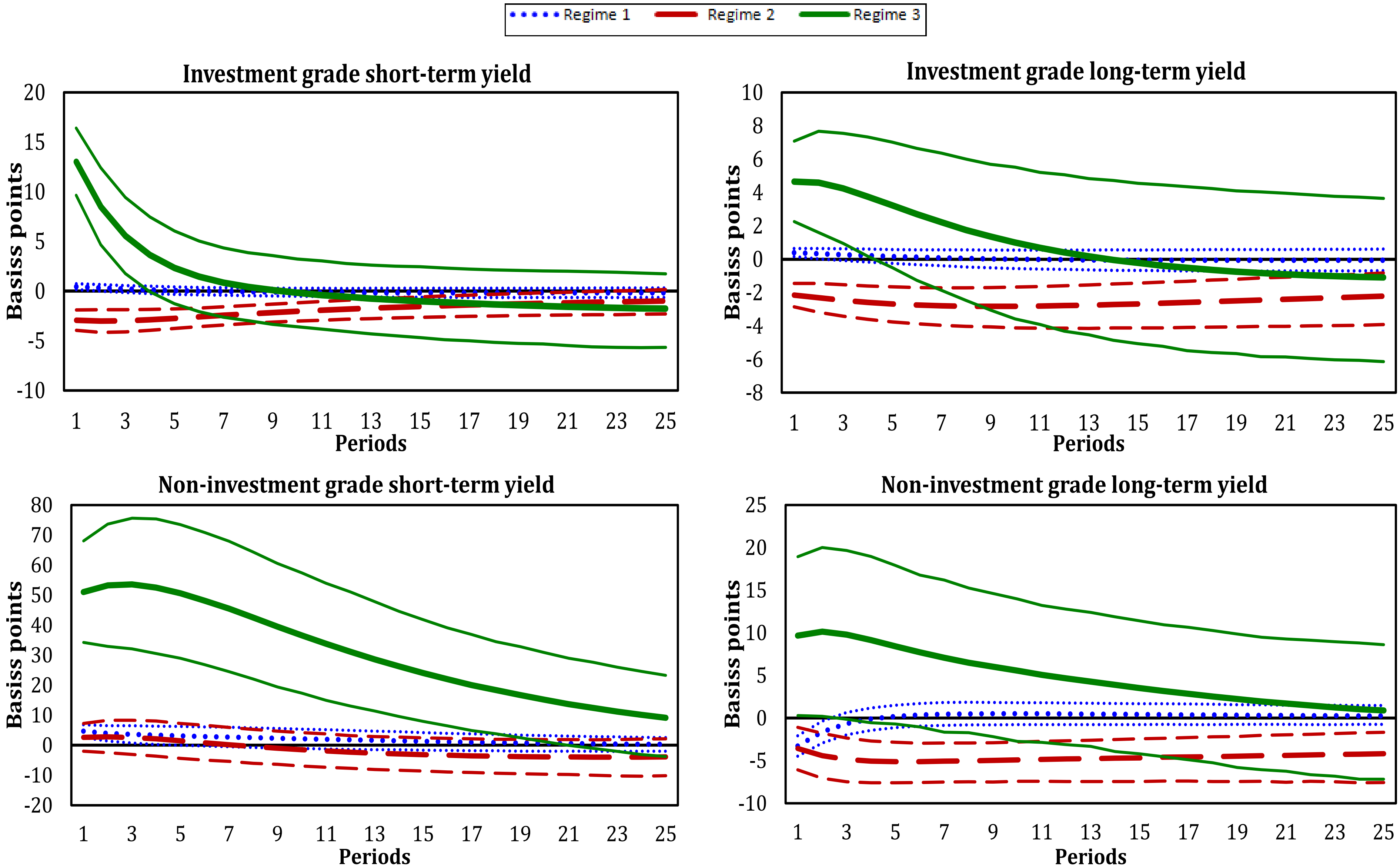

Figure 3: MSIH (3,1) model: Impulse responses to quantitative easing

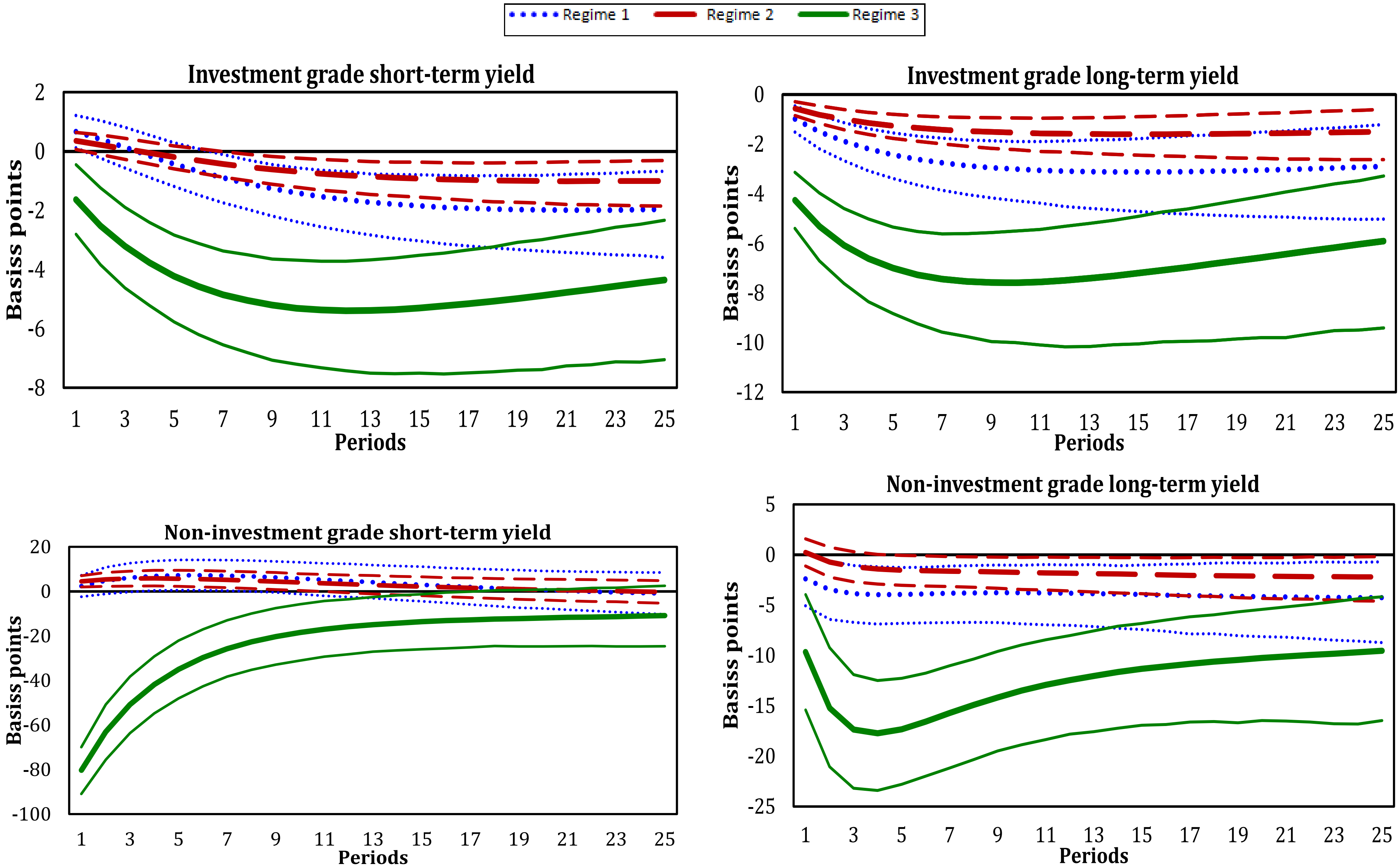

Figure 4: MSIH (3,1) model: Impulse responses to operation twist

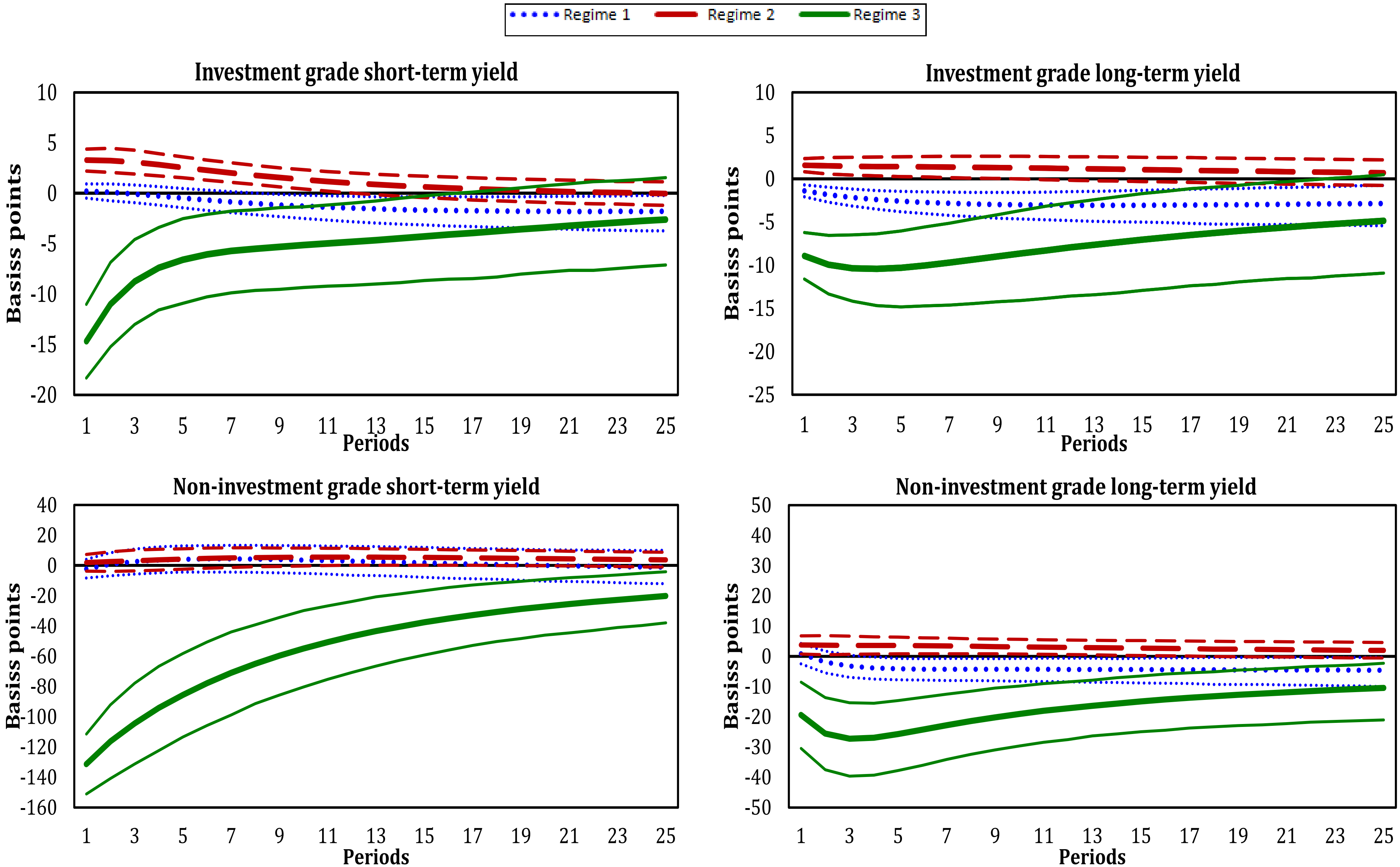

Figure 5: IRFs to conventional monetary policy: one standard deviation shock to shadow short policy rate

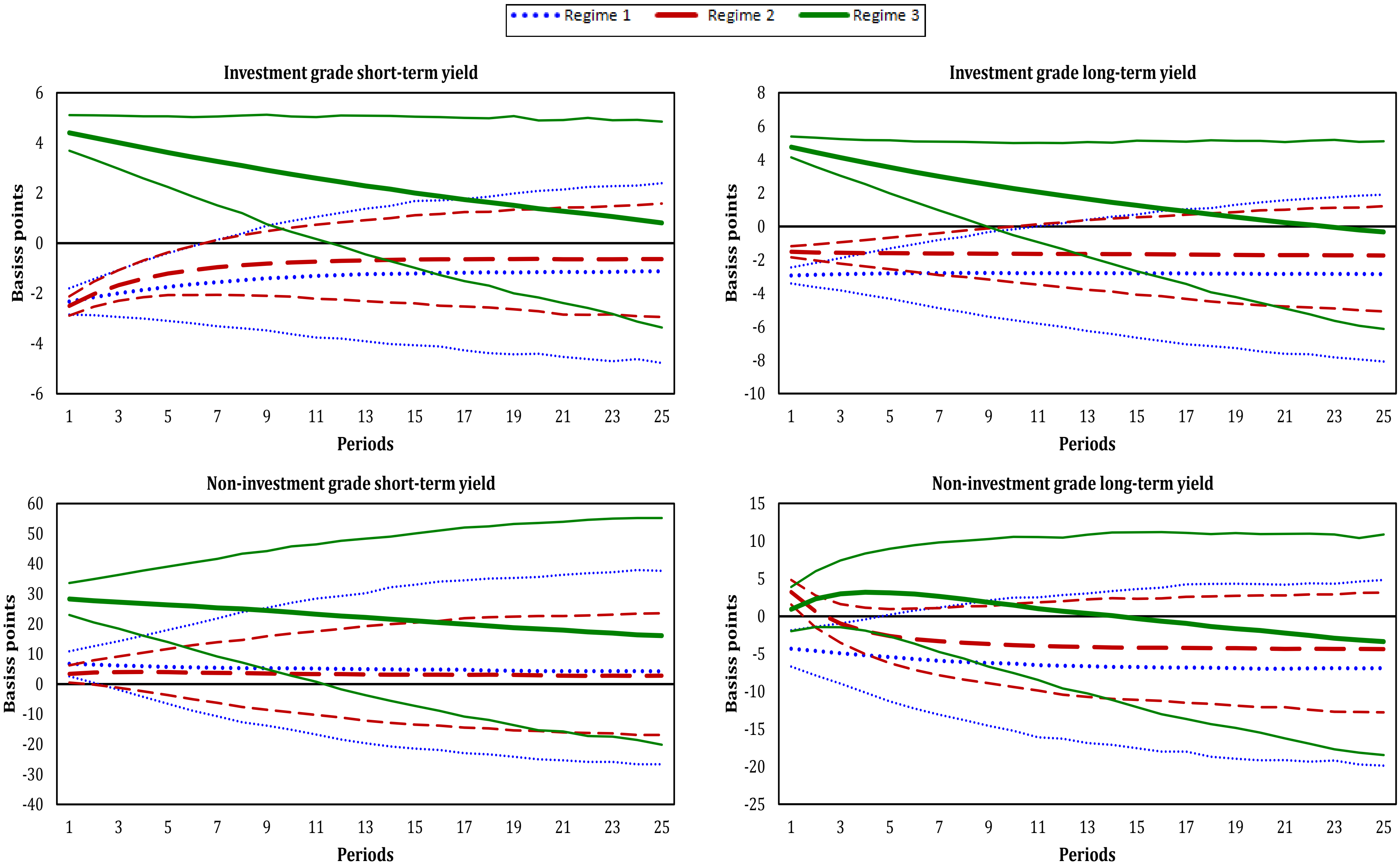

Figure 6: Economic bootstrap of IRFs for quantitative easing shocks: effects of a range of shocks to 10-year Treasury yields

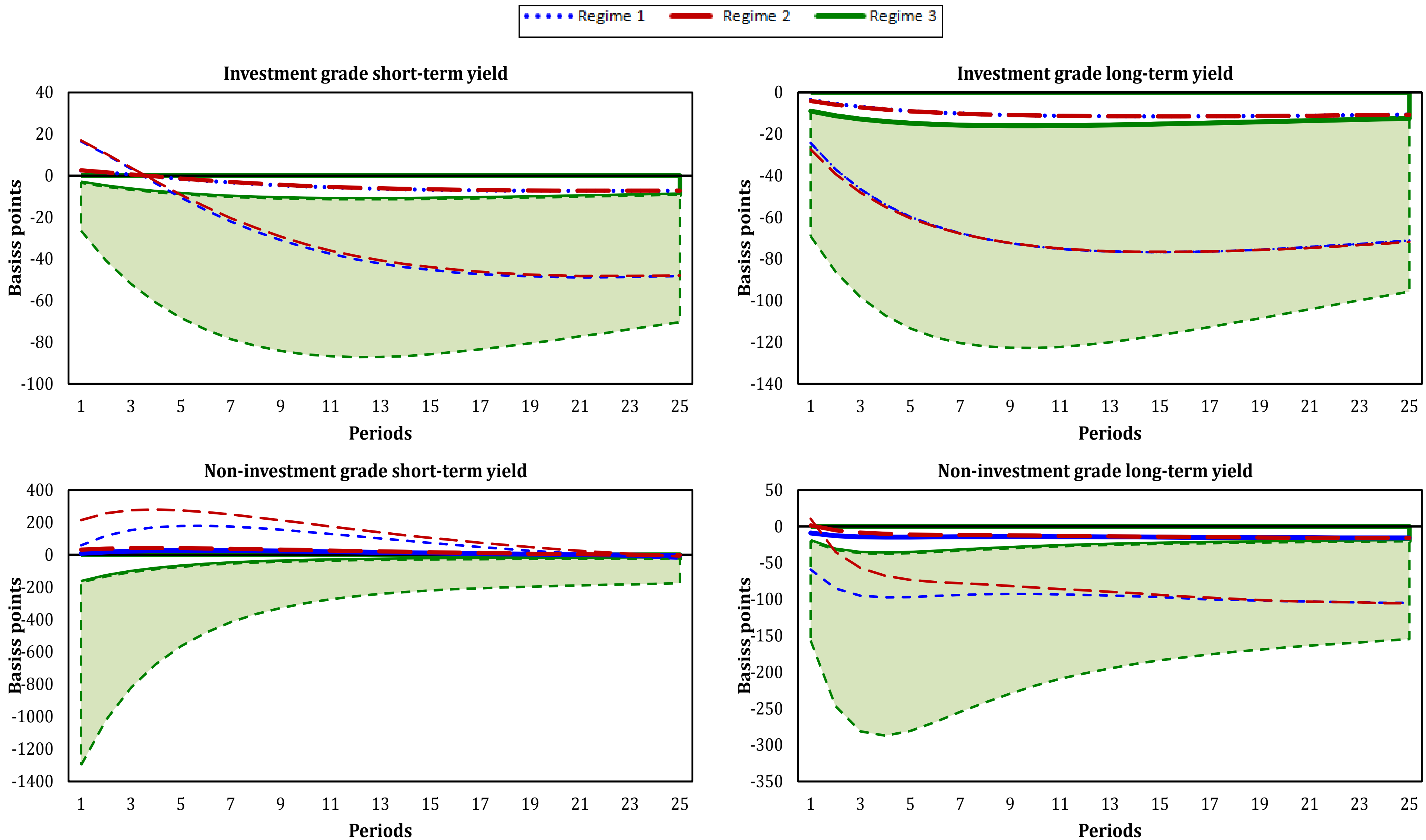

Figure 7: Economic bootstrap of IRFs for maturity extension program shocks: effects of a range of shocks to 10-year Treasury yields

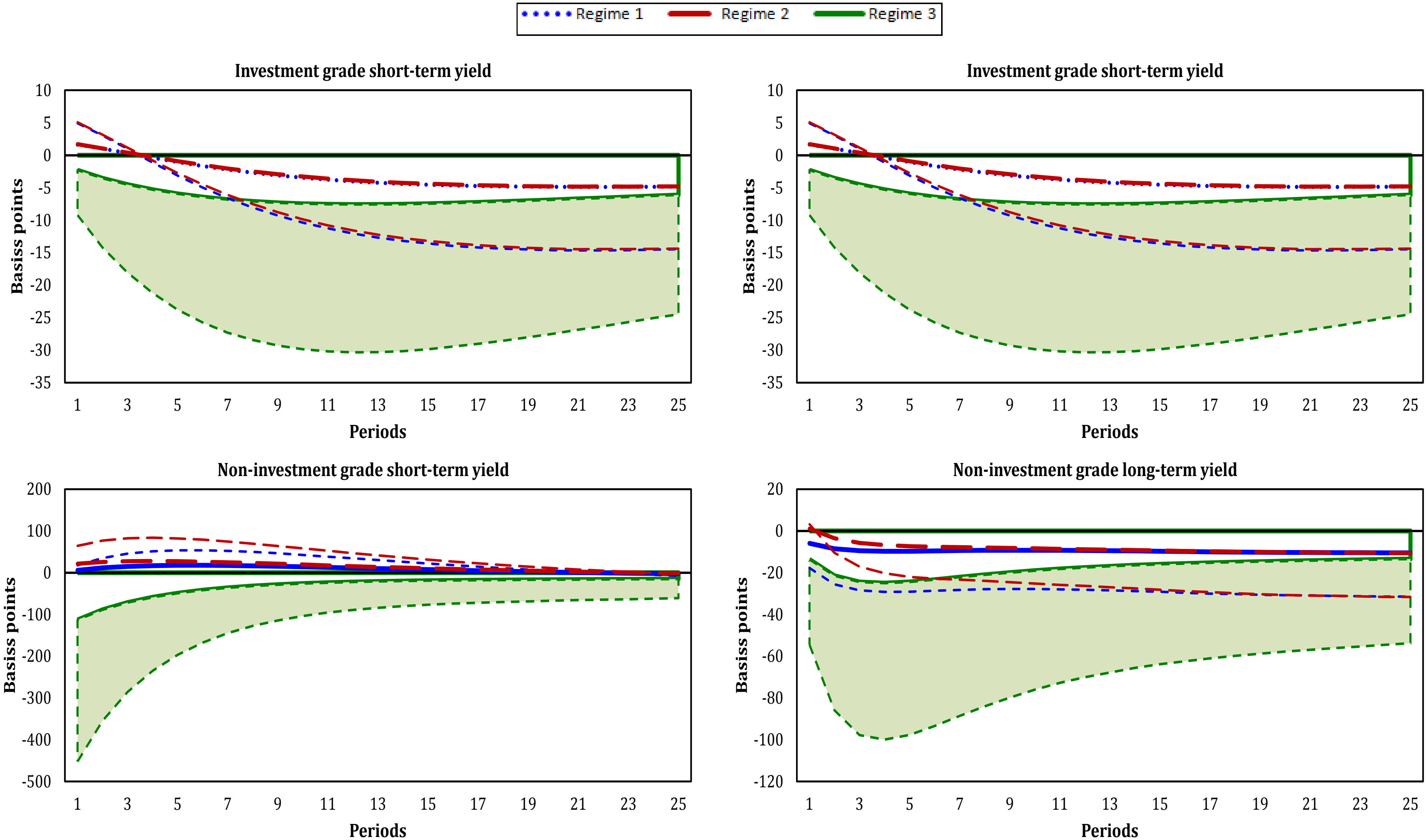

Figure 8: IRFs to maturity extension program shocks: effects of a one standard deviation shock to the weekly change in the average maturity of the securities in the Federal Reserve balance sheet

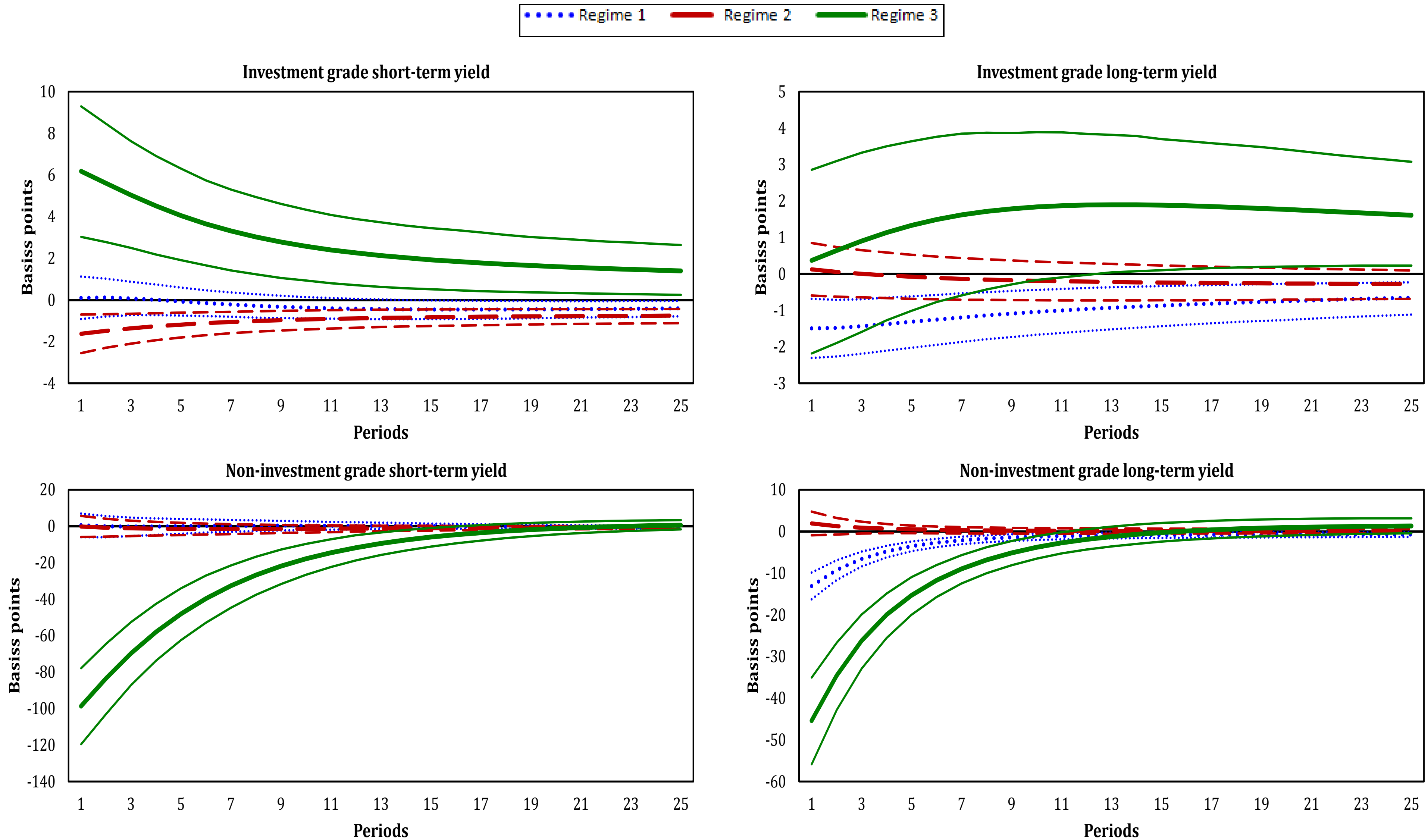

Figure 9: Effects of alternative orderings implied by Choleski identification schemes on the impact of QE shocks on long-term corporate bond yields

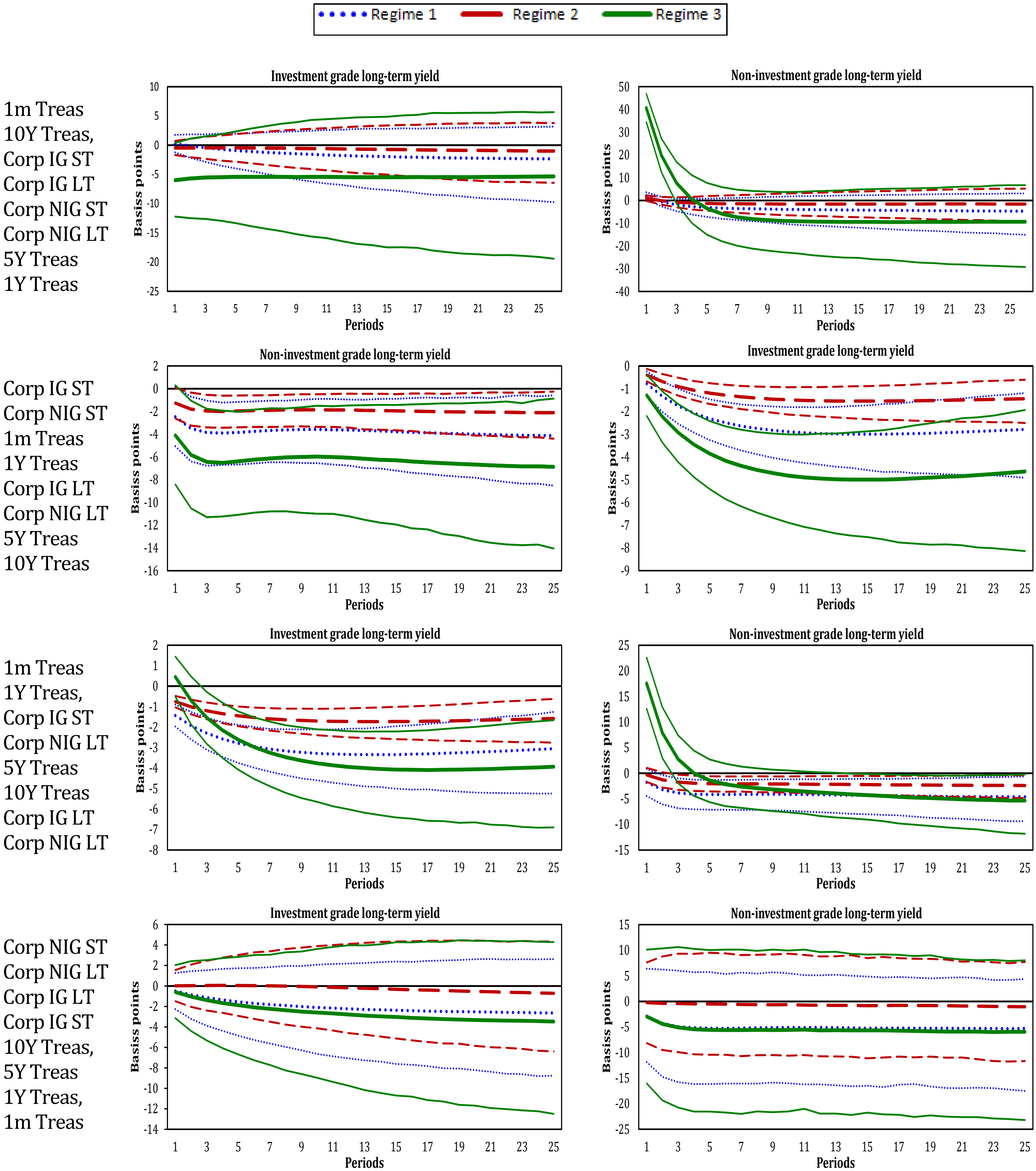

Figure 10: Effects of alternative orderings implied by Choleski identification schemes on the impact of MEP shocks on long-term corporate bond yields

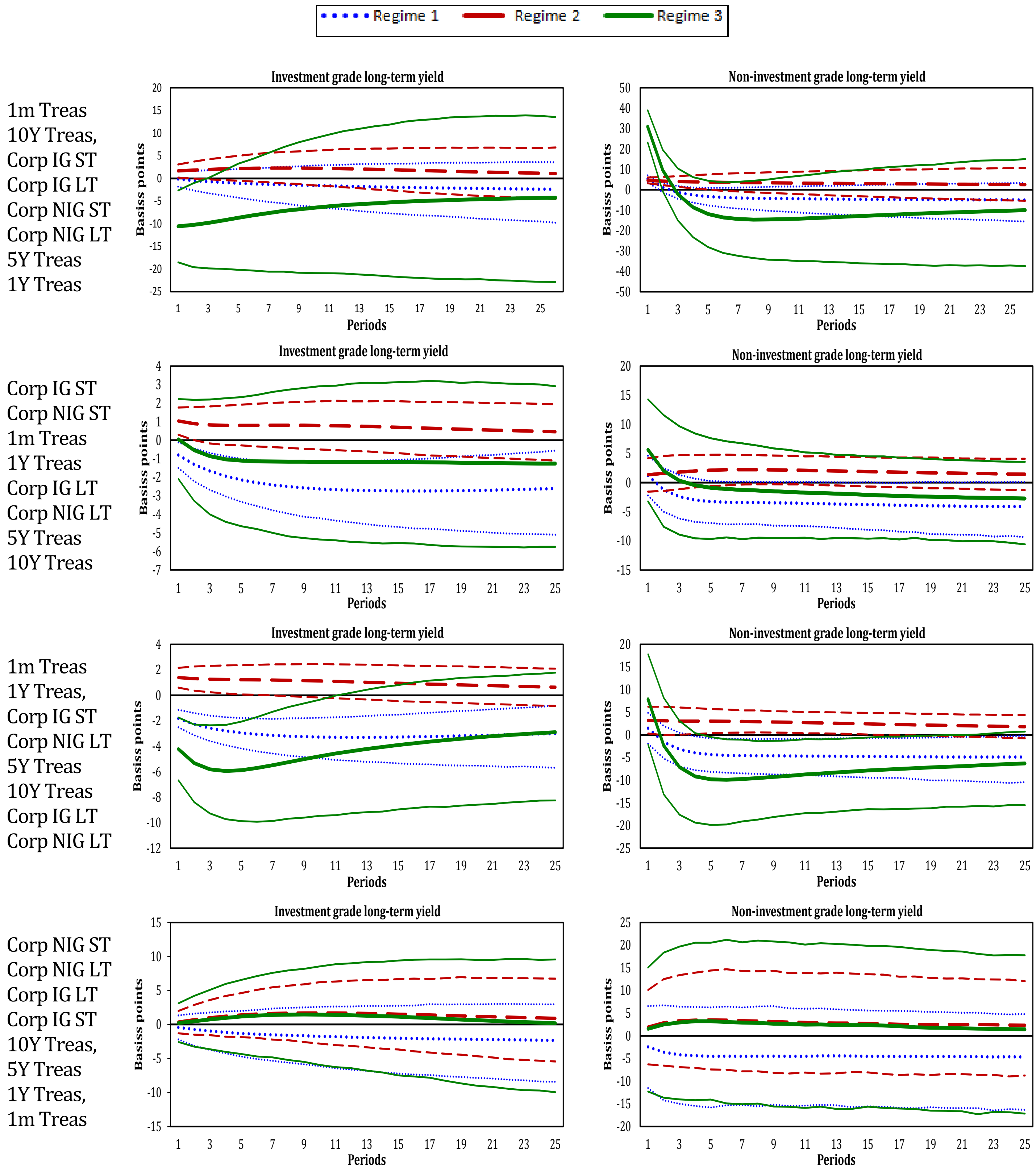

Figure 11: MSVAR for spreads: Impulse responses to conventional monetary policy

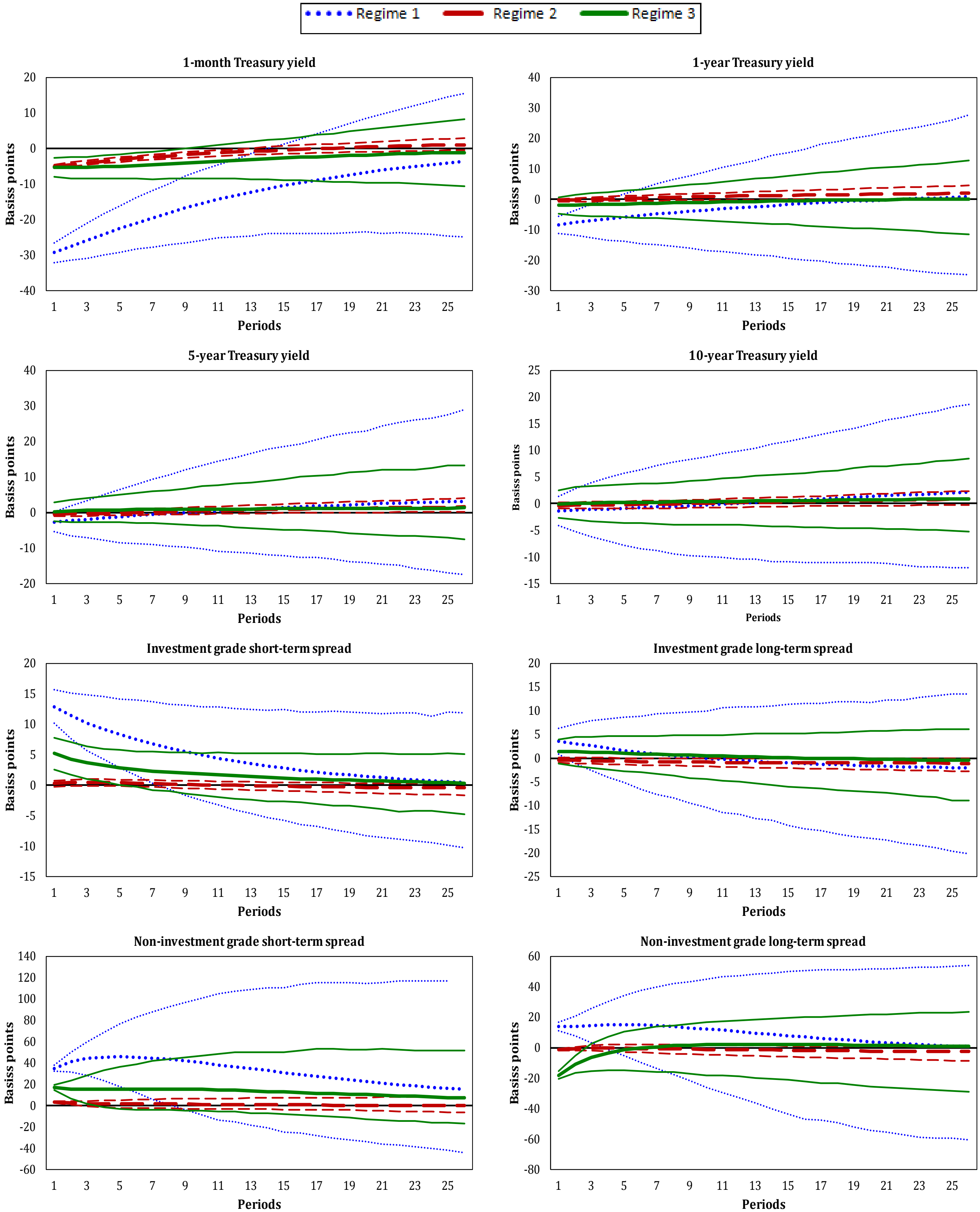

Figure 12: MSVAR for spreads: Impulse responses to quantitative easing

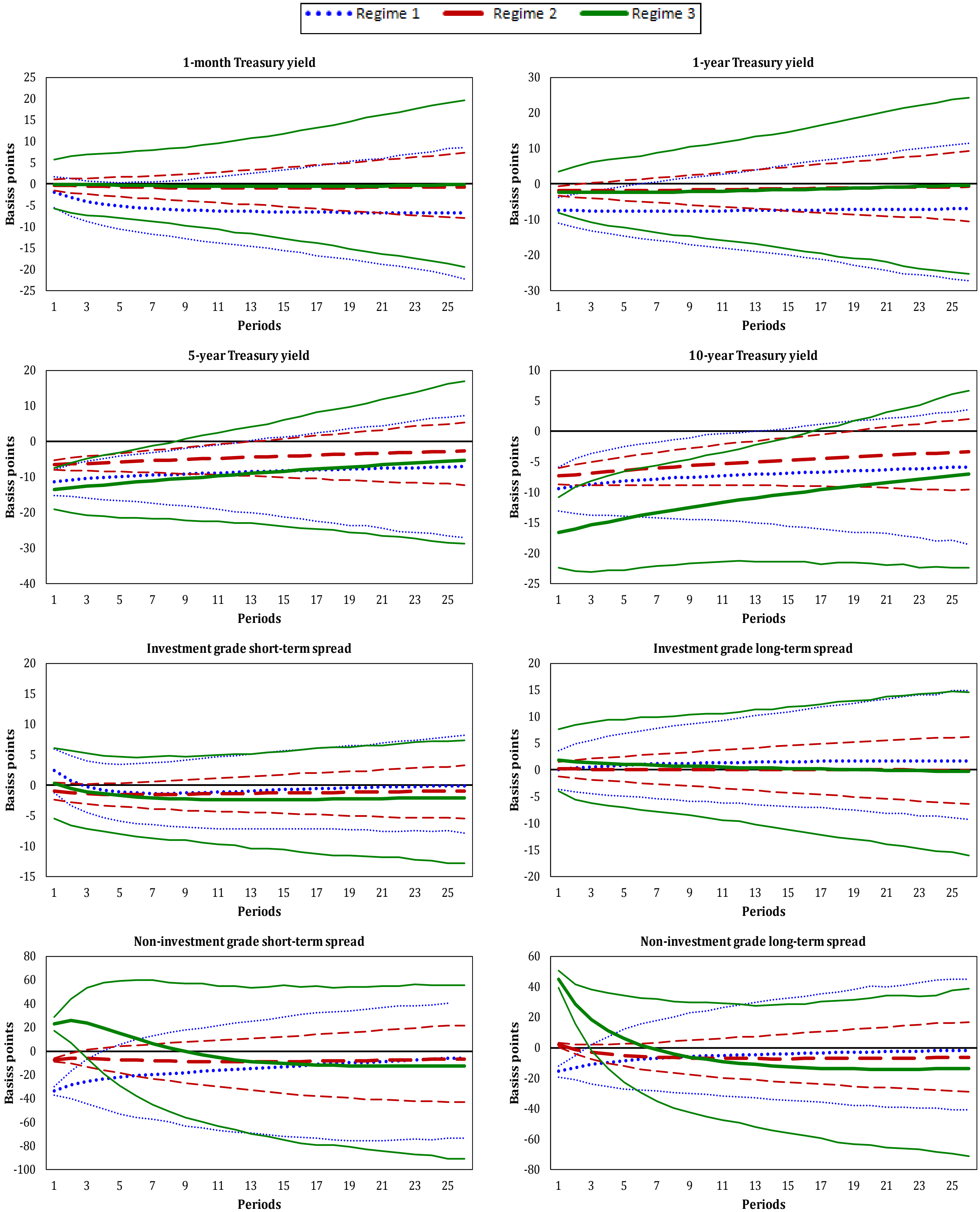

Figure 13: MSVAR for spreads: Impulse responses to maturity extension program shocks

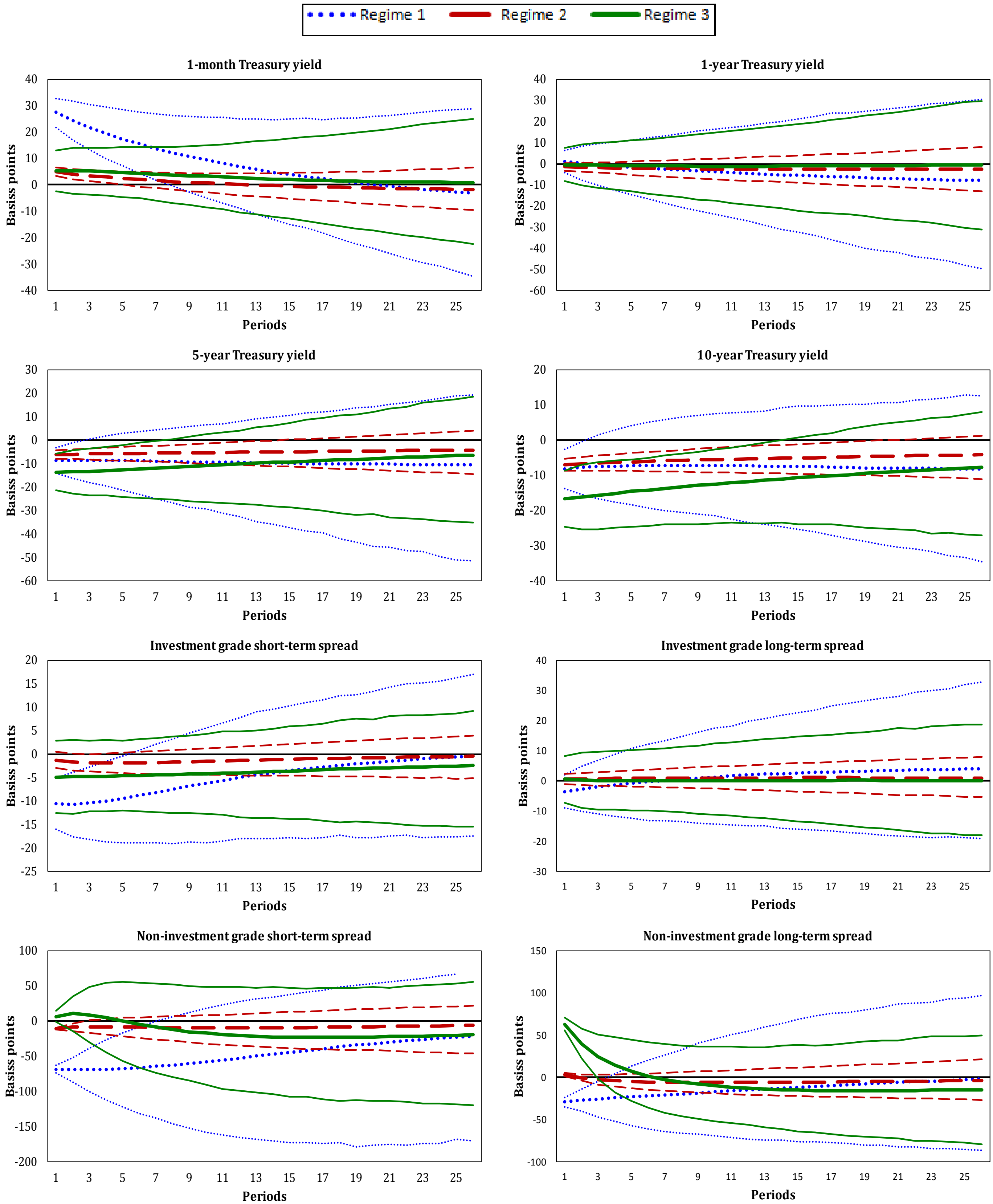

Figure 14: Using Principal Components to Quantify the Effects on Yields and Spreads: Effects of Operation Twist (Decline in Slope)