Central Bank Policies and Financial Markets: Lessons from the Euro Crisis*

Ashoka Mody **Milan Nedeljkovic**
Princeton University† **FEFA, CESifo**‡

Abstract

We identify differences in financial markets' response to the European Central Bank's various policy interventions during the eurozone crisis. Dollar liquidity interventions reduced stress in bond markets and improved economic sentiment, as reflected in higher equity prices. In contrast, the ECB's euro liquidity provisions and monetary stimulus measures delivered modest results. In both these cases, government bond spreads typically did decline but markets remained worried that spreads could rise quickly; moreover, broad economic sentiment remained unchanged. Only the Outright Monetary Transactions (OMT) "bazooka" had a substantial expansionary effect. The results emphasize the importance of unambiguous monetary policy for driving market expectations.

Jel Codes: E44, E58, C32, C38.

Keywords: Monetary Policy, Euro Crises, Uncertainty, Conditional Quantiles, MCMC, FAVAR

---

*This version: July 5, 2019. We thank Alessandro Barattieri, Olivier Blanchard, Simone Manganelli, Tomasz Michalski, Tommaso Monacelli, Urszula Szczerbowicz, Frank Westermann and seminar participants at 29th EC^2 conference, Rome; 27th MBF conference, Rome; 2019 IAAE conference, Nicosia; Koç University and University of Osnabruck for comments at the various stages of the project. We are grateful to Krista Schwarz for kindly sharing the bond liquidity data. Ivona Cickovic and Miro Vukoje provided excellent research assistance. All errors remain our sole responsibility.

†3-C-4 G Green Hall, Princeton, New Jersey 08544 USA. Email: amody@princeton.edu

‡Metropolitan University, Bulevar Zorana Djindjica 44, 11070 Belgrade, Serbia and Poschinger Street 5, 81679 Munich, Germany. E-mail: mnedelj@gmail.com.

1 Introduction

In the summer of 2007, as the global financial crisis (GFC) began gathering momentum, central banks needed to respond quickly and forcefully. Evaporating liquidity, particularly for dollars, represented the primary short-term concern. But the risk that the economy could fall into a recession—possibly a depression on the scale of the 1930s—was the other, deeper worry.

A central bank can respond to a worsening macro-financial environment with two broad types of actions. The central bank can provide liquidity to stabilize markets and promote lending.[1] Such a measure can alleviate market stress, and so is valuable; but it does not create spending power and, therefore, does little to create broad-based confidence in future economic prospects. A more active response provides monetary stimulus through lower interest rates, which "puts money in people's pockets" and stimulates demand. Such active stimulative policies, if implemented with a clear strategic purpose, help generate greater optimism about the future and, hence, create the basis for more sustained economic recovery. In a zero-lower-bound environment, expansionary stimulus includes forward guidance and the purchase of financial assets to lower the long-term interest rates.

After the onset of the global financial crisis, major central banks quickly opened up liquidity, but the timing and pace of monetary stimulus varied considerably.[2] The U.S. Federal Reserve reduced the policy rates sharply at the onset, in September 2007, and then, starting in December 2008, began forward guidance and asset purchases. In contrast, the ECB started with interest rate reductions in October 2008 and thereafter injected monetary stimulus at slower pace (Figure 1). Moreover, unlike the other central banks, which maintained a steadily expansionary monetary policy stance, the ECB raised its policy rate again, in April and July 2011, before starting another round of monetary stimulus in November 2011.

In addition to reducing the policy rate, the ECB provided monetary stimulus through ad hoc interventions in the bond markets of financially stressed eurozone governments. At first, such intervention was mainly through the Securities Markets Programme (SMP). Then, in a big move in July 2012, the ECB announced its Outright Monetary Transactions (OMT) program, a commitment to purchase bonds of governments that agreed to undertake fiscal austerity and structural reforms. Although the ECB described the SMP and OMTs as necessary to reduce dysfunctionality of financial markets, both measures, in our terminology, imparted active stimulus: they worked to reduce the medium to long-run government bond yields (Krishnamurthy et al., 2017).

[1] For the difference between monetary and liquidity policies, see Svensson (2010) and Hetzel (2012).

[2] For the taxonomy of the monetary policy measures of major central banks over 2007-2014 period, see Buraschi and Whelan (2015) .

Thus, more so than the other central banks, the ECB provided liquidity to the banking sector and relied less on monetary stimulus measures.[3] Of its liquidity interventions, a crucial component was the provision of dollars obtained through swap operations with the Fed.

[Insert Figure 1]

We use the European sovereign debt crisis as a laboratory to study the financial markets' response to different central bank interventions during the crisis. The changes in financial market conditions are the key transmission mechanism of the policy interventions and they are important predictor of downside risks to GDP growth (Adrian et al., 2019).

We begin our analysis in October 2009, the starting point of the eurozone crisis, marked by the Greek government's announcement of a gaping hole in its budget. The analysis extends to September 2012, the point at which the ECB's announcement of OMTs calmed down the fever in financial markets. Over this period, we look at the impact of ECB measures on the sovereign spreads of five countries in the euro area periphery: Greece, Ireland, Italy, Portugal, and Spain. The bond spread is the difference in yield between the bonds of a periphery government and the German government bond. We also examine how eurozone-wide industry and country stock price indices responded to the ECB's measures. This comprehensive approach—of studying bond spreads of stressed governments and equity returns—allows us multiple perspectives on the response of financial markets to central bank interventions. These perspectives help reinforce our statistical findings. Throughout, we use daily data.

We develop an empirical framework to identify financial markets' causal responses to central bank policy interventions. The framework has three elements. First, we identify policy interventions as the daily changes in policy indicators that are orthogonal to contemporaneous news releases and the public information about the state of the economy on the policy announcement days. More precisely, we project the daily changes in the policy indicators on their own lags, on lags of sovereign bond yields and other financial variables, on measures of private sector expectations about the economy as well as on measures of contemporaneous EU-wide and country-level news releases. The residual from the projection of the indicator on the days of policy announcements is the measure of policy intervention that we include in empirical models. To the extent that the projecting variables capture news flows on the announcement days and public information about the state of the economy that was not incorporated in the policy

[3] The liquidity measures broadly included: changes in the design of the open market operations; changes in the collateral requirements for euro borrowing; interventions in the covered bond market; reduction in the required reserves ratio and provision of long-term loans to banks.

indicator prior the policy change, from the market's perspective the proposed measure provides unanticipated and exogenous change in the policy.[4]

The policy indicators are variables that plausibly move with the specific type of policy intervention. We use the euro-dollar swap basis as an indicator of dollar liquidity interventions, the excess bank liquidity in the Euro-system as an indicator of euro liquidity interventions, and the yield on two-year Belgium sovereign bond as an indicator of monetary stimulus (the SMP interventions and policy rate changes) policy interventions. We verify that each of the proposed indicators loads significantly to announcements of the particular intervention.

Second, we study the changes in the conditional distribution of the bond spreads of financially distressed eurozone "periphery" governments. For that purpose, we augment the quantile vector autoregressive model (QVARX, White et al., 2015) with the measures of policy interventions and additional confounding factors. Using a novel approach to estimating quantile impulse-response functions, we study not only the median response of the spread to the interventions but, by examining the differences between the tail quantile and the median responses, we also ask whether markets perceived a potential for further decrease or, alternatively, a tendency for near-term increase in spreads.[5]

Finally, we examine the response of equity returns for all euro-area countries and for broadly delineated industry returns in the factor augmented VAR (FAVAR) framework. We add policy interventions to the vector autoregression with equity market common factors. The QVARX used for bond spreads becomes infeasible with a large number of endogenous variables.[6] The FAVAR model, in contrast, allows for simultaneously tracing the effects of policy interventions on a large number of variables (equities) while controlling for confounding factors and underlying dependencies given by common equity factors (and additional control variables).

We find that dollar liquidity measures lowered bond spreads and raised equity prices

[4] The changes in the policy indicators on the actual days of policy announcements provide a measure of the component of the policy that is unexpected by the markets given their pre-announcement information set. To be a valid measure of the policy change, this requires assuming that: i) the policy announcement is the only relevant news released on that day; ii) any systematic response of the ECB to information about the economy that is public knowledge prior to the announcement has been priced in the indicators. Using residuals from the projection of policy indicators, we relax these assumptions and obtain a measure of the component of the policy that is also orthogonal to contemporaneous news releases and public information about the state of the economy (embedded in financial variables and private sectors forecasts).

[5] In addition, the quantile impulse-responses succinctly summarize nonlinear dependences at the conditional mean or higher moments of the data and incorporate dynamic spillovers between the spreads in the intervention's transmission mechanism.

[6] Similarly, consistent estimation of factor (or FAVAR) models using principal component or MLE estimator (Bai et al., 2016) imposes conditions on the minimum cross section dimension (approximately 30 for our sample time dimension), which prevents their application with the government bond data.

significantly. In response to dollar liquidity interventions, markets anticipated the fall in the median spread and attached higher likelihood to large spread declines vis-ŕ-vis the hikes. Dollar liquidity made banks safer and thus reduced the likely bailout costs that governments may have to incur. Dollar liquidity also generated equity price gains in most euro-area countries, giving a special boost to the equity prices of banks. Thus, markets recognized that shortage of dollar liquidity could seriously undermine banks' operations and, hence, welcomed actions to alleviate that bottleneck, which also helped improve general economic prospects.

In contrast, euro liquidity measures only marginally reduced median bond spreads for Portugal, Ireland and Spain. We find no statistically significant effect on the median bond spreads of Greek and Italian governments. However, the interventions also caused markets to worry about the potential large spread increases.

While euro liquidity was a potentially a stabilizing influence, the real constraint to the eurozone's economic recovery was a lack of demand. Unable, therefore, to lend profitably to healthy borrowers, banks engaged in a "carry trade" (Acharya and Steffen, 2015, and Drechsler et al., 2016). Especially in the periphery countries, banks used ECB liquidity mainly to buy their own government bonds, which were *de facto* risk-free but earned them relatively high interest rates. This helped improve banks' profitability and the increased demand for the bonds did help reduce the spreads, although to a surprisingly small extent. Yet, banks became more vulnerable because of their greater exposure to sovereign risk. Such deepening of the sovereign-bank nexus presumably pushed up the sovereign default premium that offset the greater demand for sovereign bonds.

Finally, financial market participants understood that cheaper liquidity did little to stimulate demand and economic activity in a demand-constrained environment and so did little to raise equity prices.

The ECB's stimulus measures before OMTs, the SMP interventions and policy rate reductions between October 1, 2009 and July 20, 2012, produced mixed asset price reactions. Sovereign spreads fell for all five bonds in response to the interventions. However, financial market also perceived a risk that spreads on Greek bonds would immediately rise and spreads on Spanish, Portuguese, and Irish bonds would rise and remain elevated. Equity prices rose in several countries and sectors in response to SMP and policy rate cuts, though not by a statistically significant degree.

The increase we observe in the likelihood (risk) of higher spreads and the absence of significant equity price reaction suggest that the markets were largely unsure about the ECB's strategy. As a result, markets likely perceived that the ECB measures were revealing worrying signals about the state of the economy[7] (Kang et al., 2015); markets

[7] In addition to the actual policy change, the market participants can perceive monetary policy

also had no assurance that the ECB would sustain either its bond purchase or interest rate cuts.

The OMT announcement, in contrast, was a substantial intervention. Although there were many legal ambiguities in the operation of OMTs, investors perceived them as a *commitment* to prevent default by a eurozone government on its bonds. Sovereign spreads declined substantially and the likelihood of a further significant fall increased. Equity prices also increased significantly, especially for banks.

1.1 Related Literature

For control variables in our QVARX and FAVAR models, we follow empirical studies on movements in European sovereign bond spreads during the crisis (Mody, 2009; Beber at al, 2009; Favero et al, 2010; Mody and Sandri, 2012; Beirne and Fratzscher, 2013; De Grauwe and Yi, 2013; D'Agostino and Ehrmann, 2014; Schwarz, 2016), to which we add the analysis of the effects of central bank interventions.

The paper is primarily related to empirical literature that studies the effects of (unconventional) monetary policy interventions on the financial markets. These studies focus mainly on the U.S. Federal Reserve's actions (for example, Krishnamurthy and Vissing-Jorgensen, 2011; Wright, 2012; Gertler and Karadi, 2015; Hanson and Stein, 2015; Hattori et al, 2016). A small set of studies evaluates the effectiveness of ECB policy measures in response to the crisis. Among these, some use event-study methodology to analyze the changes in asset prices following the ECB's SMP, OMT, and long term refinancing operations (LTRO) announcements (Falagiarda and Reitz, 2015; Kang et al., 2015; Szczerbowicz, 2015; Altavilla et al., 2016; Krishnamurthy et al., 2017; Acharya, et al., 2018). The overall message from this work is that SMP and OMT announcements helped decrease the bond yields of the periphery countries and raised aggregate European stock indices; but LTRO announcements had weak effects.

Studies using a regression framework find that the SMP announcement and subsequent ECB bond purchases reduced the level and the volatility of the targeted bonds yields (Eser and Schwaab, 2016; Ghysels at al., 2016). Lucas et al. (2014), however, show that market perceptions of conditional sovereign risks remained elevated following SMP interventions.

Yet another set of studies assess the impact of ECB monetary policy "shock" on bond yields and other asset prices using single-equation or small scale VARs with different methods for identification of the policy shock (Gambacorta et al., 2014; Boeckx et al., 2017; Hachula et al., 2019). In this strand, Rodgers, et al. (2014) show that ac-

intervention as a signal about central bank's assessment of the current and future state of the economy, as discussed in e.g. Romer and Romer (2000), Gurkaynak et al. (2005), Melosi (2016), Nakamura and Steinsson (2018a), Jarocinski and Karadi (2018).

commodative policy shock quickly and persistently lowered Italian and Spanish spreads but oddly led to an increase in German yields.

We follow the strategy of identifying policy shocks and examining the market's responses to the shocks. Our richer empirical framework allows us to compare policy interventions consistently by measuring the response of disaggregated equity prices and the entire conditional distribution of the bond spreads. Together, we are able to offer identification of new and more robust empirical facts with more ambitious policy lessons. We highlight, for example, an important difference between dollar and euro liquidity policies, neglected thus far in the literature. Moreover, while our results suggest that the OMT and pre-OMT monetary stimulus (bond purchase and interest rate) interventions had comparable effects on the median of the conditional bond spreads distribution, their impact on the movements in the tails of the conditional bond spreads distribution as well as on equity prices was markedly different. These distinctions help reveal the importance of unambiguous stimulative monetary policy for driving market expectations. Finally, we also contribute to the empirical literature by providing identification of multiple monetary policy shocks within QVARX and FAVAR model, as well as by proposing a method for estimation of quantile impulse responses.[8]

The next section, Section 2, discusses the data and the QVARX and FAVAR models. Section 3 presents the findings on the bond and equity market reactions to ECB interventions. Section 4 reports various specification checks. Section 5 concludes.

2 Data and Econometric Methodology

2.1 Data

Financial data

Our data runs from October 1, 2009 to September 28, 2012. We chose a start date just before the Greek government's announcement on October 9 that its budget deficit would be much higher than previously forecast. Our baseline sample ends on July 20, 2012, six days before the pledge in London by ECB President Mario Draghi that the ECB would do "whatever it takes" to preserve the euro. We use the full sample to assess the differences in impact with and without the OMT interventions. Given our focus on the crisis period, we end the sample on September 28, 2012, when the sovereign bond yields of all countries were on a downward trajectory.

[8] The identification methodology is related to earlier work on using external high-frequency measures of monetary policy shocks (Kuttner, 2001; Gurkaynak et al., 2005) and to work on orthogonalizing an external shock measure against the information about the economy's expected future path (Romer and Romer, 2004). Ramey (2016), Miranda-Agrappino and Ricco (2017), Stock and Watson (2018) and Nakamura and Steinsson (2018b) provide recent overviews of the literature.

The data on government bond yields is primarily from Bloomberg, which provides 10-year and 2-year generic bond yields for Germany, Greece, Italy, Portugal, and Spain. We use the Thomson Datastream 10-year generic sovereign bond data for Ireland due to gaps in the Bloomberg data (October 12, 2011-September 28, 2012). However, the two series for Ireland are highly correlated for overlapping days in our sample (sample correlation is equal to 0.99). The 2-year bond data for Greece and Ireland is not available for the full period; we, therefore, exclude it from the analysis. We also exclude all non-trading days. For eurozone industry and country local currency MSCI price indices, we rely again on Bloomberg.

Figure 2 (top panel) shows plots of the 10-year bond spreads data and the corresponding daily changes. Through much of the sample period, we observe a general rise in the spreads of all five bonds with several jointly-occurring spikes, suggesting a certain degree of common movements over time and around key periods of heightened sovereign stress. There are also notable differences in the time dynamics. The rise in Greek, Irish, and Portuguese spreads is stronger in the first half of the sample; Spanish and Italian spreads increase faster and exhibit more volatility starting mid-2011.

The lower panel of Figure 2 shows the returns on 11 MSCI country indices and 43 industry indices. As with the bond data, equity returns show a significant degree of commonality with several periods of heightened volatility, which coincide with the key phases of sovereign crisis.

[Insert Figure 2]

We include several proxies for the influence of common factors. VSTOXX (the implied volatility of Euro STOXX 50 index) and VIX (the implied volatility of S&P 500 index) indices are, respectively, commonly used proxies of risk aversion of European and global investors. The spread between the 3-month Euribor and Eonia swap index measures the extent of money market tightness. The ITRAXX Europe index tracks the 125 most liquid CDS contracts for European companies.

In addition, we control for bond market liquidity (Schwarz, 2016). Bond market liquidity is defined as the daily yield spread between bonds of the German federal government and those of the German KfW, a government-owned development finance bank. Since the German federal government explicitly guarantees both bonds, their underlying credit risk is equivalent. Hence, the spread between the two yields reflects the market liquidity premium that investors demand for investing in the less liquid KfW bonds. The sources for all control variables are provided in the Appendix A. Figure 3 (upper panel) plots the control variables and the corresponding daily (log) changes.

Finally, to construct measures of unanticipated and exogenous shifts in the monetary policy that correspond to dollar liquidity, euro liquidity and monetary stimulusactive policy interventions, we use three variables, which we call policy indicators. These variables are not under the direct control of the central banks (such as the policy rate), yet they tend to move with the specific type of the intervention, thereby enabling identification of the underlying intervention from the indicators daily variation. The three month euro dollar swap basis, defined as the deviation from the covered interest rate parity with respect to the three month Libor rates[9], is the indicator for dollar interventions. The euro-dollar swap basis widened significantly over the second half of 2008 and early 2009 (Goldberg et al., 2010). It widened again between July 2010 and December 2011, each time implying that European banks faced a scarcity of dollars (Acharya et al., 2018).

For euro liquidity interventions, we follow Garcia de Andoain et al. (2016) and use aggregate Eurosystem daily excess bank liquidity. The excess bank liquidity is defined as the deposits at the Euro-system deposit facility net of the recourse to the marginal lending facility, plus current account holdings in excess of those contributing to the minimum reserve requirements. Excess liquidity increases when the banks park their funds with the ECB, reducing their exposure to the interbank market. The excess liquidity increases mechanically after the start of LTRO operations, which we control for in our estimations.

We use the yield on the two-year Belgium sovereign bond to proxy for monetary stimulus interventions: the ECB's policy rate changes (which convey information about the expected path of interest rates[10]) and sovereign bond interventions (which targeted medium-to-longer maturities). The two-year Belgium sovereign bond displays some volatility during the crisis (French, German or the Dutch bonds remained more stable throughout this period), yet it remained outside direct ECB purchases that could potentially affect the bond yield changes on a given announcement day beyond our controls.

[Insert Figure 3]

Policy announcement and other news data

We merge our financial data with a narrative dataset of the ECB policy announcements and news releases. Narrative data based on announcements is subject to judgmental bias. To limit such a bias, we rely on publicly available sources and perform several cross-checking exercises. We begin with the ECB's own list of measures undertaken[11],

[9] The basis is the spread between the Libor dollar interest rate and the synthetic dollar interest rate (obtained by swapping the Euribor interest rate into dollar).

[10] Hanson and Stein (2015); and Gertler and Karadi (2015).

[11] The webpage https://www.ecb.europa.eu/ecb/html/crisis.en.html however has not been functional since 2016.

and cross check that with alternative timelines (Bahaj, 2014, De Santis, 2014, Rodgers et al., 2014, Falagiarda and Reitz, 2015). We also compile a record of other contemporary developments, including on major EU-wide policy announcements, periphery countries' sovereign rating changes, and local economic and political news. This controls dataset focuses only on the key announcements as in Ait Sahalia et al. (2012); it is based on Bloomberg's daily news briefings for European economic news and is cross-checked with alternative timelines. The details are in Appendix B.

We time the announcements, as they appear on the Bloomberg newswire. For consistency and to control for a possibility of the within-a-day lag in Bloomberg reporting, we browsed through alternative news sources (Financial Times, Wall Street Journal and Reuters) and searched for the earliest time the news appeared. If an event occurred after the market closed (18.00 CET) or on a weekend or other non-trading day, we treated that news release as if occurred first thing on the next working day.

We code each announcement as a dummy variable. Monetary stimulus dummy takes the value 1 for the announcements of the bond market interventions and/or interest rate cuts; in contrast, for interest rate hikes, the dummy variable takes the value -1. Euro and dollar[12] liquidity dummies take the value 1(-1) for announcements of liquidity provision (tightening) and relaxation (tightening) of collateral requirements.

Finally, rating changes are coded in line with the literature (Gande and Parsley, 2005, De Santis, 2014), where the number of notches in the downgrade (upgrade) is used as the argument of the dummy variable. We also take into account changes in the credit outlook and credit watch, and assign them values 0.5 (assigned to credit watch / negative outlook) and -0.5 (taken out from credit watch / positive outlook). Table 1 provides the summary of the monetary policy events. The summary of all events is provided in Appendix E (Table AE1).

[Insert Table 1]

Identifying policy interventions

We identify a policy intervention as the daily change in the policy indicator that is orthogonal to contemporaneous news releases and public information about the state of the economy. Specifically, we run the following regressions:

$$\begin{aligned} \Delta PI_t \;=\;& \alpha + \sum_{i=1}^{p} \phi_i \Delta PI_{t-i} + \sum_{i=1}^{q} \beta_i \Delta y_{t-i} + \theta N_t + \\ & + \sum_{i=1}^{r} \rho_i x_{t-i} + \sum_{j=1}^{3} \delta_j SPF_{t,j} + \sum_{j=1}^{3} \gamma_j \Delta SPF_{t,j} + u_t \end{aligned} \tag{1}$$

[12] For completeness, we also include the days of announcements of the British pound swap interventions. The results are the same as when we focus only on the dollar swaps. .

where ΔPI_t is the daily change in the respective policy indicator (euro-dollar swap basis, excess euro liquidity or the yield on two-year Belgium bond). Δy_{t-i} is the change in bond yields of periphery countries. N_t is the vector of the news release variables, which includes the dummy for the other two monetary policy announcements, EU-level policy announcements, country-level rating changes and local news. x_{t-i} is the vector of additional covariates (daily change in Vstoxx, VIX, the KFW spread, and Eonia rate). We also include lagged values of other two policy indicators in the vector x_{t-i}.[13] $SPF_{t,j}$ is the vector of the latest available current year, next year and four quarters ahead of the Survey of Professional Forecasters forecast of the euro area inflation, output and employment; and $\Delta SPF_{t,j}$ is the latest revision in the forecasts. In the equation for excess liquidity, we include a dummy variable for the days of the 1-year and 3-year LTROs settlements.

The policy intervention variable is the residual from the regression (1) on the announcement days A_t: $M_t = \widehat{u}_t 1\{t = A_t\}$.

To the extent that the control variables capture news flows on the announcement days and public information about the state of the economy that was not incorporated in the policy indicator prior the policy change, the resulting measure M_t, from the market's perspective should represent unanticipated and exogenous change in the policy. Column 4 in Table 1 shows that the constructed measures are generally consistent with the direction of the policy change. Announcements of dollar liquidity provision lead to tightening of the euro dollar basis (positive innovation), announcements of euro liquidity provision are accompanied with the fall in the excess liquidity (negative innovation), while announcements of interest rate cuts and sovereign bond interventions are reflected in the decrease of the Belgium bond yield. To examine whether the proposed policy indicators are good proxies of the actual interventions we estimate additional regressions that add signed announcement dummy variable to the specification of the corresponding indicator. Column 5 shows that the coefficients for the dummy variables are statistically significant and of expected sign, suggesting that the proposed variables are indeed good indicators of the policy changes.

2.2 QVARX

This part of empirical approach provides model-free measures of market predictions of likely changes in the bond spreads in the presence of market spillovers and common factors. The methodology is based on vector autoregressive model for conditional quantiles, introduced in White et al. (2015) and further discussed in Chavleishvili and

[13] For example, the changes in the euro-dollar swap basis may also reflect the changes in the ECB's collateral and euro liquidity policy (Corradin and Rodriguez-Moreno, 2016) or in the policy rate stance (Du et al., 2018).

Manganelli (2017) and Kim et al. (2018). We extend their work to system estimation with a moderate number of endogenous and exogenous (or predetermined) variables and propose simulated impulse-response analysis. The empirical specification is:

$$Q_t^\theta = \alpha + AQ_{t-1}^\theta + B\Delta y_{t-1} + CM_t + Dx_{t-1} + GN_t \tag{2}$$

where Δy_{t-1} is the $K-$dimensional vector of the spread changes (in our case $K = 5$), α is the $K-$dimensional vector of intercepts, M_t is the vector of policy interventions, x_{t-1} is $p-$dimensional vector of covariates ($p = 2$) and N_t is the $3-$dimensional vector of the news variables (EU-level policy actions, country-level rating changes and local news). Q_t^θ is the $\theta-$th quantile of the conditional distribution $P\left(\Delta y_t < y \mid \Delta y_{t-1}, M_t, x_{t-1}, N_t\right)$. To control for potential endogeneity, common factors enter in lag.

The empirical framework offers several advantages. It yields a structure for studying various asymmetries in the bond market reactions to policy changes without assuming a particular nonlinear model for the data generating process.[14] Specifically, the quantile specification allows for changes in both the conditional mean and conditional volatility of the bond spreads (see White et al., 2015). Estimation of conditional quantiles also imposes weaker distributional assumptions on the underlying data generating process relative to the standard regression setting which models asymmetries in the bond market (given e.g, in Beber and Brandt, 2009).

Second, the QVARX includes confounding factors and allows for dependence of the spread's conditional quantiles on lagged quantiles and past values of other spreads, thereby capturing dynamic spillovers between the spreads at the distributional level. Since we are interested only in controlling for confounding and spillover effects on our measures of interest, this approach allows us to succinctly summarize the links that can arise at the conditional mean, volatility or higher moments of the conditional distribution. Finally, even though different quantile estimates may be of separate interest, we use them to construct the measure of the market's central prediction of the sovereign spread changes (conditional median) and the measure of uncertainty (the difference between the corresponding upper and lower quantile). The uncertainty measure is model free and, as such, also robust to misspecification of the volatility process.

We estimate the contemporaneous and dynamic impact of policy interventions on the bond spreads. The contemporaneous responses to interventions are obtained directly from estimates of corresponding elements of matrix C.

To construct dynamic impulse-responses, we rely on dynamic simulation, which,

[14] For example, asymmetries may include the possibility that bond markets attach higher probability to large spread increases relative to decreases (and vice-versa) in response to the innovation; or that markets do not react on average to the innovation but their assessment of potential risks (large movements in the spreads) changes markedly.

in the present context, shares a close connection with the nonlinear impulse-response analysis (Gallant et al., 1993; Koop et al., 1996). To see the intuition, let us focus on estimating impulse-responses for an arbitrary intervention of interest (say, dollar liquidity interventions); the same principle applies to other interventions. Let decompose vector M_t into the intervention variable of interest $M_{t,1}$ (dollar liquidity) and the remaining (two) intervention variables $M_{t,2}$: $M_t = \left[\begin{array}{cc} M_{t,1} & M_{t,2} \end{array} \right]$. Let Z_t^{SH} denote the generic variable after the intervention, while while Z_t^{NO} denotes the variable without it. The conditional quantile response to intervention $M_{t,1}$ after one period is equal to the difference between the two quantile functions (simple derivation is provided in the Appendix C)[15]:

$$Q_{t+1}^{SH} - Q_{t+1}^{NO} = A\left(Q_t^{SH} - Q_t^{NO}\right) + B\left(\Delta y_t^{SH} - \Delta y_t^{NO}\right) + D\left(x_t^{SH} - x_t^{NO}\right) \qquad (3)$$

Equation (3) has several implications: i) the quantile impulse responses are dependent on the history (the time t at which the response is computed); ii) the responses depend on its own path $\left\{Q_t^{SH} - Q_t^{NO}\right\}$ and the paths of other variables following the intervention $\left\{\Delta y_t^{SH} - \Delta y_t^{NO}\right\}$ and $\left\{x_t^{SH} - x_t^{NO}\right\}$; iii) the responses are independent of other interventions and news releases $\{M_{t,2}, N_t\}$ that occur simultaneously with $M_{t,1}$ or during the forecast horizon as long as they are independent of $M_{t,1}$.

If the change in spreads Δy_t and common factors x_t were independent of the intervention, then only the own quantile path dependence will be present and the response function could be estimated directly from VAR or using local projections (Jorda, 2005). However, such an assumption would be unrealistic in our setup given the fast response of financial variables to the news. On the other hand, it seems plausible to assume that the news N_t are independent of the intervention contemporaneously or over a short daily horizon.[16]

To minimize the specification error, we do not specify a mechanism for how the spreads Δy_t and common factors x_t respond to the intervention $M_{t,1}$. Instead, we rely on simulating the paths of $\left\{\Delta y_t^{SH}, x_t^{SH}\right\}$ and $\left\{\Delta y_t^{NO}, x_t^{NO}\right\}$, which in combination with the estimated parameters and the recursions that lead to (3) generate impulse responses. The steps are presented in the Appendix C.

The outlined procedure generates dynamic impulse responses at the quantile level. Contemporaneous and dynamic impact on uncertainty is computed analogously as the

[15] Note that the reaction on day $t+s$ measures the change in the features of the conditional distribution between the days $t+s-1$ and $t+s$ with respect to the impulse at time t.

[16] Monetary policy intervention measures are mutually independent by construction.

difference between the two (upper and lower) quantile responses:

$$\begin{aligned} UNC^{SH}_{t+h} - UNC^{NO}_{t+h} &= \left(Q^{UP,SH}_{t+h} - Q^{UP,NO}_{t+h}\right) - \left(Q^{LOW,SH}_{t+h} - Q^{LOW,NO}_{t+h}\right) \\ h &= 0, 1, ..H \end{aligned} \quad (4)$$

Before proceeding, it is useful to understand the mechanics behind the uncertainty responses. In economic terms, *higher uncertainty* can arise due to: i) higher probability of observing large positive and negative changes in the spread; ii) higher likelihood of large spread reductions, while spread increases become less likely; iii) higher likelihood of large spread increases, while spread reductions are less likely. Conversely, *uncertainty falls* if the conditional quantiles move in the opposite direction to (i-iii). Thus, the overall uncertainty movements can arise due to different market expectations vis-ŕ-vis the likelihood of spread increases or falls. In order to understand what is driving the uncertainty and which risks are elevated, we decompose total uncertainty measure in two components: right uncertainty (the difference between the upper tail and the median) and left uncertainty (the difference between the median and the lower tail). These two measures report how the markets evaluate the imminent risks of large changes relative to the expected (median) path following the interventions.[17]

We estimate the QVARX parameters building on a class of Laplace type estimators (LTE) introduced in Chernozhukov and Hong (2003). The LTE estimator is a function of integral transformation of the original criterion function, and is computed as the mean of the quasi-posterior distribution of parameters. While the theory in White et al. (2015) enables joint parameter estimation across different quantiles, the quasi-maximum likelihood estimator suffers from convergence problems in settings with large number of parameters (the curse of dimensionality).The quasi-posterior distribution of the LTE estimator, in constrast, is approximated using Markov Chain Monte Carlo method (MCMC), which alleviates the curse of dimensionality. Due to the high complexity of the specification, we use the block adaptive Random Walk Metropolis Hastings algorithm for MCMC sampling (Roberts and Rosenthal, 2009); details on the algorithm are provided in the Appendix D. We assume the diagonal structure for matrix A to keep the number of parameters estimable. This essentially implies that the dynamics of individual conditional quantiles reflect spillovers from actual lagged changes in all spreads (matrix B), persistence in quantiles (matrix A), and the impact of exogenous (or predetermined) variables (policy interventions, common factors and

[17] Left and right uncertainty provide decomposed estimates of the asymmetric distributional changes following the interventions. Alternatively, one can compute a quantile- based measure of conditional skewness (White et al., 2008, Andrade et al., 2014) and study its response, which summarizes the relative strengths between the left and right movements. The conditional skewness will fall if the left uncertainty response is larger than the right, and vice versa.

news releases, matrices C, D and G). The confidence intervals for impulse responses are constructed using the generated MCMC chain of parameter values. Specificially, we draw 3000 values from the quasi-posterior distribution and, for each draw, construct the impulse response paths. The 68-percent confidence intervals are computed using the corresponding quantiles of the response paths distribution.

2.3 The FAVAR

To examine the broader macroeconomic impact of the ECB policies, we analyze their effects on equity prices, while taking into account confounding factors and spillovers between the equity markets. To achieve this objective, we model the joint dynamics of industry and country-level indices using the factor augmented vector autoregressive model. The FAVAR specification[18] adds policy interventions to a small set of factors which drive the common component of a large set of equity returns. In particular, let y_t be the $N-$dimensional vector of the returns. Their joint dynamics are approximated with the following FAVAR equation:

$$y_t = [\Lambda\ \Gamma]\,[F_t'; x_t']' + e_t \tag{5}$$

where F_t is the $k-$dimensional vector of unobserved equity common factors, x_t is the $r-$dimensional vector of observed factors and Λ and Γ are the corresponding $(N \times k)$ and $(N \times r)$ matrices of factor loadings. The factor dynamics are governed by the vector autoregression:

$$[F_t'; x_t']' = A\,(L)\,[F_t'; x_t']' + BM_t + CN_t + u_t \tag{6}$$

where $A(L)$ is the lag operator, M_t is vector of policy interventions, N_t is the vector of the news releases variables and u_t are the VAR innovations.

The vector y_t consists of the returns on the aggregate euro area MSCI index, 43 euro area MSCI industry indices and eleven MSCI country indices. We include industry and country indices together in FAVAR since the small number of country observations prevents consistent estimation of separate FAVAR specification for country indices (Bai, 2003, Bai et al., 2016).[19] The joint modelling of industry and country returns in this way implicitly assumes that their dynamics are dominantly driven by common (global)

[18] The FAVAR model introduced in Bernanke et al (2005) and Boivin et al (2009) adds policy indicators as endogenous variable in VAR equation (6) and uses different methods for identifying monetary policy shock from this representation.

[19] Consistent estimation of the factor space by the principal components or MLE estimator imposes conditions on the minimum cross section dimension of y_t, which is approximately 30 for our sample time series dimension (720).

factor(s). The assumption is consistent with the empirical evidence that global factors tend to explain a more significant part of covariance of country-industry equity portfolios compared to country and/or industry factors only (Bekaert et al., 2009). Indeed, three factors, suggested by the Bai and Ng (2002)'s criterion explain close to 70 percent of the total variation in stock returns in our sample, of which the first factor explains more than 64 percent.

Identification of impulse responses in FAVAR with exogenous policy intervention measures amounts to identification of the reduced form coefficients in equation (5). Bai et al. (2016) recently proposed three sets of identification restrictions on the loadings matrix Λ and on the variance of factor innovations u_t that provide just identified model. Following Bai et al. (2016) (identification restriction IRb) we assume that factor innovations are mutually uncorrelated and that the upper (3×3) submatrix of Λ is lower triangular. The former condition is weaker relative to usual assumptions in factor models as it allows for correlation between the factors, keeping the innovations uncorrelated. The latter condition implies that the aggregate euro area MSCI index (ordered first in the y_t vector) loads only on the first factor F_t^1 and that an arbitrary industry index (ordered second) loads only on the first two factors (the both indices also load to observed covariate x_t). The dynamics for all other stock indices are left unconstrained. The restriction that the aggregate stock index loads only on the first factor is consistent with the fact that F_t^1 captures the bulk of the variation in disaggregated stock returns and can be interpreted as "global". We also verify that the choice of industry index which is restricted to load only on the first two factors does not affect the results.

We estimate the parameters in equation (5) using the iterative procedure from Boivin et al. (2009). The VAR equation (6) is estimated by OLS with three lags, suggested by the AIC criterion. The stock returns and continuous control variables are standardized prior to estimation as the principal component estimator is not scale invariant. The resulting impulse-responses are rescaled and displayed in original units.

The confidence intervals for impulse-responses are obtained through bootstrap. In particular, we follow Yamamoto (2018) (see also Mertens and Ravn, 2013; and Goncalves and Perron, 2014) and use the two-step procedure to generate bootstrap samples. In the first step, we use the residual bootstrap to sample VAR endogenous variables $\left[F_t^{b\prime}; x_t^{b\prime}\right]'$. In the second step, we generate the bootstrap y_t^b draws using the wild bootstrap with bootstrapped factors from the first step.[20] Specifically, the bootstrap draws are obtained as: $y_t^b = \left[\widehat{\Lambda}\ \widehat{\Gamma}\right] \left[F_t^{b\prime}; x_t^{b\prime}\right]' + \widehat{e_t}\xi_t$, where $\widehat{e_t}$ are the estimated residuals and ξ_t is the vector of realizations of a random variable taking on values of -1 or 1 with probability 0.5. We then use the resulting series y_t^b to obtain new factor estimates, which are regressed on its lags, bootstrapped monetary policy measures and exogenous variables to

[20] We use the wild bootstrap to acommodate for potential heteroscedasticity in the returns data.

produce the bootstrap draws of VAR coefficients. We control for the estimation error in the proposed measure of policy intervention by sampling them through additional wild bootstrap run. The two vectors of Rademacher random variable draws (ξ_t) used in bootstrap of equity returns and policy measures are sampled independently. We also control for potential small-sample bias in VAR estimates by applying the small-sample bias correction (Killian, 1999). We use 2000 bootstrap realizations and report the 90% confidence intervals.

3 Results

In this section we report results from the baseline specifications of the QVARX model for bond spreads and of the FAVAR model for equities. The QVARX model is estimated using daily data from October 1, 2009 to July 20, 2012 for the conditional median and two tail quantiles (10 and 90). The vector of exogenous variables includes the VSTOXX index of implied volatility and the KfW-bund spread, as proxies for the general European risk aversion sentiment and bond market liquidity. The FAVAR model is estimated over the same period with VSTOXX index as the observed factor (x_t) and EU-level news releases (N_t) as additional control variate in the VAR equation.

While we include all three policy interventions in the empirical models simultaneously, we will group the presentation of the results along the interventions types. For each intervention we consider three responses: (i) changes in the bond market's central prediction of the sovereign spread changes (conditional median responses from QVARX); (ii) changes in the bond market's assessment of potential large movements in the spreads (uncertainty responses from QVARX); and (iii) changes in equity market average returns (conditional mean responses from FAVAR). For the equity returns, we report responses for all countries and several industries; the full set of industry estimates is reported in Appendix E.

We normalize the size of the accommodative policy interventions in line with their expected direction of change discussed in the previous section. Recall that negative widening of the euro-dollar swap basis corresponds to increased stress in the dollar funding market, while increase in the euro excess liquidity relates to tightening of the euro interbank money market. Thus, for the euro-dollar swap basis (dollar liquidity injection), the size of the impulse is equal to the 90th sample quantile (rise by 1.2 basis points); for excess liquidity (euro liquidity injection), it is the 10th sample quantile of the daily change (decrease by 11.5 billion euros); and for the Belgian bond's two-year yield (stimulus measures), our normalization is a fall by 7 basis points (10th sample quantile of the daily change). For each intervention and each response, we plot the contemporaneous and the subsequent five-day cumulative reactions together with their confidence intervals. Longer horizon responses at daily level are potentially sensitive to correlation between the subsequent news and the present central bank interventionsECB actions and are reported in the additional specification checks in the following section.

Dollar liquidity injections

Provision of dollar liquidity reduced the median spreads of all five bonds (Figure 4, top row). The contemporaneous and the first day reactions are strongest in magnitude and mostly statistically significant; the responses tend to die out or become positive (reversion) thereafter. Importantly, we do not observe any reversion to pre-intervention levels and the cumulative responses remain statistically significant. The absolute size of daily reactions is also economically significant. While the spreads median in-sample daily change ranges from 0.2 basis points for Italy to 3 basis points for Greece, the estimated maximum daily expected reductions in spreads vary from 2.5 basis points (Italy) to 11.5 basis points (Greece) in response to the dollar liquidity intervention that shrinks the dollar basis by 1.2 basis points.

Moreover, the likelihood of large spread declines (left uncertainty) increases. This higher likelihood of spread decrease is primarily instantaneous and statistically significant for Greek, Portuguese, and Italian bonds. The likelihood of large spread increases (right uncertainty) also decreases for Greece and does not change in a significant manner for other bonds. Overall, therefore, dollar liquidity injections had a sizeable and consistent calming effect on eurozone sovereign bond markets.

[Insert Figure 4]

The dollar liquidity interventions also led to a significant contemporaneous increase in the equity indices of all countries (Figure 5). The increases in Spanish and Italian equities were the largest, at around 1.8% daily change following the intervention. The returns become negative for most of the indices after two days; however, they do not eliminate earlier positive gains. Thus, financial markets welcomed steps to alleviate the dollar funding risks of European banks, which improved the general sentiment.

Eurozone banking stocks gained the most, rising by close to 2.4%. Most other sectors also experienced a bounce. Estimated reactions are economically significant as they correspond to 90th quantile of the empirical distribution of the equity returns.

[Insert Figure 5]

Banks benefited from a particularly sharp increase in their stock prices because they were desperately short of dollars (ECB, 2012). The banks had financed their sizable U.S. dollar assets (amounting to roughly 3.2 trillion dollars at the end of 2010) by issuing short-term unsecured dollar debt (certificates of deposits and commercial papers); the banks had also borrowed dollars through foreign exchange swaps. But dollars became increasingly scarce as the main holders of the short-term dollar debt, U.S. money market mutual funds (MMMF), faced large-scale investor redemptions amid growing concerns about the fragility of European banks (Mody, 2018; Chernenko and Sunderam, 2014). These redemptions caused a significant contraction in the total amount of available unsecured dollar funding, especially for the banks with larger sovereign exposure (De Marco, 2018).[21] This contraction in funding together with the rising cost of foreign exchange swaps created a serious risk for eurozone banking operations. In turn, the stress felt by banks fed through to sovereigns, who were presumed to be liable for bank bailout costs. Hence, dollar liquidity proved crucial in stabilizing the eurozone's financial system, which also helped improve general economic prospects.

Euro liquidity injections

Following euro liquidity interventions, the conditional median of Portuguese and Irish bond spreads fell significantly on a cumulative basis over the six-day period (Figure 6). Spanish bond spreads also fell on the first and third days following the intervention, but their cumulative six-day median decline was modest and statistically insignificant. The median reaction of the other two spreads was statistically insignificant.

However, following euro liquidity injection, for all bonds other than the Greek sovereign bond, markets viewed large spread increases as more likely relative to spread falls, indicating shift in the prevailing risks perceptions. In other words, the right uncertainty increased significantly relative to the left uncertainty.

Thus, as banks used their easier access to euros (at low interest rates) to buy substantial quantities of government bonds, the spreads on those bonds tended to decline. Yet, banks became more vulnerable because of their greater exposure to sovereign risk. In turn, therefore, the likelihood increased that government sovereign spreads would rise quickly and significantly.

For the Greek bond, we observe statistically significant fall in the likelihood of large spread increases. In contrast to the other periphery countries, the share of Greek sovereign bonds in domestic bank portfolios (albeit significant) did not increase following the euro liquidity interventions (Acharya and Steffen, 2015). Hence, markets had no reason to reassess the risk of spread increases.

Equity indices generally lost ground after euro liquidity injections (Figure 7). Thus, the evidence from the bond and equity markets is consistent with the observation that

[21] De Marco (2018) shows that short-term unsecured dollar funding for Eurozone banks from US MMMFs fall from approximately 500 billion EUR in January 2011 to the low of 170 billion EUR in the fourth quarter of 2011, reflecting primarily the fall in the funding of the banks with higher exposure to sovereign debt.

banks used ECB liquidity mainly to buy their own government bonds (Acharya and Steffen, 2015, and Drechsler et al., 2016). The additional liquidity created little incentive to lend to firms and thereby boost economic growth (Bocola, 2016).

[Insert Figure 6 and 7]

Monetary stimulus

Monetary stimulus interventions before the OMT led to a contraction in expected spreads of all five bonds (Figure 9). The estimates are also economically significant with maximum daily reductions between 10.6 basis points (Greece) and 27.9 basis points (Ireland) in response to an intervention that reduced the Belgium two-year bond yield by 7 basis points. This is not a surprise since some of the measures were direct purchases by the ECB of sovereign bonds.

The signs and statistical significance of the estimated median responses are broadly consistent with earlier event study literature. However, our estimated magnitudes are lower than in the earlier studies. This is in line with the richer structure of the QVARX model, which controls for the impact of simultaneous events, with our measure of policy intervention that excludes anticipated and endogenous component of the intervention, and with our definition of stimulus measures, which includes interest rate changes in addition to interventions in the government bond markets.

Although median spreads declined, stimulus interventions before the OMT led to higher likelihood of large spread increases for Spanish, Irish, Portuguese, and Greek bonds. These observed reactions suggest that the markets were largely unsure about the ECB's strategy. The ECB conducted its purchases of government bonds through its Securities Markets Programme in a manner that lacked transparency. In addition, unlike the Fed, which maintained a steadily expansionary monetary policy stance throughout the crisis period, the ECB raised its policy rate twice, in April and July 2011, before starting another round of policy rate cuts in November 2011. The rate cuts came well after signs of the deteriorating economy were evident and, hence, markets had reason to be concerned that the ECB may not sustain its actions. As a result, markets likely perceived that the latest injection of stimulus was signaling additional negative news about the state of the economy, a view that would tend to increase the expectation of future spread increases (Benzoni et al., 2015).[22]

The insignificant reaction of equity prices to the ECB's sovereign bond purchases and policy rate cuts (Figure 9) reinforces our interpretation that markets perceived a lack of commitment to continued stimulus and interpreted the measures as signaling a worsening economy.

[22] In the context of the Eurozone crisis Benzoni et al. (2015) showed that mixed and uncertain policy signals can generate uncertainty risk premium in equilibrium models of defaultable bonds.

[Insert Figure 8 and 9]

To contrast the impact of the OMTs to earlier active measures, we re-estimate the QVARX and FAVAR models after extending the sample to September 28, 2012. Thus, we add the orthogonalized changes in the policy indicator on the three announcement days related to the ECB's conditional commitment to purchase government bonds (July 26, August 2, and September 6, 2012).[23] We find a stronger decline in the conditional median compared with the decline for the period that ended before the OMT announcements (Figure 10). Only the Irish bonds do not appear to have benefited from the OMT effect. This is consistent with the fact that the spread on the Irish bonds was already on the downward path following the announcement in July 2011 of easier repayment terms on official lending by eurozone governments (Mody, 2018). The OMT announcements also led to a higher likelihood of declines in the spreads. The only exception is Spain where the relative likelihood of large changes remained skewed towards the possibility of spread rises.

Finally, the immediate equity market response to the OMT announcements is generally positive and statistically significant (Figure 11). Although the returns become negative after two days, the revision does not eliminate initial gains. The positive reaction was strongest in the case of Spanish and Italian stocks, which were under especially great stress in the days before the OMT announcements. While gains elsewhere were uneven, the only country that did not see equity price increases was Greece. It appears as if the state of the Greek economy under a bailout program was so weak that the associated fall in sovereign bond yields through OMT could not raise the optimism in the real sector.

Among all sectors, the banking sector equity price rose most impressively. The size of the reaction is highly economically significant, corresponding to the 99^{th} quantile of the returns' empirical distribution.

In sum, our results confirm the general perception that the OMT announcements caused markets to breathe a huge sigh of relief. Stress in the bond markets decreased, which helped banks' balance sheets and improved general economic prospects throughout the euro area.

[Insert Figure 10 and 11]

[23] In particular, we re-estimate QVARX and FAVAR models after adding the OMT interventions to the active policy intervention variable and creating the separate OMT variable that captures additional effect of the OMTs relative to previous active interventions.

4 Specification Checks

We evaluate the specifications presented from various perspectives. We only report a subset of the results in this section, while the rest are in the accompanying Appendix E.

4.1 QVARX

Starting with model fit, for each country/quantile pair, Table 2 reports the percentage of times the actual ten year sovereign bond spread change was below the estimated conditional quantile, together with the p-values of the general specification test of the dynamic quantile model (Escanciano and Velasco, 2010). Given the high dimensionality of the empirical model, the results indicate good performance - estimated frequencies are close to their population values and the null hypothesis of the satisfying performance is not rejected for the majority (13 out of 15) of country/quantile pairs.

[Insert Table 2]

Next, we use spreads on two-year government bonds (rather than ten-year government bonds) as an alternative dependent variable. The data on Greek and Irish bonds is not available for the entire period[24]; and so we estimate QVARX model for three remaining bonds. We observe the same pattern of responses as before with a slightly stronger magnitude of reaction (Figures AE1 and AE2 in Appendix E). The only qualitative difference to our baseline results is with respect to market perception of relative risks, which becomes more skewed to spread increases for Italian bond in response to sovereign bond and interest rate interventions.

We then estimate the specification with ten-year bond yields (rather than spreads) as the dependent variable. The results are very similar to the baseline specification and are reported in Figure AE3. The similarity in responses between the yields and the spreads also implies that the effect of monetary policy interventions on bond yields during the crisis was primarily driven by the shifts in the risk premium.

Next, we check if the control variables we used are sensible. We first estimate conditional median (Figure AE4) and uncertainty responses (Figure AE5) to each of the three control news categories. In line with the earlier empirical literature, we find that the country bailouts and EU-level actions (such as announcements regarding European bailout funds) led to downward spread revisions, while rating downgrades and heightened local risks increased the expected spreads and raised the right vis-ŕ-vis left

[24] The data for two year Greek bond ceases on March 12, 2012, while the data for Irish two-year bond is not available between January 2010 and February 2011.

uncertainty, implying a further possible increase in spreads. Hence, we can be confident that the control news set captures relevant confounding events.

Further, we confirm that the main results are not sensitive to the choice of other control variables. Given relatively high sample correlation between the VSTOXX, VIX, and ITRAXX Europe index (above 0.45), we alternate between them in estimations. The results are qualitatively and often quantitatively analogous to the baseline and are reported in Figures AE6 and AE7.

We also assess the sensitivity of the uncertainty estimates to the choice of benchmark quantile levels. To do this we re-estimate the baseline specification at other quantile levels (15, 20, 80 and 85) and construct an alternative set of uncertainty measures. We do not include extreme quantiles (95th and 99th), given the difficulties in their estimation in the high dimensional system. The results with alternative quantile levels are close to the baseline specification (Figures AE8 and AE9). The only difference is that the estimated fall in the Greek spread right uncertainty in response to euro liquidity intervention and the estimated rise in the likelihood of large fall in Italian spread following the dollar intervention become insignificant at alternative quantile levels.

We examine the persistence of the estimated effects by evaluating the responses over the thirty days period (Table AE2). The majority of the previously discussed cumulative responses remained statistically significant over the longer horizon, suggesting that the effects of interventions were not relatively short-lived.

Finally, we ask if our results are the consequent of a "lucky" choice of ECB announcement dates. We perform a random perturbation test. In particular, we construct 200 artificial ECB timelines and re-estimate the QVARX model. We split the sample to non-overlapping 120 (working) day sub-periods such that the number of random announcement days drawn in each six-month sub-period matches the actual number of events within the same period. In this way, we avoid the possibility that random events are concentrated far away from the actual realization of events. Table 3 reports the conditional median reaction of spreads to each randomized policy intervention. Estimated randomized conditional median reactions are small, not significant and often of opposite sign to the baseline estimates, suggesting that our estimates are capturing systematic rather than random relations between the variables. The uncertainty reactions lead to a similar conclusion, and are not reported.

[Insert Table 3]

4.2 FAVAR

We performed several specification checks of the FAVAR specification. None of these altered our results in a qualitative or even meaningfully quantitative way. Hence, we report the results in Appendix E and provide an overview of the tests we performed here.

First, we perturbed the choice of control variables and used either VIX or ITRAXX Europe index as the observed factor (Figure AE10-AE11). Second, we included additional confounding factors to vectors x_t or N_t one at a time. We started by including sets of local news releases and sovereign rating changes to the vector N_t in the VAR equation (Figure AE12-AE13). We included spreads on two-year Spanish and Italian bonds as the additional factors (x_t) that could potentially capture spillovers from the building up of sovereign risk on equity returns (Figure AE14).[25] We also included daily change in euro-dollar swap basis and in the three-month Euribor-Eonia spread as additional source of confounding information (x_t, Figures AE15 and AE16). The results across different specifications are fully in line with our baseline estimates.

Third, we estimated the FAVAR model with industry returns only. The estimates were close to the baseline, suggesting that the results are not sensitive to joint estimation of industry and country returns (Figure AE17). We also confirmed that the results are not sensitive to the number of lags included in VAR equation of FAVAR (Table AE3) and to different orderings of industry returns within vector y_t (not reported). As in the case of sovereign bond spread responses, we find that the dollar liquidity injections and OMT intervention had a persistent statistically significant effect on the equity markets (evaluated over the subsequent thirty days, Table AE4).

Finally, we repeated the placebo analysis in FAVAR framework by constructing 200 artificial ECB timelines and re-estimating the FAVAR model for each of the constructed datasets. As in the QVARX case, estimated impulse responses from randomized datasets are small and not significant, suggesting that our estimates are capturing systematic relations between the variables (Figure AE18).

5 Concluding Remarks

During the global financial crisis, dollar shortage was a key vulnerability of eurozone banks. Using dollars supplied by the U.S. Federal Reserve, the ECB's provision of dollars was crucial in stabilizing the eurozone's financial system, which also helped improve general economic prospects. In contrast, provision of euro liquidity through

[25] We take Spanish and Italian bonds as the representative ones for the periphery countries. Including bonds of other countries would put a constraint on the VAR equation of FAVAR as the number of parameters to estimate grows more rapidly to above 200.

multiple operations had limited effects. To be sure, banks used the easier liquidity to buy sovereign bonds, which reduced the spreads charged on those bonds. But such operations also strengthened the so-called "sovereign-bank" doom loop, raising the concern that the more intimate financial connection between governments and their banks would cause problems down the line. Hence, markets anticipated spreads would likely rise again. Broad economic sentiment did not improve.

The response to the ECB's stimulative measures—direct interventions in bond markets and reduction in the policy rate—was also weak, mirroring, in some respects, the response to the euro liquidity interventions. The ECB's stimulative measures lacked transparency and the commitment underlying them was always shaky. Hence, these measures, rather than helping achieve financial stabilization and economic recovery, mainly signaled the recognition of a bleaker economic outlook.

Markets did believe the ECB's OMT promise. Immediately following the OMT announcements, government bond spreads fell and the sentiment with regard to the banking sector as well as the broader economy improved markedly. Such success in the second half of 2012 is, however, no guarantee of OMT effectiveness in the future (see Mody, 2018 for a discussion). Today, unlike then, the ECB and the system of eurozone's national central banks hold substantial fractions of government bonds through the bond purchase (quantitative-easing) program. There will be political limits to the amount of a country's bonds that the ECB could buy. For, if the stressed country were to default on the bonds purchased by the ECB, other member states would need to share losses as they replenish the ECB's capital. Such a concern would cause hesitation and delays, undermining the potential of OMTs.

More generally, our empirical results say that in periods of heightened uncertainty, central bank interventions are effective if they: i) provide clear signals of the central bank's commitment to stabilize the economy; and ii) address the source rather than the symptom of financial stress. In contrast, ambiguous signals about the likely course of the central bank actions and, hence, uncertainty about the prospects of the economy, have more limited effects. In particular, the strategy of liquidity provision to banks without creating confidence in economic prospects can increase risk-taking incentives of banks.

References

ACHARYA, V. V., D. PIERRET, AND S. STEFFEN (2018): "Lender of Last Resort versus Buyer of Last Resort–Evidence from the European Sovereign Debt Crisis," Discussion paper 18-035, Swiss Finance Institute.

ACHARYA, V. V., AND S. STEFFEN (2015): "The Greatest Carry Trade Ever? Understanding Eurozone Bank Risks," *Journal of Financial Economics*, 115(2), 215–236.

ADRIAN, T., N. BOYARCHENKO, AND D. GIANNONE (2019): "Vulnerable growth," *American Economic Review*, 109(4), 1263–89.

AIT-SAHALIA, Y., J. ANDRITZKY, A. JOBST, S. NOWAK, AND N. TAMIRISA (2012): "Market Response to Policy Initiatives During the Global Financial Crisis," *Journal of International Economics*, 87(1), 162–177.

ALTAVILLA, C., D. GIANNONE, AND M. LENZA (2016): "The Financial and Macroeconomic Effects of OMT Announcements," *International Journal of Central Banking*, 12, 29–57.

ANDRADE, P., E. GHYSELS, AND J. IDIER (2014): "Inflation Risk Measures and Their Informational Content," Discussion paper, SSRN: https://ssrn.com/abstract=2439607.

BAHAJ, S. A. (2014): "Systemic Sovereign Risk: Macroeconomic Implications in the Euro Area," Discussion paper 2014-6, LSE, Centre For Macroeconomics.

BAI, J. (2003): "Inferential Theory for Factor Models of Large Dimensions," *Econometrica*, 71(1), 135–171.

BAI, J., K. LI, AND L. LU (2016): "Estimation and Inference of FAVAR models," *Journal of Business & Economic Statistics*, 34(4), 620–641.

BAI, J., AND S. NG (2002): "Determining the Number of Factors in Approximate Factor Models," *Econometrica*, 70(1), 191–221.

BEBER, A., AND M. W. BRANDT (2009): "When it Cannot Get Better or Worse: The Asymmetric Impact of Good and Bad News on Bond Returns in Expansions and Recessions," *Review of Finance*, 14(1), 119–155.

BEBER, A., M. W. BRANDT, AND K. A. KAVAJECZ (2008): "Flight-to-quality or Flight-to-liquidity? Evidence from the Euro-area Bond Market," *The Review of Financial Studies*, 22(3), 925–957.

BEIRNE, J., AND M. FRATZSCHER (2013): "The Pricing of Sovereign Risk and Contagion During the European Sovereign Debt Crisis," *Journal of International Money and Finance*, 34, 60–82.

BEKAERT, G., R. J. HODRICK, AND X. ZHANG (2009): "International Stock Return Comovements," *The Journal of Finance*, 64(6), 2591–2626.

Benzoni, L., P. Collin-Dufresne, R. S. Goldstein, and J. Helwege (2015): "Modeling Credit Contagion via the Updating of Fragile Beliefs," *The Review of Financial Studies*, 28(7), 1960–2008.

Bernanke, B. S., J. Boivin, and P. Eliasz (2005): "Measuring the Effects of Monetary Policy: a Factor-Augmented Vector Autoregressive (FAVAR) Approach," *The Quarterly Journal of Economics*, 120(1), 387–422.

Bocola, L. (2016): "The Pass-through of Sovereign Risk," *Journal of Political Economy*, 124(4), 879–926.

Boeckx, J., M. Dossche, and G. Peersman (2017): "Effectiveness and transmission of the ECB's balance sheet policies," *International Journal of Central Banking*, 13(1), 297–333.

Boivin, J., M. P. Giannoni, and I. Mihov (2009): "Sticky Prices and Monetary Policy: Evidence from Disaggregated US data," *The American Economic Review*, 99(1), 350–384.

Buraschi, A., and P. Whelan (2015): "Bond Markets and Unconventional Monetary Policy," in *Handbook of Fixed-Income Securities*, ed. by P. Veronesi, vol. 1, chap. 6, pp. 93–116. John Wiley, Sons, Inc.

Chavleishvili, S., and S. Manganelli (2017): "Quantile Impulse Response Functions," Mimeo, Goethe University.

Chernenko, S., and A. Sunderam (2014): "Frictions in Shadow Banking: Evidence from the Lending Behavior of Money Market Mutual Funds," *The Review of Financial Studies*, 27(6), 1717–1750.

Chernozhukov, V., and H. Hong (2003): "An MCMC Approach to Classical Estimation," *Journal of Econometrics*, 115(2), 293–346.

Corradin, S., and M. Rodriguez-Moreno (2016): "Violating the Law of One Price: The Role of Non-conventional Monetary Policy," Working paper 1927, ECB.

D Agostino, A., and M. Ehrmann (2014): "The Pricing of G7 Sovereign Bond Spreads–The Times, They are A-changin," *Journal of Banking & Finance*, 47, 155–176.

De Grauwe, P., and Y. Ji (2013): "Self-fulfilling Crises in the Eurozone: An Empirical Test," *Journal of International Money and Finance*, 34, 15–36.

De Marco, F. (2018): "Bank Lending and the European Sovereign Debt Crisis," *Journal of Financial and Quantitative Analysis, forthcoming.*

De Santis, R. A. (2014): "The Euro Area Sovereign Debt Crisis: Identifying Flight-to-liquidity and the Spillover Mechanisms," *Journal of Empirical Finance*, 26, 150–170.

Drechsler, I., T. Drechsel, D. Marques-Ibanez, and P. Schnabl (2016): "Who Borrows from the Lender of Last Resort?," *The Journal of Finance*, 71(5), 1933–1974.

Du, W., A. Tepper, and A. Verdelhan (2018): "Deviations from covered interest rate parity," *The Journal of Finance*, 73(3), 915–957.

ECB (2012): "Euro Money Market Study," December 2012, ECB.

Escanciano, J. C., and D. T. Jacho-Chávez (2010): "Approximating the Critical Values of Cramér-von Mises Tests in General Parametric Conditional Specifications," *Computational Statistics & Data Analysis*, 54(3), 625–636.

Escanciano, J. C., and C. Velasco (2010): "Specification Tests of Parametric Dynamic Conditional Quantiles," *Journal of Econometrics*, 159(1), 209–221.

Eser, F., and B. Schwaab (2016): "Evaluating the Impact of Unconventional Monetary Policy Measures: Empirical evidence from the ECB? s Securities Markets Programme," *Journal of Financial Economics*, 119(1), 147–167.

Falagiarda, M., and S. Reitz (2015): "Announcements of ECB Unconventional Programs: Implications for the Sovereign Spreads of Stressed Euro Area Countries," *Journal of International Money and Finance*, 53, 276–295.

Favero, C., M. Pagano, and E.-L. Von Thadden (2010): "How does Liquidity Affect Government Bond Yields?," *Journal of Financial and Quantitative Analysis*, 45(1), 107–134.

Gallant, A. R., P. E. Rossi, and G. Tauchen (1993): "Nonlinear Dynamic Structures," *Econometrica*, pp. 871–907.

Gambacorta, L., B. Hofmann, and G. Peersman (2014): "The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-country Analysis," *Journal of Money, Credit and Banking*, 46(4), 615–642.

Gande, A., and D. C. Parsley (2005): "News Spillovers in the Sovereign Debt Market," *Journal of Financial Economics*, 75(3), 691–734.

Garcia-de Andoain, C., F. Heider, M. Hoerova, and S. Manganelli (2016): "Lending-of-last-resort is as Lending-of-last-resort Does: Central Bank Liquidity Provision and Interbank Market Functioning in the Euro Area," *Journal of Financial Intermediation*, 28, 32–47.

Gertler, M., and P. Karadi (2015): "Monetary Policy Surprises, Credit Costs, and Economic Activity," *American Economic Journal: Macroeconomics*, 7(1), 44–76.

Ghysels, E., J. Idier, S. Manganelli, and O. Vergote (2016): "A High-frequency Assessment of the ECB Securities Markets Programme," *Journal of the European Economic Association*, 15(1), 218–243.

Goldberg, L. S., C. Kennedy, and J. Miu (2010): "Central Bank Dollar Swap Lines and Overseas Dollar Funding Costs," Working paper 15763, NBER.

Goncalves, S., and B. Perron (2014): "Bootstrapping Factor-augmented Regression Models," *Journal of Econometrics*, 182(1), 156–173.

Gürkaynak, R. S., B. Sack, and E. Swanson (2005): "The Sensitivity of Long-term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models," *American Economic Review*, 95(1), 425–436.

Hachula, M., M. Piffer, and M. Rieth (2019): "Unconventional Monetary Policy, Fiscal Side Effects, and Euro Area (Im) balances," *Journal of the European Economic Association, forthcoming.*

Hanson, S. G., and J. C. Stein (2015): "Monetary Policy and Long-term Real Rates," *Journal of Financial Economics*, 115(3), 429–448.

Hattori, M., A. Schrimpf, and V. Sushko (2016): "The Response of Tail Risk Perceptions to Unconventional Monetary Policy," *American Economic Journal: Macroeconomics*, 8(2), 111–36.

Hetzel, R. L. (2012): *The Great Recession: Market Failure or Policy Failure?* Cambridge University Press.

Jarocinski, M., and P. Karadi (2018): "Deconstructing Monetary Policy Surprises: The Role of Information Shocks," Discussion paper 12765, CEPR.

Jorda, O. (2005): "Estimation and Inference of Impulse Responses Local Projections," *American Economic Review*, 95(1), 161–182.

Kang, D. W., N. Ligthart, and A. Mody (2015): "The European Central Bank: Building a Shelter in a Storm," Working paper 527, CFS.

Kilian, L. (1999): "Finite-sample Properties of Percentile and Percentile-t Bootstrap Confidence Intervals for Impulse Responses," *The Review of Economics and Statistics*, 81(4), 652–660.

Kim, T.-H., D. J. Lee, and P. Mizen (2018): "Impulse Response Analysis in Conditional Quantile Models and an Application to Monetary Policy," Mimeo, University of Nottingham.

Koop, G., M. H. Pesaran, and S. M. Potter (1996): "Impulse Response Analysis in Nonlinear Multivariate Models," *Journal of Econometrics*, 74(1), 119–147.

Krishnamurthy, A., S. Nagel, and A. Vissing-Jorgensen (2017): "ECB Policies Involving Government Bond Purchases: Impact and Channels," *Review of Finance*, 22(1), 1–44.

Krishnamurthy, A., and A. Vissing Jorgensen (2011): "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity*, 42, 215–287.

Kuttner, K. N. (2001): "Monetary Policy Surprises and Interest Rates: Evidence from the Fed funds Futures Market," *Journal of Monetary Economics*, 47(3), 523–544.

Lucas, A., B. Schwaab, and X. Zhang (2014): "Conditional Euro Area Sovereign Default Risk," *Journal of Business & Economic Statistics*, 32(2), 271–284.

Melosi, L. (2016): "Signalling Effects of Monetary Policy," *The Review of Economic Studies*, 84(2), 853–884.

Mertens, K., and M. O. Ravn (2013): "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States," *The American Economic Review*, 103(4), 1212–1247.

Miranda-Agrippino, S., and G. Ricco (2017): "The Transmission of Monetary Policy Shocks," Mimeo, University of Warwick.

Mody, A. (2009): "From Bear Stearns to Anglo Irish: How Eurozone Sovereign Spreads Related to Financial Sector Vulnerability," Working paper 9-108, IMF.

——— (2018): *Euro Tragedy: A Drama in Nine Acts*. Oxford University Press.

Mody, A., and D. Sandri (2012): "The Eurozone Crisis: How Banks and Sovereigns Came to be Joined at the Hip," *Economic Policy*, 27(70), 199–230.

Nakamura, E., and J. Steinsson (2018a): "High-frequency Identification of Monetary Non-neutrality: The Information Effect," *The Quarterly Journal of Economics*, 133(3), 1283–1330.

Nakamura, E., and J. Steinsson (2018b): "Identification in Macroeconomics," *Journal of Economic Perspectives*, 32(3), 59–86.

Ramey, V. A. (2016): "Macroeconomic Shocks and Their Propagation," in *Handbook of Macroeconomics*, ed. by J. B. Taylor, and H. Uhlig, vol. 2, chap. 2, pp. 71–162. Elsevier.

Roberts, G. O., and J. S. Rosenthal (2009): "Examples of Adaptive MCMC," *Journal of Computational and Graphical Statistics*, 18(2), 349–367.

Rogers, J. H., C. Scotti, and J. H. Wright (2014): "Evaluating Asset-market Effects of Unconventional Monetary Policy: A Multi-country Review," *Economic Policy*, 29(80), 749–799.

Romer, C. D., and D. H. Romer (2000): "Federal Reserve information and the behavior of interest rates," *American Economic Review*, 90(3), 429–457.

——— (2004): "A new Measure of Monetary Shocks: Derivation and Implications," *American Economic Review*, 94(4), 1055–1084.

Schwarz, K. (2016): "Mind the gap: Disentangling Credit and Liquidity in Risk Spreads," Discussion paper, SSRN: https://ssrn.com/abstract=1486240.

Stock, J. H., and M. W. Watson (2018): "Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments," *The Economic Journal*, 128(610), 917–948.

Svensson, L. E. (2010): “Monetary Policy and Financial Markets at the Effective Lower Bound,” *Journal of Money, Credit and Banking*, 42(s1), 229–242.

Szczerbowicz, U. (2015): “The ECB Unconventional Monetary Policies: Have They Lowered Market Borrowing Costs for Banks and Governments?,” *International Journal of Central Banking*, 11(4), 91–127.

White, H., T.-H. Kim, and S. Manganelli (2008): “Modeling Autoregressive Conditional Skewness and Kurtosis with Multi-quantile CAViaR,” Working paper 957, ECB.

——— (2015): “VAR for VaR: Measuring Tail Dependence Using Multivariate Regression Quantiles,” *Journal of Econometrics*, 187(1), 169–188.

Wright, J. H. (2012): “What Does Monetary Policy Do to Long-term Interest Rates at the Zero Lower Bound?,” *The Economic Journal*, 122(564), 447–466.

Yamamoto, Y. (2018): “Bootstrap Inference for Impulse Response Functions in Factor-Augmented Vector Autoregressions,” *Journal of Applied Econometrics, forthcoming*.

Table 1: Monetary policy measure:

Date of release	Date in estimations	Policy action	Policy measure	Coefficient
		Euro liquidity		
03/12/2009	03/12/2009	The ECB's Governing Council signals gradual phasing out of liqudity operations	2.381	
04/03/2010	04/03/2010	ECB announces return to variable rate tender procedures in the regular 3-month longer-term refinancing operations (LTROs), starting with the operation to be allotted on 28 April 2010.	0.049	
25/03/2010	25/03/2010	ECB announces that it will continue to accept bonds with BBB- rating as collateral in its monetary operations	-1.412	
09/05/2010	10/05/2010	ECB announces a supplementary six-month LTRO at a rate which will be fixed at the average minimum bid rate of MRO during the period	-7.721	
10/06/2010	10/06/2010	ECB announces return to fixed rate tender procedure in 3-month LTROs	-4.020	
28/07/2010	28/07/2010	ECB announces stricter rules on bank collateral by revising haircuts on some classes of assets. It also provides details on the haircut schedule effective from January 2011	6.387	
04/08/2011	04/08/2011	ECB announces a liquidity-providing supplementary LTRO with a maturity between 6-12 months	-0.595	-0.99***
06/10/2011	06/10/2011	ECB announces second covered bond purchase programme and the details of new 6-12 months LTRO	-10.126	(0.37)
08/12/2011	08/12/2011	ECB announces 12-36 months LTRO + collateral changes + lower minimum reserve requirements	-26.094	
09/02/2012	09/02/2012	ECB announces specific national eligibility criteria and risk control measures for the temporary acceptance of additional credit claims as collateral in Eurosystem credit operations for 7 central banks (4 periphery).	-3.717	
22/06/2012	22/06/2012	ECB announces expanding pool of assets that can be used as collateral in monetary operations	-28.656	
03/07/2012	03/07/2012	ECB announces cap at the current levels of the amount of government-guaranteed debt that banks can offer as collateral in monetary operations	18.390	
		Sovereign bond interventions and interest rate changes ("stimulus")		
09/05/2010	10/05/2010	ECB introduces Securities Markets Programme	-18.396	
02/12/2010	02/12/2010	ECB announce that it will continue to provide exceptional financial liuquidity and will expand the bank's bond-buying programme to contain the sovereign debt crisis in the euro zone	-7.682	
07/04/2011	07/04/2011	ECB increases the key reference rate by 25 basis points.	-1.816	
07/07/2011	07/07/2011	ECB increases the key reference rate by 25 basis points	3.028	
07/08/2011	08/08/2011	ECB announces active implementation of the SMP program (unofficially buying Spanish and Italian bonds)	-16.699	
03/11/2011	03/11/2011	ECB reduces the key reference rate by 25 basis points	-4.913	-0.06***
08/12/2011	08/12/2011	ECB reduces the key reference rate by 25 basis points	1.798	(0.02)
05/07/2012	05/07/2012	ECB reduces the key reference rate by 25 basis points	-7.782	
26/07/2012	26/07/2012	The President Draghi says that the ECB will do whatever it takes to protect the euro.	-3.045	
02/08/2012	02/08/2012	Announcement of the Outright Monetary Transactions (OMTs) programme	-1.903	
06/09/2012	06/09/2012	ECB announces the technical features of the OMT.	-2.122	
		Dollar liquidity		
27/01/2010	27/01/2010	ECB announces discontinuation of the temporary swap lines with the US Federal Reserve System on 1 February 2010.	-0.200	
09/05/2010	10/05/2010	ECB announces activation of the USD swap lines	4.612	
17/12/2010	17/12/2010	ECB announces activation of the Sterling swap lines	0.641	
21/12/2010	21/12/2010	ECB announces continuation of the USD swap lines	1.089	
29/06/2011	29/06/2011	ECB announces continuation of the USD swap lines	0.743	1.99***
25/08/2011	25/08/2011	ECB announces continuation of the Sterling swap lines	0.569	(0.56)
15/09/2011	15/09/2011	ECB announces three additional US dollar liquidity-providing operations with a maturity of three months. These operations will be conducted in addition to the ongoing weekly seven-day operations announced on 10 May 2010.	2.108	
30/11/2011	30/11/2011	ECB announces temporary network of reciprocal swap lines with the FED, BoE, BoJ, SNB and BoC, which will remain valid until 1 February 2013. It also announces that the existing US dollar liquidity-providing operations will be conducted at a lower price; the initial margin for three-month US dollar operations is reduced, while weekly margin calls are introduced	4.840	
12/09/2012	12/09/2012	ECB announces continuation of the Sterling swap lines	0.408	

Notes: The first two columns reports the dates of ECB policy announcements: actual and in estimations (if the announcement is outside the trading hours). Column 3 provides short description of the policy change. Column 4 reports estimated policy measure defined as the orthogonalized change in: excess bank liquidity (in billion EUR, top panel), yield on two-year Belgium sovereign bond (in basis points, middle panel) and three month euro-dolar basis (in basis points, lower panel) on the announcement days. Column 5 reports estimated coefficient for the announcement dummy of the related intervention, when this variable is included in the regression (1) for the policy instrument.

Table 2: QVARX model fit:

quantile	10		50		90	
	Hits	DCQ test	Hits	DCQ test	Hits	DCQ test
Greece	9.87%	0.525	50.63%	0.205	90.13%	0.162
Ireland	8.62%	0.024	49.51%	0.375	90.96%	0.373
Italy	8.48%	0.010	49.93%	0.330	90.82%	0.130
Portugal	9.46%	0.101	50.49%	0.426	90.82%	0.262
Spain	8.62%	0.152	49.80%	0.300	90.54%	0.148

Notes: For each country in row and each quantile level in column, Table 2 reports: the percentage of times the actual ten year sovereign bond spread change was below the estimated quantile level (first column); the $p-$value of the dynamic conditional quantile (DCQ) specification test (second column) of Escanciano and Velasco (2010). The conditioning set under the alternative for each bond spread in the row includes regressors from equation (2) and the second lag of the corresponding bond spread. Critical values of the test statistic are obtained using the approximation procedure outlined in Escanciano and Jacho-Chavez (2010). In calculations we use 3000 draws from 10 independent (m=10 in notation of their paper) standard normal random variables.

Table 3: Placebo tests:

Spread	Estimate	Euro Liquidity	Dollar liquidity	Monetary Stimulus
Greece	Median	0.017	0.020	0.022
	CI	[-0.031 0.098]	[-0.046 0.098]	[-0.072 0.094]
Ireland	Median	0.003	0.002	0.010
	CI	[-0.033 0.032]	[-0.035 0.039]	[-0.039 0.043]
Italy	Median	0.004	0.002	0.010
	CI	[-0.021 0.029]	[-0.023 0.038]	[-0.035 0.474]
Spain	Median	0.004	0.007	0.003
	CI	[-0.024 0.027]	[-0.035 0.035]	[-0.041 0.042]
Portugal	Median	0.002	0.005	0.016
	CI	[-0.031 0.037]	[-0.041 0.058	[-0.043 0.063]

Notes: The table reports estimated contemporaneous responses of the change in the ten year government bond spreads vis-ŕ-vis Germany (rows) with respect to randomly drawn interventions (columns). The first row for each country reports estimated average conditional median response across 200 artificial timelines. The second row reports 68% confidence interval based on the empirical placebo distribution.

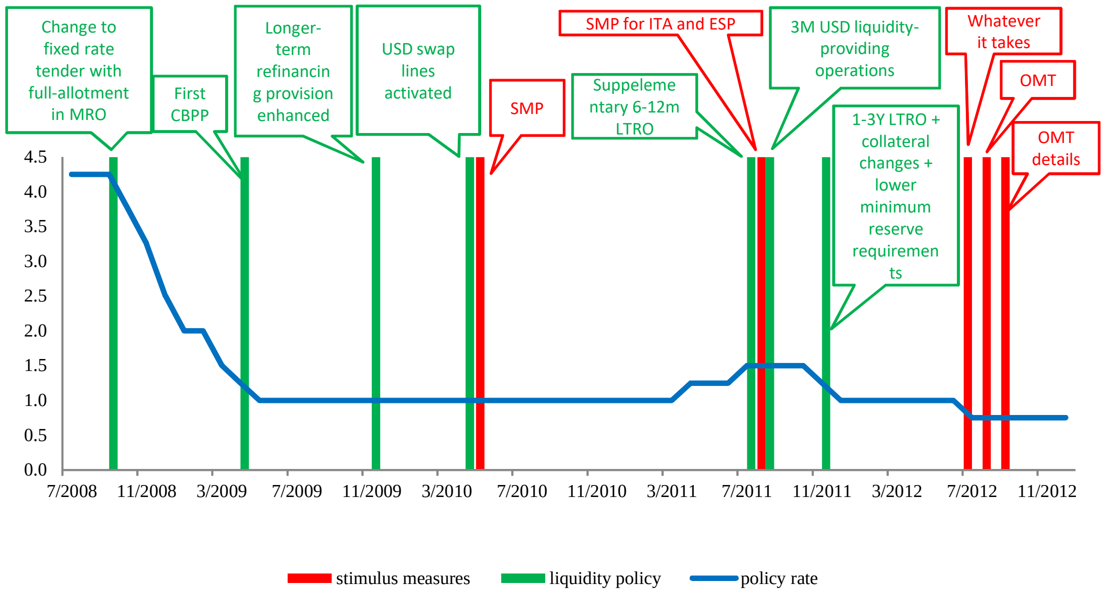

Figure 1: Key ECB policy measures, 07/2008-10/2012:

Notes: The figure reports timeline of the key liquidity and monetary stimulus policy measures implemented by the ECB (bars) and the path of the ECB main reference rate (solid line).

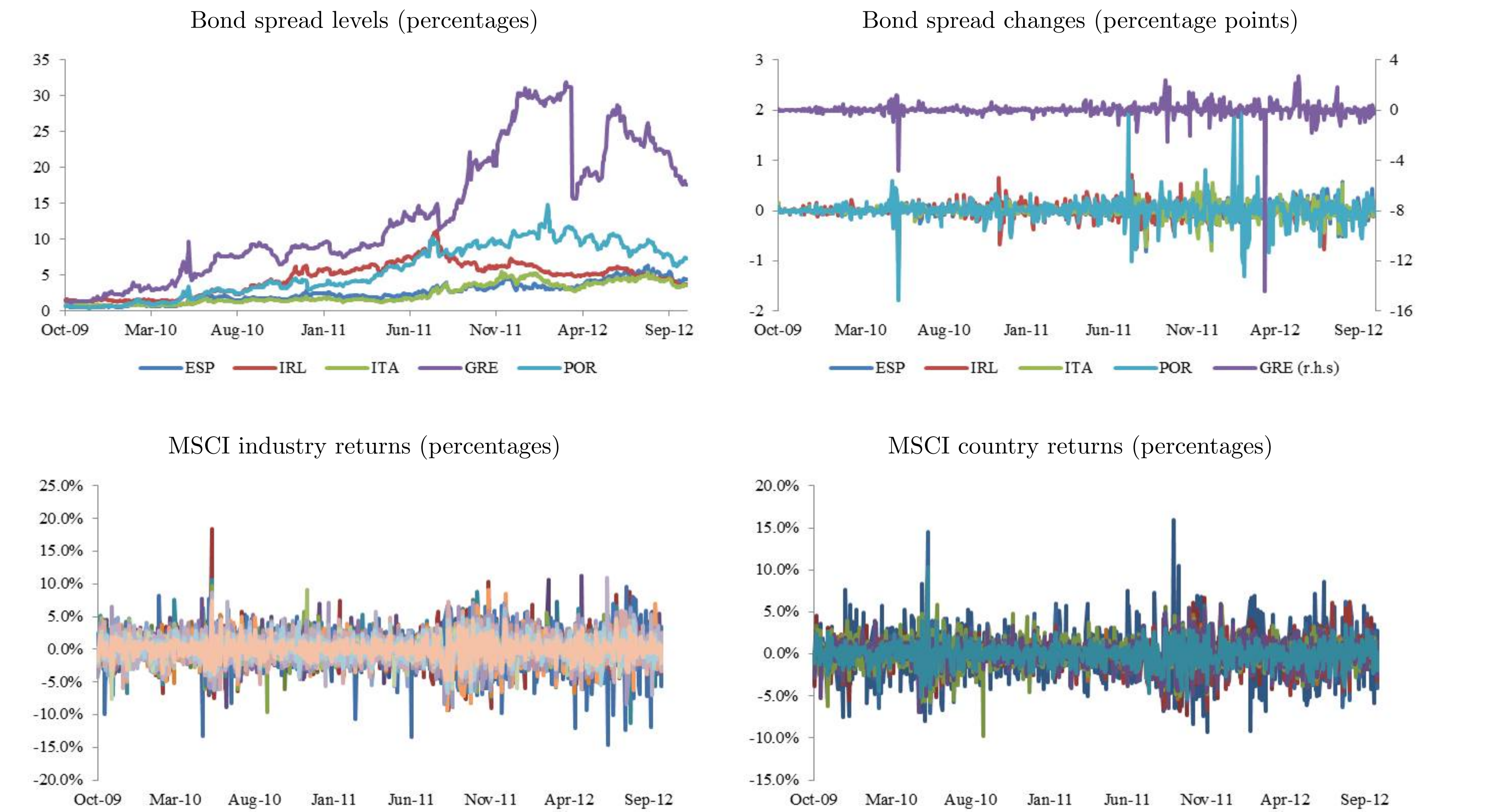

Figure 2: Bond and equity data:

Notes: The figure reports time evolution of the 10Y government bond yield spreads vis-ŕ-vis Germany (first row) and of the MSCI industry and country returns (second row). The sources for all variables are reported in Appendix.

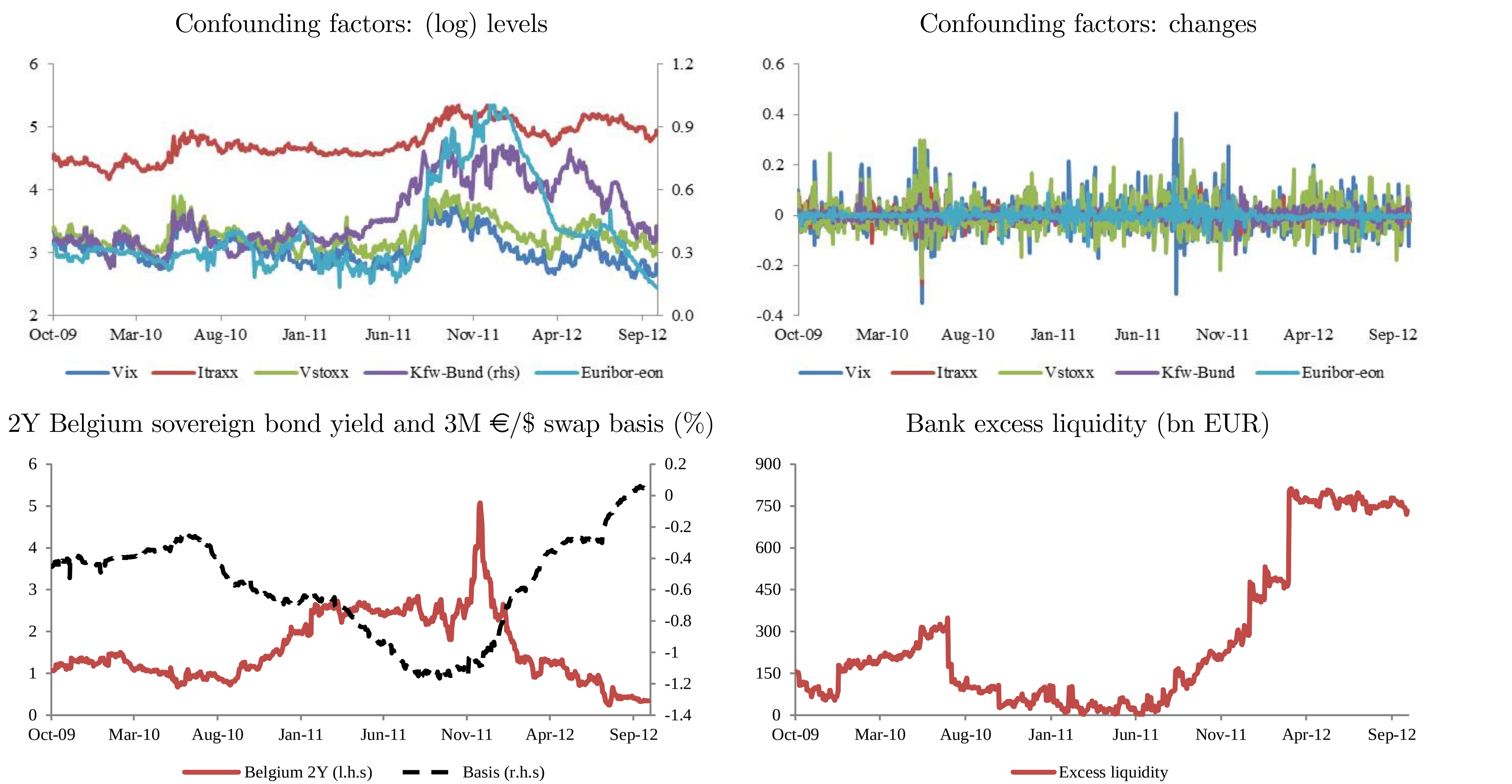

Figure 3: Confounding factors and policy indicator variables:

Notes: The figure reports time evolution of the potential confounding factors (first row) and of the policy indicator variables (second row). The sources for all variables are reported in Appendix A.

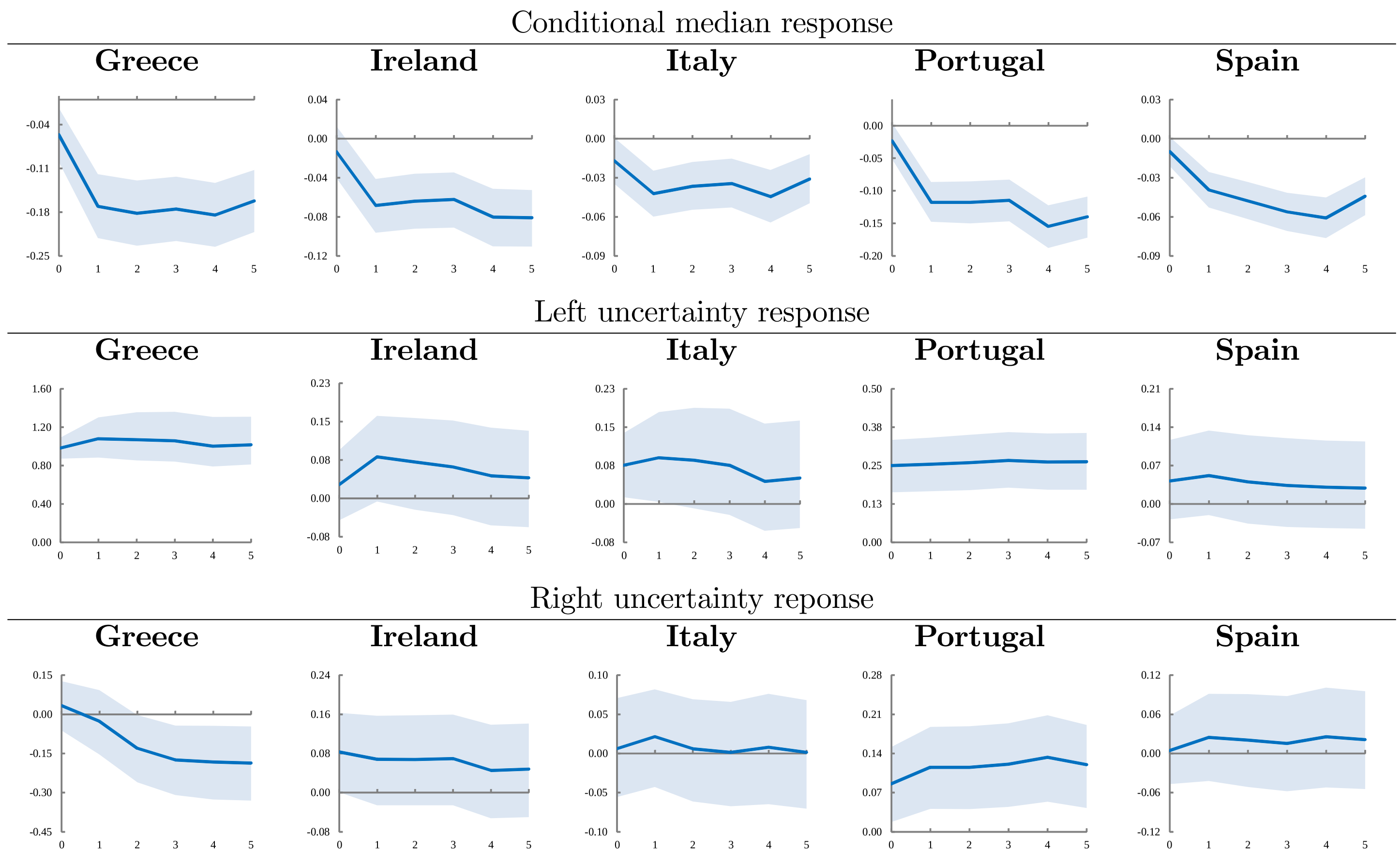

Figure 4: Dollar liquidity intervention: 10 year government bond spreads (percentage points):

Notes: The figure reports daily cummulative conditional median (top row), left (middle row) and right uncertainty (bottom row) response of the change in 10Y sovereign bond spread vis-a-vis Germany to the dollar liquidity intervention that increases the three months euro-dollar swap basis by 1.2 basis points. Left (right) uncertainty is the difference between the 50$^{\text{th}}$ and the 10$^{\text{th}}$ (90$^{\text{th}}$ and 50$^{\text{th}}$) conditional quantile. The shaded areas are 68% confidence intervals.

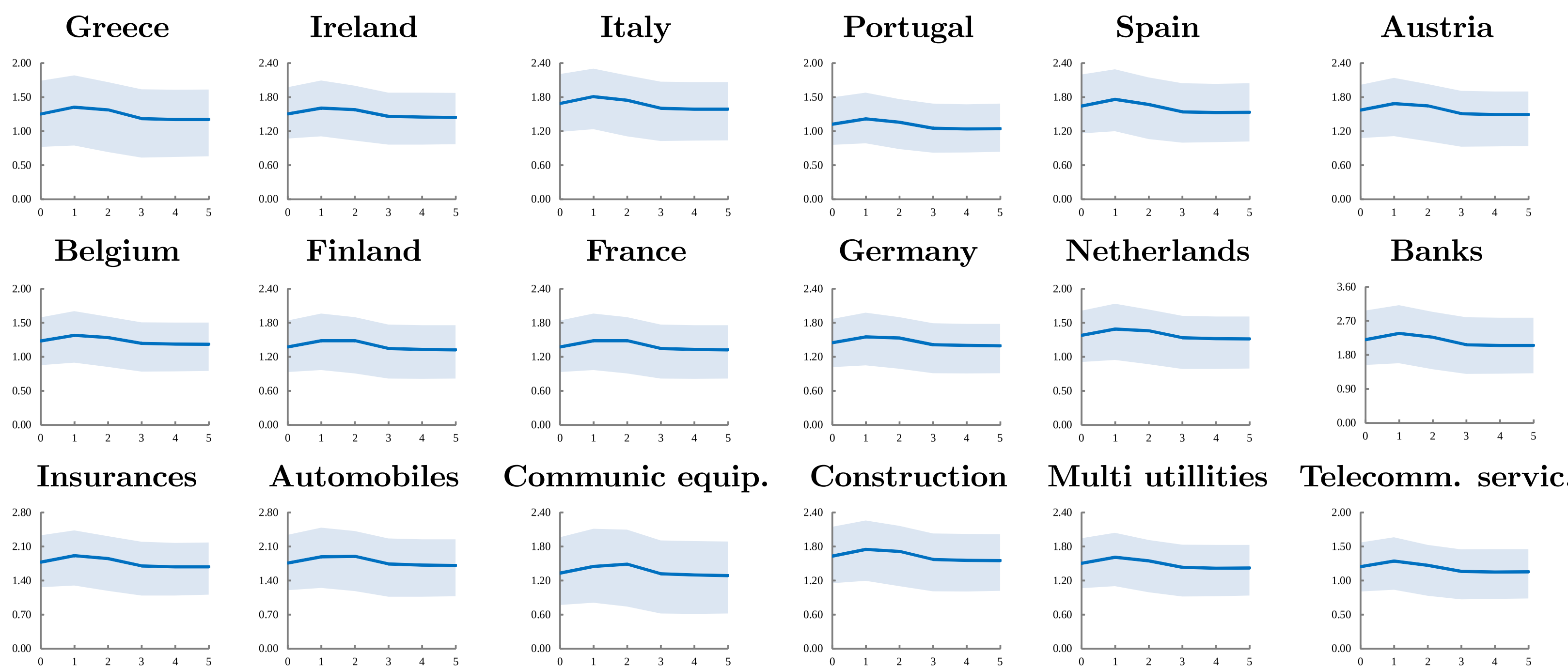

Figure 5: Dollar liquidity intervention: Stock returns responses (percentages):

Notes: The figure reports estimated cummulative responses of MSCI country (top row and first five columns in the second row) and industry returns (last column in the second row and the bottom row) to the dollar liquidity intervention that increases the three-month euro-dollar swap basis by 1.2 basis points. The shaded areas are 90% confidence intervals.

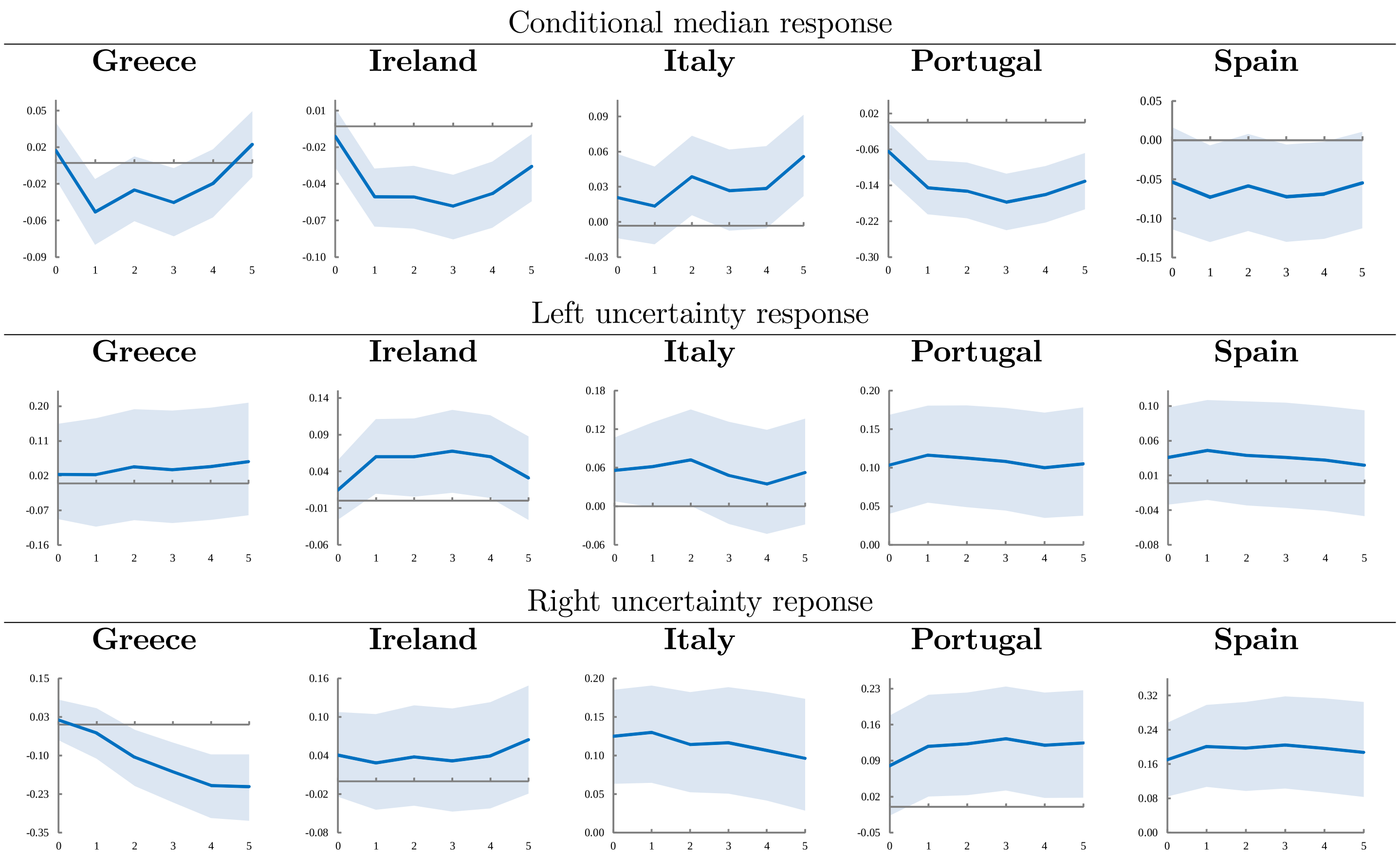

Figure 6: Euro liquidity intervention: 10 year government bond spreads (percentage points):

Notes: The figure reports daily cummulative conditional median (top row), left (middle row) and right uncertainty (bottom row) response of the change in 10Y sovereign bond spread vis-a-vis Germany to the euro liquidity intervention that decreases the Eurosystem excess liquidity by 11.5 bn EUR. Left (right) uncertainty is the difference between the 50$^{\text{th}}$ and the 10$^{\text{th}}$ (90$^{\text{th}}$ and 50$^{\text{th}}$) conditional quantile. The shaded areas 68% confidence intervals.

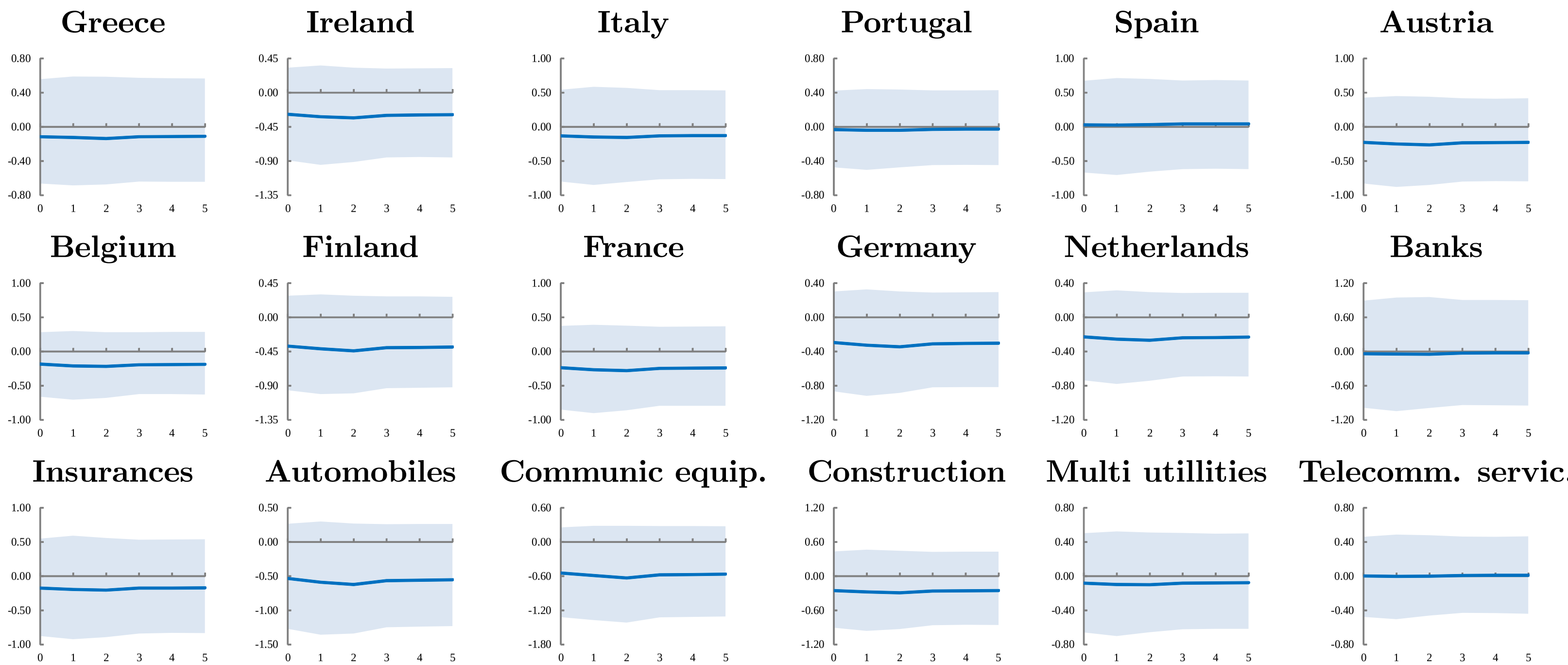

Figure 7: Euro liquidity intervention: Stock returns responses (percentages):

Notes: The figure reports estimated cummulative responses of MSCI country (top row and first five columns in the second row) and industry returns (last column in the second row and the bottom row) to the intervention to the ECB euro liquidity intervention that decreases the Eurosystem excess liquidity by 11.5 bn EUR. The responses are based on the estimated FAVAR. The shaded areas are 90% confidence intervals.

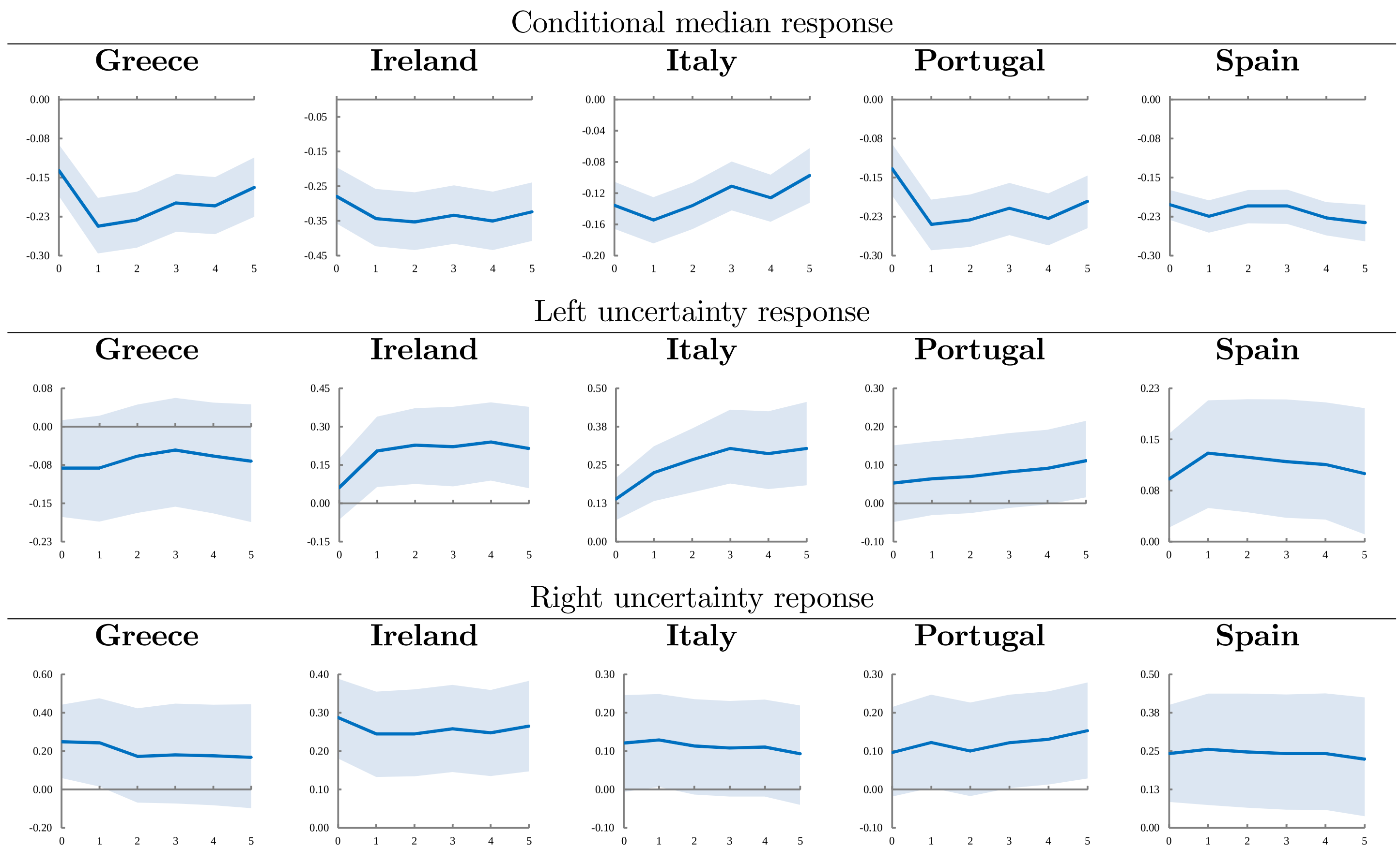

Figure 8: Monetary stimulus intervention: 10 year government bond spreads (percantage points):

Notes: The figure reports daily cummulative conditional median (top row), left (middle row) and right uncertainty (bottom row) response of the change in 10Y sovereign bond spread vis-a-vis Germany to the monetary stimulus intervention that decreases the Belgium 2Y sovereign bond yield by 7 basis points. Left (right) uncertainty is the difference between the 50^{th} and the 10^{th} (90^{th} and 50^{th}) conditional quantile. The shaded areas are 68% confidence intervals.

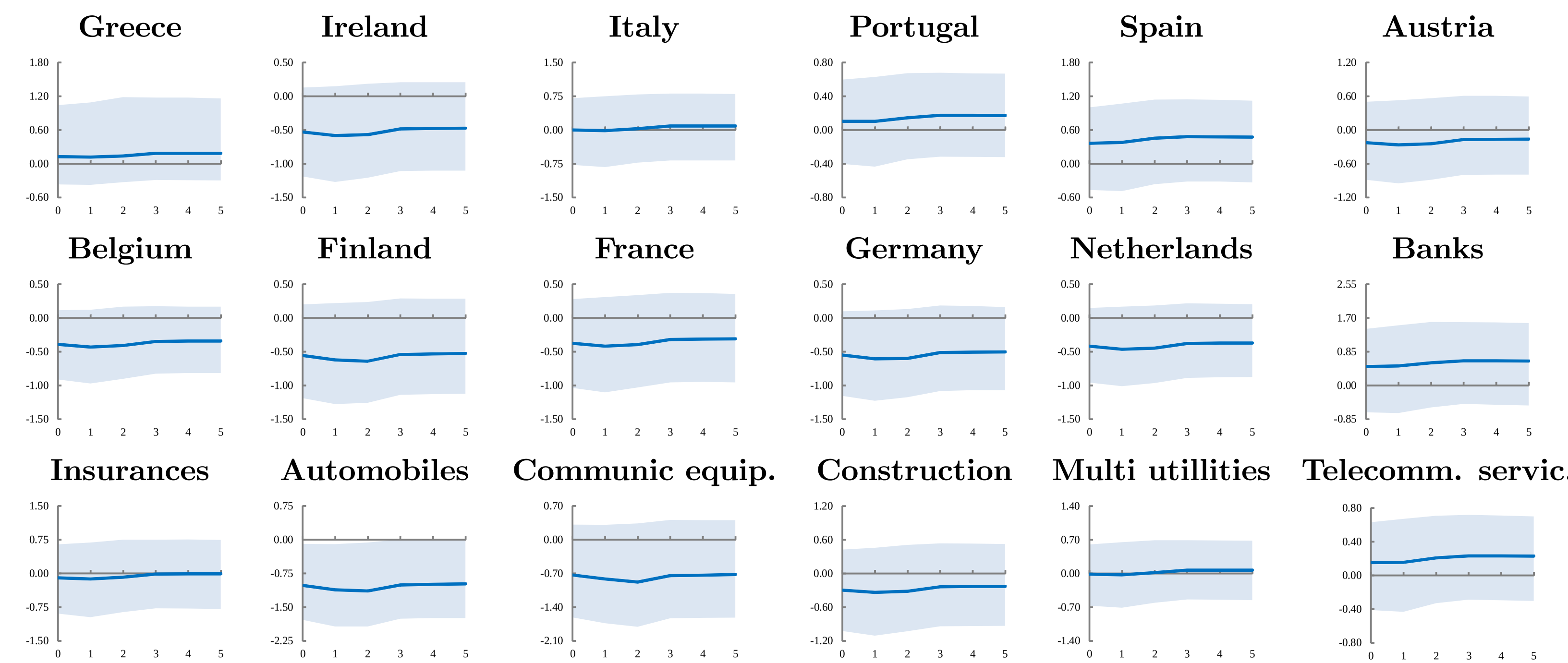

Figure 9: Monetary stimulus intervention: Stock returns responses (percentages):

Notes: The figure reports estimated cummulative responses of MSCI country (top row and first five columns in the second row) and industry returns (last column in the second row and the bottom row) to the monetary stimulus intervention that decreases Belgium 2Y sovereign bond yield by 7 basis points. The responses are based on the estimated FAVAR. The shaded areas are 90% confidence intervals.

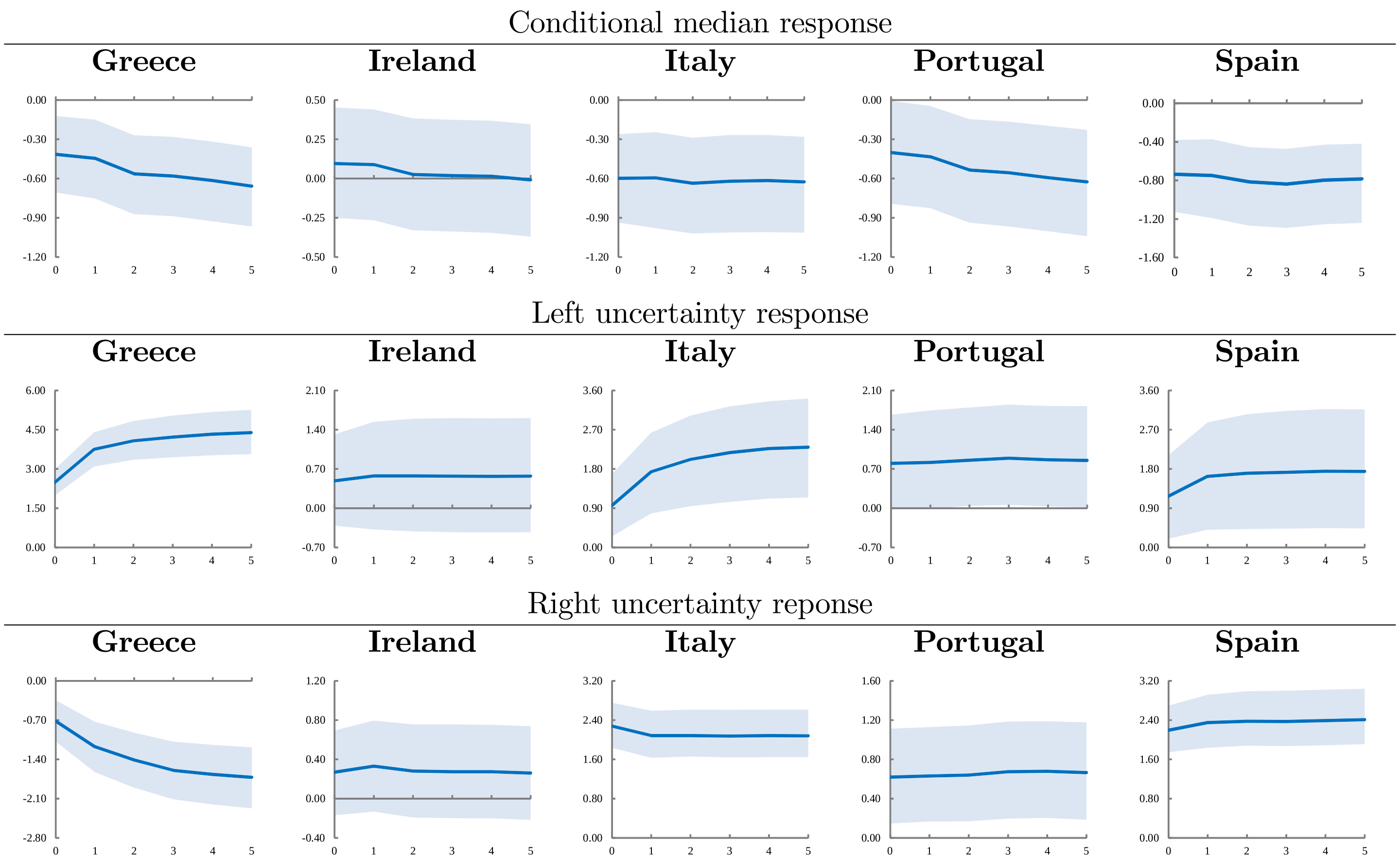

Figure 10: OMT policy intervention: 10 year government bonds (percentage points):

Notes: The figure reports daily cummulative conditional median (top row), left (middle row) and right uncertainty (bottom row) response of the change in 10Y sovereign bond spread vis-a-vis Germany to the OMT policy intervention that decreases the Belgium 2Y sovereign bond yield by 7 basis points. Left (right) uncertainty is the difference between the 50^{th} and the 10^{th} (90^{th} and 50^{th}) conditional quantile. The shaded areas are 68% confidence intervals.

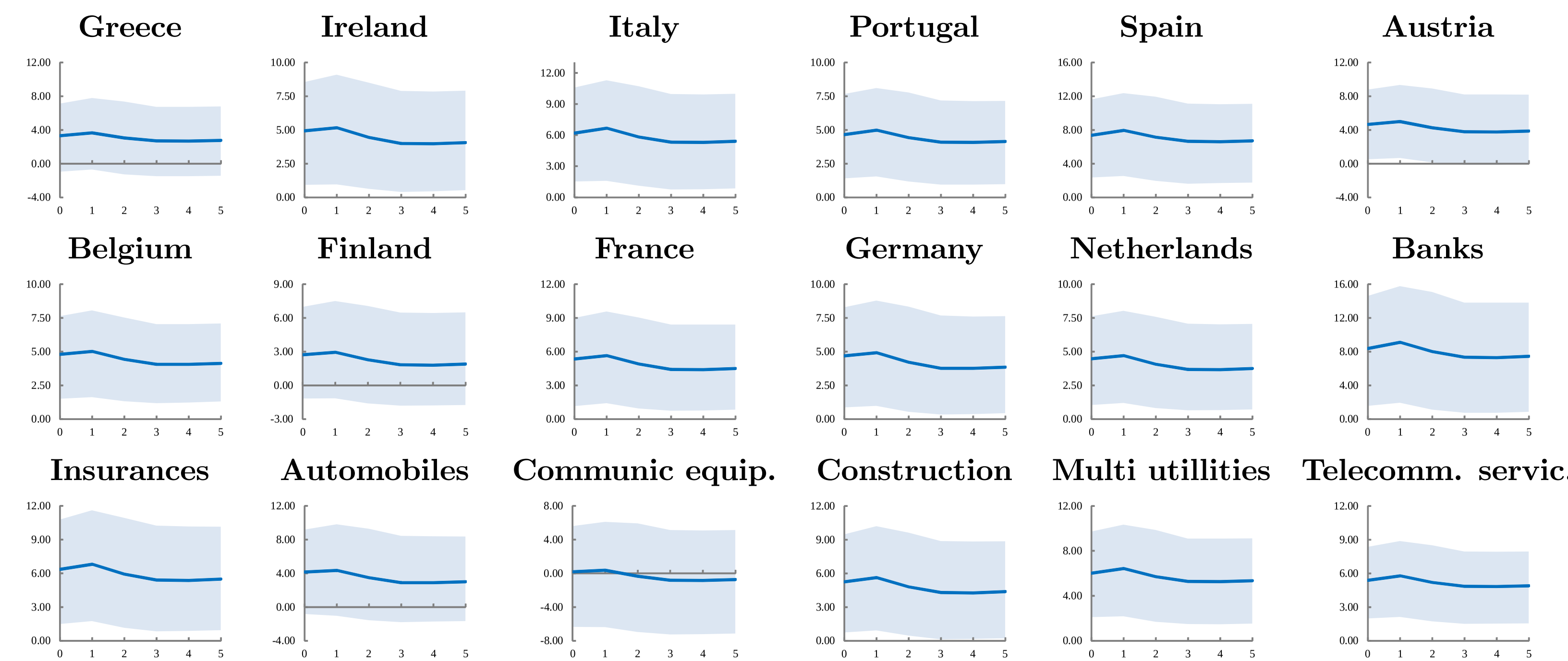

Figure 11: OMT policy intervention: Stock returns responses (percentages):

Notes: The figure reports estimated cummulative responses of MSCI country (top row and first five columns in the second row) and industry returns (last column in the second row and the bottom row) to active monetary policy intervention that decreases Belgium 2Y sovereign bond yield by 7 basis points over the OMT period. The responses are based on the estimated FAVAR. The shaded areas are 90% confidence intervals.