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THE EFFECTIVENESS OF UNCONVENTIONAL MONETARY POLICY ON RISK AVERSION AND UNCERTAINTY

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Abstract

This paper examines the impact of unconventional monetary policy of ECB measured by its balance sheet expansion on euro area equity market uncertainty and investors risk aversion within a structural VAR framework. An expansionary balance sheet shock decreases both risk aversion and uncertainty at least in the medium-run. A negative shock on policy rates has also a negative impact on risk aversion and uncertainty. These results are generally robust to different specifications of the VAR model, estimation procedures and identification schemes. Conversely, periods of high uncertainty are followed by a looser conventional monetary policy. The effect of uncertainty on ECB's total assets and of risk aversion on conventional or unconventional monetary policy is not always statistically significant.

JEL-classification: C32; E44; E52; G12

Keywords: Unconventional monetary policy; euro area; risk aversion; uncertainty

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1. Introduction

In the wake of the global financial crisis central banks throughout the world embarked on unconventional monetary policy (UMP) measures in order to counter the risks to macroeconomic and financial stability. As policy rates approach the zero lower bound, the more common form of UMP involve the massive expansion of central banks' balance sheets replacing short-term interest rates as the main policy instrument.

In the same vein the European Central Bank (ECB) reacted with a basket of UMP measures to provide banks with liquidity and to improve bank lending. Subsequently, the euro area sovereign debt crisis induced pressure on financial markets and made new policy actions necessary. These UMP measures include the fixed rate tenders with full allotment initiated after the collapse of Lehman Brothers, the extension of the maximum maturity of the Long-Term Refinancing Operations (LTRO), and three Covered Bond Purchase Programs (CBPP) between June 2009 and June 2016 purchasing €76.4 billion of covered bonds issued by banks in the euro area. Moreover, the ECB launched the Securities Market Program (SMP) purchasing €219.5 billion of some euro area government bonds from the secondary market between May 2010 and the summer of 2012. The Outright Monetary Transactions (OMT) announced at the summer of 2012, which intended to replace the SMP, highlighted the readiness of ECB to intervene in secondary sovereign bond markets to reduce risk premia and safeguard monetary policy transmission. In June 2014 the ECB announced the launch of a series of targeted long-term refinancing operations (TLTRO) which aim to provide financing to credit institutions in order to further ease private sector credit conditions and stimulate bank lending to non-financial corporations and households. A second series of TLTRO were introduced on March 2016. In November 2014, national central banks started an Asset-Backed Security Purchase Program (ABSPP) to support credit creation in the non-financial corporate sector. Finally, on January 2015 the ECB announced a large-scale Asset Purchase Program (APP). This program expanded the purchases under the ABSPP and CBPP to include also bonds issued by euro area governments, agencies and European institutions, the so called Public Sector Purchase Program (PSPP). Combined monthly purchases under APP were announced to amount to €60 billion and they will be conducted up to September 2016. Later on the ECB decided to run the program until the end of March 2017, or beyond, if necessary, and to expand its monthly purchases to €80 billion. Figure 1 presents the evolution of ECB's total assets from December 2007 to June 2016 along with the announcement dates of the aforementioned unconventional monetary policy interventions. From December 2007 to December 2012 ECB's total assets increase steadily especially during the fall of 2011. From 2012 to mid-2014 we observe a contraction of ECB's balance sheet. This reflects to a large extent the lower levels of outstanding LTRO which were not compensated by alternative measures. Finally, from mid-2014 to the end of the sample period total assets increase once more after the implementation of the ABSPP the PSPP and the TLTRO.

The effect of conventional monetary policy rules (i.e., short-term interest rates) on financial markets is well understood as many empirical and theoretical studies in this field indicate that expansionary (contractionary) monetary policy affects the stock market positively (negatively) (Rigobon & Sack, 2004; Bernanke & Kuttner, 2005). Moreover, these studies indicate that this effect is induced primarily by changes in risk premia, with very little of the effect coming directly from changes in the risk-free rate. Thus, a lax monetary policy has a positive impact on the risk bearing capacity of financial investors. More recently Bekaert, Hoerova, & Lo Duca (2013) decompose the VIX index into two components, a proxy for risk aversion and uncertainty, and empirically demonstrate that a lax monetary policy implemented by the Fed decreases both risk aversion and uncertainty, with the former effect being stronger. Similar evidence is provided by Nave & Ruiz (2015) for the Eurozone. Neither of these two papers, however, examine the effect of the UMP measures taken by central banks in the aftermath of the recent financial crisis on risk aversion and uncertainty.

The existing literature on the effect of UMP measures mostly focuses on their impact on the shape of the yield curve and the exchange rates using event-studies methodologies (Eser & Schwaab, 2016; Altavilla, Carboni, & Motto, 2015 for the impact of ECB's UMP measures). These studies indicate that UMP measures have depreciated bonds yields and domestic currencies.[1] The impact of UMP measures, of which balance sheet expansion is one particular example, however on the volatility of equity markets and the risk-bearing capacity of investors is still to be explored.

The paper aims to fill this gap in the literature by examining the effect of the ECB's balance sheet expansion, on equity market uncertainty and risk aversion. In so doing, the paper uses a structural VAR (SVAR) methodology building on the models of Bekaert, Hoerova, & Lo Duca (2013) and Boeckx, Dossche, & Peersman (2014). This framework of analysis enables us to examine the dynamic effect of UMP measures taking into account the endogeneity between monetary policy announcements and financial variables. The motivation of this study is to examine the broader impact of these policy measures on market participants' risk attitude and market uncertainty going beyond the immediate impact that other studies have documented on the yield curve.

The main findings of this study are as follows: First, an expansion of ECB's balance sheet significantly decreases risk aversion after about 10 months and persist for more than 3 years. Second, an expansion of the ECB's balance sheet decreases uncertainty from the first month after the shock. This effect is also persistent, lasting for more than 3 years. Third, a negative shock in ECB's policy rate (measuring conventional monetary policy stance) decreases risk aversion and uncertainty from the first month after the shock. These results are robust to different specification of the SVAR model. Third, using a different identification scheme a lax conventional or unconventional monetary policy increases risk aversion and uncertainty contemporaneously. In the medium-run, however, the impact becomes negative. Fourth, a sign restriction identification strategy corroborates in general with our benchmark results. Uncertainty decreases on impact after an unconventional monetary policy shock, while risk aversion decreases 1 month after this shock. Finally, periods of high uncertainty are followed by a looser conventional monetary policy. The effect of uncertainty on ECB's total assets and of risk aversion on conventional or unconventional monetary policy is less robust.

[1] Another stream of research examines the macroeconomic impact of UMP (Gambacorta, Hofmann, & Peersman, 2014). They find that these policy measures have a positive effect on output and prices.

This paper is closely related to the "risk-taking transmission channel" of monetary policy literature (Borio & Zhu, 2012). Easier funding conditions provided by a lax *conventional* monetary policy may reduce perceived risks and induce higher risk-taking allowing financial intermediaries to increase their leverage (Bruno & Shin, 2015). Following this stream of research, this paper provides new empirical evidence showing that *unconventional* policy measures can also reduce uncertainty and market participants' risk aversion. This paper is also related to recent studies examining the transmission of UMP measures via the risk-bearing capacity of the financial sector. Gilchrist & Zakrajsek (2013) examine the impact of UMP news in the US using an event-study methodology on the risk-bearing capacity of financial intermediaries using CDS spreads. They indicate that the UMP measures employed by the Fed have substantially lowered the overall level of credit risk in the economy; however the LSAP announcements appear to have had no measurable effect on credit risk in the financial intermediary sector. Hattori, Schrimpf, & Sushko (2016) examine the impact of UMP news on tail risks in the US stock and money market. In a similar context Roache & Rousset (2013) examine the effect of Fed's UMP news on Euro/USD exchange rate, an equity index and five commodities. Both studies indicate that UMP announcements reduce tail risks in the equity market pointing to the "risk-taking channel" of monetary policy.

The remainder of the paper is organized as follows. Section 2 presents the data and the measurement of the two key variables: uncertainty and risk aversion. Following Bekaert, Hoerova, & Lo Duca (2013) we estimate these two variables by decomposing the VSTOXX index. Section 3 presents the benchmark SVAR model and discuss its identification and estimation. In Section 4 we report the empirical results of the paper and we conduct a number of robustness checks. Section 5 concludes the paper.

2. Data, variables and measurement

This section describes the data and variables employed in the empirical analysis of the paper. The sample period covers the period spanning the time interval from December 2007 to June 2016. The starting period of our sample is selected so that it coincides with the onward of ECB's unconventional monetary policy. This short time period that we examine makes it necessary to use monthly observations in order to have sufficient information to estimate the VAR model.

2.1. The data

The reference index that this paper employs for the euro area equity market is the EURO STOXX 50. It contains 50 stocks of large capitalization from 11 Eurozone countries. The following data concerning this index are used: Daily closing prices of the index, its dividend-price ratio and daily closing prices of the VSTOXX index. This index measures the risk-neutral volatility of EURO STOXX 50. It is extracted from options traded on the EURO STOXX 50 with a 1-month maturity horizon. In a robustness analysis we also employ the VIX index (measuring the risk-neutral volatility of the S&P 500 index) as a proxy variable for financial stress in the international level. These data are downloaded from Datastream.

The paper also uses a number of macroeconomic, monetary policy and financial variables for the euro area. In particular, we use the 3-month yield of the euro area AAA-rated government bonds in the forecasting regressions that follow below. We also use the 1-month yield of all euro area government bonds in the empirical analysis to identify balance sheet shocks using sign restrictions. As the euro area business cycle indicator we use Eurozone industrial production index. We also consider the seasonally-adjusted harmonized index of consumer prices as a measure of prices in the euro area. These data are downloaded from ECB Statistical Data Warehouse.

The main refinancing operation (MRO) rate represents the conventional monetary policy instrument. The ECB total assets/liabilities provide a measure of the balance sheet size capturing the unconventional monetary policy as suggested in the relevant literature (Boeckx, Dossche, & Peersman, 2014). As before these data are downloaded from ECB Statistical Data Warehouse.

2.2. Estimating uncertainty and risk aversion

This section presents the estimation of two key inputs to our analysis, namely, equity market uncertainty and investors risk aversion. The estimation procedure is based on the decomposition of the VSTOXX index. The latter represents the option-implied volatility of the EURO STOXX 50 index. The VSTOXX is a forward-looking measure of volatility under the risk-neutral probability measure. Importantly, this implied volatility measure is model-free as it is directly computed as a weighted-average of European options prices written on the index with maturity interval of 1 month. It is also the premium that investors demand to sell volatility in a swap contract (known as a volatility swap). To this end, it reflects both the expected variance of the index under the physical probability measure (which summarizes the actual probabilities of future states) as well as the variance risk premium. Previous empirical studies (Carr & Wu, 2009) indicated that the variance risk premium is almost always negative and time-varying. These empirical stylized facts can be attributed to time-varying risk aversion and non-Gaussian components in state variables (Bekaert & Engstrom, 2013; Drechler & Yaron, 2011) or model uncentainty (Drechler, 2013). Following Bekaert, Hoerova, & Lo Duca (2013) we will consider expected variance and variance risk premium as proxies for equity market uncertainty and investors risk aversion, respectively.

Let r_t denote the daily log-return of the index. Then the realized variance over the time period $(t, t+\tau)$ is defined as:

$$RV_{t,t+\tau} = \sum_{i=t}^{t+\tau} r_i^{2}$$

The expected variance is defined as $EV_t = E_t^{P}\left[RV_{t,t+\tau}\right]$, where $E_t^{P}[.]$ denotes the conditional at time t expectation under the physical probability measure P. The variance risk premium is defined as:

$$VRP_t = E_t^{Q}\left[RV_{t,t+\tau}\right] - E_t^{P}\left[RV_{t,t+\tau}\right],$$

where $E_t{}^Q[.]$ denotes the conditional at time t expectation under the risk-neutral probability measure Q.[2] The risk-neutral expected variance can be directly computed by the VSTOXX index quotes as follows:

$$RNV_t \equiv E_t{}^Q\left[RV_{t,t+\tau}\right] = \frac{1}{12}\left(\frac{VSTOXX_t}{100}\right)^2$$

Therefore, to decompose the VSTOXX index into expected variance and variance risk premium we need to estimate the expected variance EV_t, given that it is an unobserved quantity. This estimate can be obtained following two different approaches. The first is based on projecting future realized variance in a set of current instruments (Bekaert & Hoerova, 2014). The second employs the Filtered Historical Simulation (FHS) technique (Barone-Adesi, Engle, & Mancini, 2008). Table 1 summarizes the variables used along the empirical analyses.

2.2.1. Forecasting regressions

The first approach is based on projecting future monthly realized variance $RV_{t,t+\tau}$ computed from daily log-returns on a set of current instruments which include the lagged monthly realized variance $RV_{t-\tau,t}$, the risk-neutral variance RNV_t computed from the VSTOXX index, the log of dividend-price ratio of the index, the 3-month euro area yield, and a dummy variable indicating a negative return of the index the previous month. We estimate 24 models using all possible combinations of the independent variables. As it is often done in the literature we also compare the predictive performance of these models with 3 non-estimated models with fixed coefficients. The first is the usual random walk model; the second uses the risk-

[2] Note here that the definition of the variance risk premium is the negative of the variable that we use in this paper. By switching the sign, our variable should be almost always positive and increasing with risk aversion, whereas the actual variance risk premium becomes more negative as risk aversion increases. To further clarify this issue let assume the existence of a one-period representative agent with power utility function so that in equilibrium he invests all his wealth in the stock market. Then one can prove that:

$$E_t{}^P\left[RV_{t,t+\tau}\right] - E_t{}^Q\left[RV_{t,t+\tau}\right] \approx \gamma\mu^P_{3,(t,t+\tau)}$$

where γ is the relative risk aversion coefficient and $\mu^P_{3,(t,t+\tau)}$ is the third-order central moment of the log-return distribution under measure P (Bakshi & Madan, 2006). Empirical stylized facts indicate that $\mu^P_{3,(t,t+\tau)} < 0$, which explains why the variance risk premium defined in the finance literature is negative and decreasing with risk aversion. The variance risk premium defined in the paper is given as:

$$VRP_t \approx \gamma\left(-\mu^P_{3,(t,t+\tau)}\right)$$

indicating that our variable should be positive and increasing with risk aversion neutral variance as a regressor with a coefficient equal to 1, while the third uses the risk-neutral variance and the lagged realized variance both with coefficients equal to 0.5.

[insert Table 1 here]

We compare the out-of-sample performance of these 27 models. For estimated models we perform recursive estimations starting in December 2007, after having 40 months of data going back to September 2004, and adding one observation at a time. We then compute the root mean squared error (RMSE), the mean absolute error (MAE) and the mean percentage error (MPE). Our sample period includes dates with extreme realized variance observations that could dramatically influence the ranking of the models. To this end, we winsorize the top 5% of the realized variance observations in our sample, and perform regressions using the winsorized sample. We find that the regression model with independent variable the risk-neutral variance has the lowest RMSE and MAE. In terms of the MPE, the three-variable model which includes the risk-neutral variance, the dividend-price ratio and the 3-month euro area yield outperforms all others. We evaluate whether the forecast error measures are significantly different among competing models through the Diebold & Mariano (1995) test. We find that the RMSE and the MAE criteria have little power to distinguish among alternative models, while the MPE is the most distinguishing one. To this end, we choose the three-variable model as our forecasting regression model to estimate expected variance. Appendix A.1 provides the details of this forecasting horserace.

2.2.2. Filtered historical simulation

The second approach to estimate expected variance is based on the FHS methodology. In short, we first fit an appropriate GARCH model on the observed daily returns of the index during the sample period. An adequate model requires that the standardized innovations and their squares remain serially uncorrelated. At the same time, we choose a more parsimonious specification among the candidate models by minimizing the Bayesian Information Criterion. In so doing, we compare various GARCH-type models, including the GARCH, the EGARCH (Nelson, 1991) and the GJR (Glosten, Jagannathan, & Runkle, 1993) models assuming that the error term follows the standardized Normal or the Student-t distribution. We find that the GJR(1,1) with a Student-t distribution performs better than all others specifications. At the second stage, we employ this model as a filter to infer the empirical daily innovations from the observed realized log-returns. The empirical distribution of the 1-month ahead log-return distribution and its associated expected variance is then generated at the final stage, by means of simulating the filtered process on 100,000 innovation bootstraps.

The variance risk premium, our proxy for risk aversion, is then calculated as the difference between the risk-neutral variance measured by the VSTOXX index and the expected variance estimated either by the forecasting regression approach or the FHS. Note here that in the finance literature the variance risk premium is the negative of the variable that we use. By switching the sign, our indicator tends to increase with risk aversion, whereas the variance risk premium becomes more negative with risk aversion.

2.2.3. Market uncertainty and risk aversion estimates

Figure 2 shows the estimated equity market uncertainty series from December 2007 to June 2016 in a monthly frequency. Figure 3 presents risk aversion for the same sample period. Inspection of the figures indicates that the two different estimates of uncertainty and risk aversion are close to each other. Both increase in the aftermath of Lehman Brothers default (fall 2008) and during the fall of 2011 when the euro area debt crisis has intensified. As expected risk aversion estimates are positive in almost all data points.

3. VAR model

We analyze the effect of monetary policy within a vector autoregressive (VAR) model which allows us to examine the dynamic effects of shocks, while imposing a minimum set of assumptions about the structure of the economy. In this respect we build on the approaches of Bekaert, Hoerova, & Lo Duca (2013) and Nave & Ruiz (2015). We consider the VAR model to be a generally accepted way to examine the relationships whithin a group of variables which is used extensively in the monetary policy literature. In this framework conventional or unconventional monetary policy shocks are captured by the shocks in the respective equations of the system.

3.1. Five-variable structural VAR

Our benchmark VAR model includes 5 variables collected in the vector $y_t = (IP_t, RA_t, UC_t, PR_t, TA_t)'$, where the different factors are measured using the variables described in the previous section: the logarithm of the industrial production index (IP_t) as an indicator of the bysiness cycle, the risk aversion (RA_t) estimated from the FHS methodology, the equity market uncertainty (UC_t) also estimated from the FHS, the MRO rate (PR_t) as an indicator of ECB's conventional monetary policy, and the logarithm of the ECB's total assets (TA_t) as an indicator of unconventional monetary policy. This 5-variable VAR model can be considered as a generalization of the 4-variable VAR model of Bekaert, Hoerova, & Lo Duca (2013) where the extra fifth variable is the total assets of the ECB.

We consider the following structural VAR model:

$$A_0 y_t = \mu + \sum_{j=1}^{p} A_j y_{t-j} + \varepsilon_t$$

where μ is the (5×1) intercept vector, A_0 is a (5×5) matrix of the parameters of the contemporary relation between the endogenous variables of the model and ε_t is the (5×1) vector of the structural shocks of the model, where $E(\varepsilon_t {\varepsilon_t}') = I$. To estimate this structural VAR model, we first write it as a reduced-form VAR as follows:

$$y_t = a + \sum_{j=1}^{p} B_j y_{t-j} + u_t$$

where $a = {A_0}^{-1}\mu$, $B_j = {A_0}^{-1}A_j$, for $j = 1,2,\dots,p$, and $u_t = {A_0}^{-1}\varepsilon_t$, where $\Sigma = E(u_t {u_t}') = ({A_0}' A_0)^{-1}$. To identify the structural relation we must add restrictions on the implulse response functions of the shocks. A frequently used approach is to use the Cholesky decomposition of the estimate of the variance-covariance matrix. This decomposition places restrictions on matrix A_0 implying a recursive shock identification such that the order in which the variables appear into vector y_t becomes relevant.

3.2. Identification

The structural shocks for the VAR model are identified following the relevant literature (Kremer, 2015). The industrial production index is ordered first assuming that is does not respond instantatly to a structural shock in financial and monetary policy variables, where the latter include market uncertainty, risk aversion, the MRO rate and the ECB's total assets. Risk aversion and equity market uncertainty are ordered after the industrial production index assuming that these variables respond instantly to a structural shock in industrial production. This also implies that these two financial variables do not respond instantly to a shock in conventional or unconevetional moneraty policy but with a lag of at least one month. Within the financial variables block we order risk aversion before uncertainty. The monerary policy variables are ordered last. This assumption implies that the MRO rate and the volume of the ECB's total assets respond instantly to a shock in industrial production, uncertainty and risk aversion. Stated alternatively, we implicitely assume that any shock to these variables during a given month is part of the information set available to the decision making body of the ECB when it set the monetary policy instruments. Within the monetary policy block we order the MRO rate before the volume of total assets. According to Kremer (2015) this implies that, from the one hand, conventional monetary policy is determined without regard to the factors behind the decisions concering unconventional monetary policy, at least within a month. On the other hand, the instantaneous reaction of ECB's total assets to MRO rate shocks captures the liquidity demand of banks to the new interest rate conditions. Summing up, the order of the five endogenous variables of the VAR model is exactly the order that these variables appear in vector y_t. In accordance with the relevant literature the lag order is set equal to $p = 4$ according to the Akaike Information Criterion.

3.3. Estimation

In a 5-variable VAR model with intercept with 4 lags the number of parameters to be estimated are equal to $5 + 5 \times 5 \times 4 = 105$. With our limited sample (103 observations) this entails the risk of over-parametirization, imprecise VAR estimates, and large standard errors of forecasts. Bayesian methods were proposed in the literature to solve these problems. The general idea is to treat the ambiguity over the exact value of the model's parameters as a probability distribution of the parameter vector. The degree of ambiguity represented by this distribution can then be altered by the information contained in the data if the two sources of information are different. The use of informative priors shrinks the unrestricted model towards a parsimonious naïve benchmark, thereby reducing parameter ambiguity and improving forecast accuracy. Nevertheless, for robustness, we have also estimated the VAR model using the standard OLS estimation procedure. These results are discussed later in section 4.2.2.

The prior distribution of the reduced-form VAR belongs to the independent Normal-Wishart family. This prior implies that both the vector of the VAR parameters and the variance-covariance matrix are treaded as unknown, with no assumed dependence between error term variance and parameter variance. In particular, the prior for the vector of parameters of the VAR follows the multivariate Normal distribution. The mean vector and the variance-covariance matrix of this distribution take the form of the standard Minnesota prior mean and variance. To this end, the mean vector has all entries equal to zero except those concerning the first own lag of each endogenous variable which are attributed values of 0.9, as most of the endogenous variables can be considered to follow unit-root or near unit-root processes. The overall tightness parameter $\lambda_1 = 0.05$, the cross-variable specific variance parameter $\lambda_2 = 0.6$, the lag decay $\lambda_3 = 2$ and the constant specific variance parameter $\lambda_4 = 100$.[3] The prior distribution for the variance-covariance

[3] An extensive robustness analysis with different autoregressive coefficient values ranging between 0.7 and 1 and different values for the hyperparameters, and especially the level of shrinkage, indicates that the results are similar to those reported in the text. These results are available upon request.

matrix is an inverse Wishart distribution with scale matrix the diagonal covariance matrix obtained from individual AR regressions.

For robustness we have also estimated the VAR model using the normal-diffuse prior, which relies on an uninformative prior for the variance-covariance matrix. The results are quantitatively similar to those reported in the text and can be provided by the author upon request.

Following the relevant literature the results are reported in the form of impulse response functions (IRFs). After a burn-in period of 5,000 draws, a total of 15,000 draws from the posterior distribution are used to produce the median impulse responses. We also report the 16^{th} and 84^{th} percentiles of the posterior distribution as it is standard in the Bayesian VAR literature. These impulse response bands reflect both model uncertainty and sampling uncertainty.

4. Empirical results

4.1. Benchmark 5-variable VAR

4.1.1. Identified balance sheet shocks

Before discussing the dynamic effects of the balance sheet shocks it is interesting to examine the time series of the identified shocks. Inspection of these shocks can shed light on their sources assessing whether they capture the main policy measures taken by the ECB causing an expansion of its balance sheet. Figure 4 presents the median values of the identified balance sheet shocks for each month of the sample period. A positive shock indicates an expansionary balance sheet shock, while a negative one reflects a tightening of the balance sheet relative to the endogenous response to the other shocks included in the VAR. The figure indicates that the identified positive shocks coincide with expansionary balance sheet policy measures taken by the ECB. This provides evidence that our identification scheme is plausible. In particular, expansionary balance sheet shocks coincide with the implementation of the fixed-rate full allotment policy in October 2008, the 1-year LTRO in May 2009 and December 2009, the first two CBPP in June 2009 and October 2011 and the 3-year LTRO in December 2011 and March 2012. Interestingly, the start of the SMP1 program in May 2010 and the announcement of the ABSPP/CBPP3 and APP/PSPP in September 2014 and January 2015, respectively, are not identified as significant expansionary balance sheet shocks. These results should be however interpreted with caution as we examine the dynamics of the balance sheet shocks with respect to the announcement dates which do not necessarily coincide with the implementation of these measures. Moreover, the 6-month LTRO in February 2009 is identified as a restrictive balance sheet shock, indicating that the increase in the ECB's total assets was less than that anticipated by the endogenous reaction to the ongoing turmoil in the financial markets. Restrictive balance sheet shocks are also observed in June 2010 when the 1-year LTRO and the first CBPP ended and in February 2013 after the early repayment of the 3-year LTRO.

4.1.2. Impulse response functions

Figure 5 presents the IRFs from an unconventional monetary policy unit shock obtained from the 5-variable VAR model. The impulse responses indicate that the shock is characterized by a negative impact on risk aversion from the first month which becomes significant at lag 10 and remains negative for most than 3 years. The impact reaches a minimum -0.00005 after 15 months.[4] Similarly, an expansionary unconventional monetary policy leads to a significant decrease of uncertainty after one month which also persists for more than 3 years. The maximum negative impact is about -0.00007 at lag 9.[5] The graphs of Figure 5 also indicate that an unconventional monetary policy shock is characterized by an increase of about 0.03% in the balance sheet of the ECB which persists for more than 3 years. Moreover, an expansionary unconventional monetary policy leads to an increase in industrial production but the impact is significant only after 2.5 years. Finally, an expansionary monetary policy leads to a significant decrease in the MRO rate. This negative impact may indicate that a decision from the ECB policy making body to increase its balance sheet may be followed by an analogous expansionary monetary policy decision using conventional tools.

[4] This means that a 1% increase in the balance sheet of ECB decreases risk aversion by 5×10^{-7}. This can be translated to a negative impact of $100\sqrt{12 \times 5 \times 10^{-7}} = 0.24\%$ in annualized volatility percentage points.

[5] Again, this indicates that a 1% increase in the balance sheet decreases uncertainty by 0.29% in annualized volatility percentage points.

Figure 6 reports the IRFs from a conventional monetary policy shock. For ease of presentation we have switched the sign of the MRO rate identified shocks; positive shocks are expansionary while negative ones are contractionary. To this end, both a conventional and an unconventional monetary policy expansionary shock are now positive. A unit shock in the MRO rate leads to a significant decrease in both risk aversion and uncertainty which persists for almost 2 years. The maximum impact is about -0.00007 at lag 8 and 5 for risk aversion and uncertainty, respectively. Also, an expansionary shock in the MRO rate leads to a significant positive impact in industrial production after the first month which remains for most than 3 years. The impact reaches a maximum of 0.0026 after approximately 2 years. Finally, an expansionary conventional monetary policy is characterized by a significant increase in the volume of the ECB's total assets. This result could be due to the fact that a decrease in the MRO rate may cause the increase of liquidity demand transactions (MRO and LTRO) from the part of banks.

Apart from the impact of conventional and unconventional monetary policy shocks on the macroeconomic and financial variables of the VAR model it is also interesting to examine the impact of these variables to the MRO rate and the ECB's total assets. Figure 7 reports the IRFs from a unit shock in uncertainty. In terms of monetary policy variables the graphs indicate that a positive shock in uncertainty has an immediate negative impact on the MRO rate which remains significant for more than 3 years. The maximum negative impact is -0.05% at lag 7. The impact on ECB's total assets is also significantly positive where the maximum value of 0.018% is observed after 3 months. The graphs of the figure also indicate that a positive shock in the MRO rate has a negative impact on industrial production which fades out after 6 months. After lag 17 the impact becomes positive and significant. This can be explained by the fact that an increase in uncertainty is followed by a lax monetary policy which impacts positively industrial production in the medium-run. A positive shock in uncertainty has also a significant positive impact on risk aversion for the first 6 months.

The effect of a positive shock in risk aversion in the two monetary policy variables is similar (see Figure 8) to the impact of uncertainty reported previously.

Once again, the MRO rate decreases instantly and this negative effect remain significant for at least 3 years. The maximum negative impact is about -0.03% after 8 months. ECB's total assets also increase instantly following a positive shock in risk aversion. The maximum impact of about 0.009% is observed after 3 months. Finally note that an increase in risk aversion is characterized by a significant decrease in industrial production which fades out after 7 months.

Summing up, these results indicate that, first, conventional and unconventional monetary policy shocks affect equity market uncertainty and investors risk aversion. Unconventional monetary policy shocks have an immediate negative impact on equity market uncertainty; their impact on risk aversion appears in the medium-run. This result indicates that equity investors price an expansionary monetary policy shock rather quickly when trading in the market driving down its volatility. On the other hand, they adjust their risk aversion only in the medium-run. Conventional monetary policy shocks have a negative impact on both uncertainty and risk aversion from the first month which persists for more than 3 years. The short-term response of risk aversion to a shock in the MRO rate stands in contrast to its medium-term response to a balance sheet shock. Thus, for the period examined, investors adjust their risk aversion quicker to a conventional rather to an unconventional monetary policy shock. Second, shocks in risk aversion and uncertainty impact both conventional and unconventional monetary policy stance.

4.2. Robustness

In this subsection we consider six types of robustness checks: (1) measurement of uncertainty and risk aversion; (2) different estimation procedure (3) alternative ordering of variables; (4) conducting the analysis with a six-variable VAR with the consumer price index entering into the vector of variables; (5) adding a global financial stress index in the benchmark VAR; (6) using zero and sign restrictions to identify the unconventional monetary policy shocks

4.2.1. Alternative uncertainty and risk aversion estimates

We estimate the 5-variable VAR model by replacing uncertainty and risk aversion with the estimates provided by predictive regressions. The results are reported in Appendix A.2. In general, they confirm our previous results. Two points should be, however, noted here with respect to the previous outcomes. First, the effect of an unconventional monetary policy shock in risk aversion is significant from the first month, indicating that looser monetary policy stance lowers risk aversion also in the short-run. Second, a shock in uncertainty lowers the MRO rate but this effect is only significant in the medium-run. On the same time, the response of ECB's total assets is insignificant.

4.2.2. OLS estimates

As a robustness check we estimate the benchmark 5-variable VAR model using the standard OLS estimation procedure. The results are reported in Appendix A.3. These results, in general, confirm those retrieved from the Bayesian estimation approach. A positive shock in total assets decreases risk aversion 1 month after the shock. The negative impact is also significant in the medium-run (between lags 12 and 24). In contrast, the impact on uncertainty from a balance sheet expansion is insignificant. A positive shock in the MRO rate also increase risk aversion and uncertainty 1 month after the shock. The impact on risk aversion persists for 6 months while that on uncertainty fades out 2 months after the shock. Finally, the MRO rate responds negatively to a positive shock in both risk aversion and uncertainty. This impact persists for nearly a year. Similarly, ECB's total assets respond positively to a shock in risk aversion and uncertainty with this effect persisting for more than 2 years.

4.2.3. Alternative ordering of variables

In one alternative ordering, the order of risk aversion and uncertainty in the 5-variable VAR model are reversed. The results, reported in Appendix A.4, are generally in line to those reported in the main text. The only exception is that the response of ECB's total assets to a shock in risk aversion is insignificant. In a second robustness check, we follow Bekaert, Hoerova, & Lo Duca (2013) identification scheme in which risk aversion and uncertainty are ordered last, thus allowing them to respond instantly to conventional and unconventional monetary policy shocks. These results are reported in Appendix A.5. A positive shock in total assets has a positive and significant contemporary effect on risk aversion of 0.0002. The response becomes negative and significant since 1 year later and continues at least for 3 years later, with a minimum value of -0.00008 in lag 18. Similarly, a positive shock in total assets has a positive and significant contemporary effect on uncertainty. The response becomes negative and significant since 8 months later with a minimum value of -0.0001 after 1 year. Thus, a lax unconventional monetary policy stance has a negative effect on risk aversion and uncertainty in the medium-run. These results also indicate that a positive shock in the MRO rate increases contemporaneously the risk aversion (though the effect is insignificant) and uncertainty. After 7 months the response becomes negative and significant for both risk aversion and uncertainty. Again, we conclude that a lax conventional monetary policy stance has a negative effect on risk aversion and uncertainty at least in the medium-run.

The effect of an increase in the policy rate to risk aversion and uncertainty using this identification scheme are in line to those reported by Bekaert, Hoerova, & Lo Duca (2013) for the US and Nave & Ruiz (2015) for the Eurozone for the pre-crisis period. This paper, however, provides new evidence showing, first, that the effect of a conventional monetaty policy shock on risk aversion and uncertainty continues to exist in the post-crisis period and, second, that the same effect is observed when the ECB employs unconventional policy tools by expanding its balance sheet.

In terms of the response of the MRO rate and the ECB's total assets to a positive shock in risk aversion and uncertainty the alternative indentification scheme results indicate that only the policy rate responds negatively and signficantly to this shock. The response of total assets though positive remains insignificant.

4.2.4. Six-variable structural VAR

We also examine a six-variable structural VAR model following Nave & Ruiz (2015) considering the consumer price index (CPI) as an additional variable. To identify the shocks, a Cholesky identification scheme is used with CPI and industrial production ordered first, followed by risk aversion and uncertainty, and MRO rate and ECB's total assets ordered last. This model is estimated using the same Bayesian approach used for the 5-variable VAR. Figure 9 reports the IRFs from a unit shock in total assets. Risk aversion response is negative from the first month after the shock, however this effect becomes singificant in the medium-run (i.e., after 1 year). The effect on uncertainty is negative and singificant from the first month after the shock. The maximum negative impact of -0.00006 is observed at lag 8. CPI also responds positively and significantly to an increase in the size of the ECB's balance sheet from the first month after the shock up to more than 2 years. Industrial production signficanty decreases for the first month after a positive shock in total assets. This negative impact remains significant up to 2 years ownward. In the long-run (i.e., from lag 52) the IRF turns out to be positive and significant. This finding is striking, at least with respect to previous empirical evidence. For example, Boeckx, Dossche, & Peersman (2014) estimate a humped-shaped response of output to a positive balance sheet shock. These different results may be attributed to different identification schemes of these shocks and the shorter sample period that these papers use. In particular, using a sign restriction identification approach these authors assume that a balance sheet shock has an immediate negative impact on the CISS index (this index measures financial stress in the euro area and it is highly correlated with our risk aversion proxy variable with a correlation coefficient of 70%). This impact fades out in the medium-run. In constrast, our identification scheme results in a negative and significant impact on risk aversion in the medium-run which may, in turn, explain the long-run positive response of industrial production to an expansion in the ECB's total assets, given that a negative shock in risk aversion has a positive impact on industrial production from the first month after the shock (see Figure 12).

Figure 10 reports the IRFs from a shock in the MRO rate. The response of both risk aversion and uncertainty is negative and significant to a lax monetary policy stance from the first month after the shock until 2 years later. The maximum reponse is observed at lag 7 and 5 for risk aversion and uncertainty, respectively. A lax monetary policy has a significant positive effect on CPI and industrial production which persists for more than 3 years. Finally, a decrease in the MRO rate is followed by an increase in ECB's total assets which remains significant for more than 2 years.

The responses of the six variables to a shock in uncertainty are reported in Figure 11. The results indicate that the contamporanous response of the MRO rate is negative and singificant. The response remains negative until at least 3 years with the maximum negative impact of -0.03% observed after 5 months. The contamporaneous response of ECB's total assets is positive and singificant which also persists for more than 3 years. The maximum impact is about 0.02% at lag 3. The impact on risk aversion is also positive and significant from 1 month after the shock until 5 months later. Finally, a positive shock in uncertainty has a significant negative impact on industrial production from the first month after the shock until month 16.

Figure 12 reports the IRFs from a unit shock in risk aversion. The impact on the MRO rate of a shock in risk aversion is negative and significant from lag 2 and ownward. As for the size of the balance sheet, a higher risk aversion increases ECB's total assets contamporaneously until 3 years later. The maximum impact of 0.008% is observed at lag 3. Finally the effect of risk aversion on industrial production is negative and significant from the first month after the shock until 10 months later.

4.2.5. Global financial stress

One may argue that the reported empirical evidence regarding the relation between conventional, unconventional monetary policy, risk aversion and uncertainty in the euro area during the recent financial crisis period can be attributed to the variation in financial stress in the international level that could influence both the policy actions of the ECB and risk aversion and uncertainty of the European equity market. To examine this possible channel we also include in the previously examined 6-variable structural VAR the squared VIX index (i.e., the risk-neutral variance of the US equity market) as a general proxy for financial turmoil and economic risk over the sample period in the global context. The results are reported in Appendix A.6. They are, in general, similar to those already reported in the previous section. A shock in ECB's total assets or the MRO rate has a significant impact on risk aversion and uncertainty. Moreover, a shock in uncertainty has a negative (positive) impact on the MRO rate (balance sheet size). The only difference now is that the impact on ECB's total assets, the MRO rate and industrial production from a shock in risk aversion is insignificant. On the other hand, a shock in VIX decreases the MRO rate contemporaneously until 3 years later, while it increases the size of the balance sheet with the maximum impact observed 2 months after the shock. Industrial production also responds negatively in the short-run to a positive shock in VIX. Finally, we observe a contemporaneous positive response of European equity market uncertainty and risk aversion to a shock in VIX.

These results provide evidence that, even if domestic equity market uncertainty, risk aversion and domestic monetary policy respond to global financial stress indicators, ECB's monetary policy still impacts euro area equity market uncertainty and investors risk aversion. Conversely, euro area market uncertainty impacts ECB's monetary policy.

4.2.6. Zero and sign restrictions

A frequently used alternative to the Cholesky identification scheme is based on a mixture of zero and sign restrictions on the contemporaneous impact matrix ${A_0}^{-1}$. This enables us to identify exogenous balance sheet shocks without placing the recursive identification assumptions on the endogenous variables. This can allow for a contemporaneous impact between policy and financial variables, as well as between risk aversion and uncertainty which was not possible under the previous identification scheme. In so doing, we use a 6-variable VAR model which adds to our benchmark 5-variable VAR the 1-month yield of the all euro area government bonds denoted as YLD. This new variable would enable us to separate exogenous balance sheet shocks from endogenous responses to sovereign bond market pressure.

The identifying restrictions we impose are the following. First, we assume that the contemporaneous impact of industrial production to an unconventional monetary policy shock is zero. One the other hand, innovations to industrial production are allowed to have an immediate impact on balance sheet. This is a common assumption made in the relevant literature (Gambacorta, Hofmann, & Peersman, 2014). Second, we assume that the contemporaneous impact of risk aversion to an exogenous balance sheet shock is zero. While one can argue that an expansion of the balance sheet should have an immediate impact on financial markets, risk aversion may not respond instantly as investors gradually adjust their risk bearing capacity to a different level. This may be due to the fact that they are willing to change their risk tolerance level after observing the impact of monetary policy on some key financial variables, such as bond yields or equity market volatility. Third, we impose a zero contemporaneous impact of exogenous balance sheet shocks on the MRO rate. This is a common assumption made in the relevant literature (Boeckx, Dossche, & Peersman, 2014) in order to avoid that the unconventional monetary policy shock is associated with a change in the policy rate. Finally, we assume that an expansionary unconventional monetary policy shock does not increase sovereign bond yields. This restriction is needed in order to separate exogenous balance sheet shocks from the endogenous response of ECB to tackling the pressure in the euro area sovereign bond market. All sign restrictions are imposed on impact and the first month after the shock. They are summarized in Table 2. To identify the shocks we use the recent methodology developed by Arias, Rubio-Ramirez, & Waggoner (2014). The prior distributions and hyperparameters used are those employed in the benchmark estimation (see Section 3.3).

The advantage of using a combination of zero and sign restrictions is that we can allow for a contemporaneous impact between risk aversion and uncertainty, as well as, between uncertainty and conventional or unconventional monetary policy. Moreover, previous studies have identified balance sheet shocks by restricting financial market stress indicators (e.g., the VIX index in the US or the CISS index in the Eurozone) to respond negatively to a shock in central bank total assets (Gambacorta, Hofmann, & Peersman, 2014; Boeckx, Dossche, & Peersman, 2014). In this paper, as we are mainly interested on the impact of unconventional monetary policy on risk aversion and uncertainty, our identification strategy is more agnostic with respect to these variables.

Figure 13 shows the IRFs from a unit shock in total assets. These are generally in line with the results documented previously in the paper. An expansionary balance sheet shock has a significant negative impact in risk aversion 1 month after the shock which persists for 6 months. The response in uncertainty is also negative on impact.

A 1% shock in total assets decreases uncertainty by approximately 0.84% volatility percentage points. The negative impact vanishes after 2 years. Industrial production responds positively to an unconventional monetary policy shock after about 2 years. The MRO rate responds negatively to a balance sheet shock. The maximum negative impact of 0.007% is observed at lag 14. Finally, in line with the sign restrictions, a unit balance sheet shock decreases bond yields by about 0.07% on impact. This response remains negative for more than 2 years.

5. Conclusions

Recent empirical evidences indicate that a lax *conventional* monetary policy decreases risk aversion and uncertainty. However, in the aftermath of the recent financial crisis with policy rates approaching the zero lower bound central banks embarked on *unconventional* monetary policy measures in order to counter the risks to macroeconomic and financial stability. The more common form of these measures involves the massive expansion of central banks' balance sheets. However, the effect of unconventional monetary policy on market uncertainty and investors risk aversion has not yet been examined. This paper aims to fill this gap by examining the impact of ECB's balance sheet expansion of the euro area equity market uncertainty and the risk-bearing capacity of market participants.

The benchmark results of the empirical analysis indicate that an expansion of ECB's balance sheet decreases risk aversion after about 10 months and persist for more than 3 years. Moreover, a lax unconventional monetary policy stance decreases uncertainty from the first month after the shock. This effect is also persistent, lasting for more than 3 years. Conventional monetary policy stance also affects risk aversion and uncertainty during the recent period. Thus a negative shock in ECB's policy rate decreases risk aversion and uncertainty from the first month after the shock. These results are generally robust to different specification of the SVAR model and estimation approaches. When we use a different identification scheme a lax conventional or unconventional monetary policy increases risk aversion and uncertainty contemporaneously. In the medium-run, however, their impact becomes negative. Conversely, periods of high uncertainty are followed by a looser conventional monetary policy. A further robustness analysis using a combination of sign and zero restrictions to identify exogenous balance sheet shocks corroborates in general with our benchmark results. Uncertainty decreases on impact after an unconventional monetary policy shock, while risk aversion decreases 1 month after this shock. Finally, the effect of uncertainty on ECB's total assets and of risk aversion on conventional or unconventional monetary policy is not always statistically significant.

The results of the paper point towards the broader impact of unconventional monetary policy measures on market participants' risk attitude and market uncertainty going beyond the immediate impact that other studies have documented on the yield curve and exchange rates. These results also lend support to the literature on the "risk-taking transmission channel" of monetary policy. Unconventional policy measures reduce uncertainty and market participants' risk aversion allowing financial intermediaries to increase their leverage which might affect real economic outcomes. The exact link between monetary policy and market participants' risk-bearing capacity warrants further empirical and theoretical examination.

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Table 1: Description of variables

Variable	Label	Description
Realized variance	RV	Monthly realized variance computed using daily returns
Market uncertainty	UC	Estimates of 1-month ahead expected variance EV generated by (a) forecasting regression, or, (b) the FHS method
Risk-neutral variance	RNV	The squared implied volatility of options on the EURO STOXX 50 index, $(VSTOXX/100)^2/12$
Risk aversion	RA	The variance risk premium defined as $RNV - UC$
Proxy for global financial stress		The squared of the VIX index, $(VIX/100)^2/12$
Dividend-price ratio		The dividend-price ratio of the EURO STOXX 50 index in logs
3-month AAA-rated bond yield		The yield of the AAA-rate government bonds of the Eurozone
1-month government bond yield	YLD	The yield of all euro area government bonds
Industrial production index	IP	The industrial production index of the Eurozone in logs
Consumer price index	CPI	Eurozone harmonized and seasonally-adjusted consumer price index in logs
MRO rate	PR	The main refinancing operation rate of the ECB
Total assets/liabilities	TA	The size of total assets in the balance sheet of the ECB in logs

Table 2: Identification of an unconventional monetary policy shock

Industrial production	Risk aversion	MRO rate	Bond yields	Total assets
0	0	0	<	>

Figure 1: ECB's total assets in millions of euro, December 2007-June 2016.

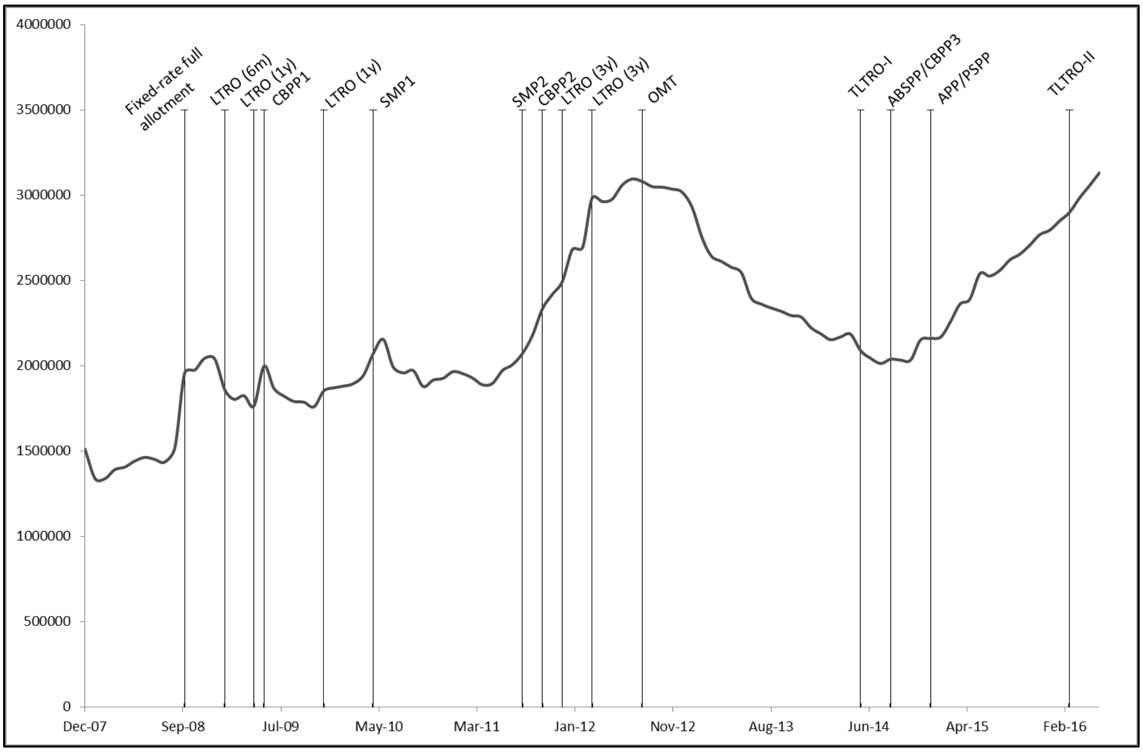


Figure 2: Equity market uncertainty estimates. December 2007-June 2016.

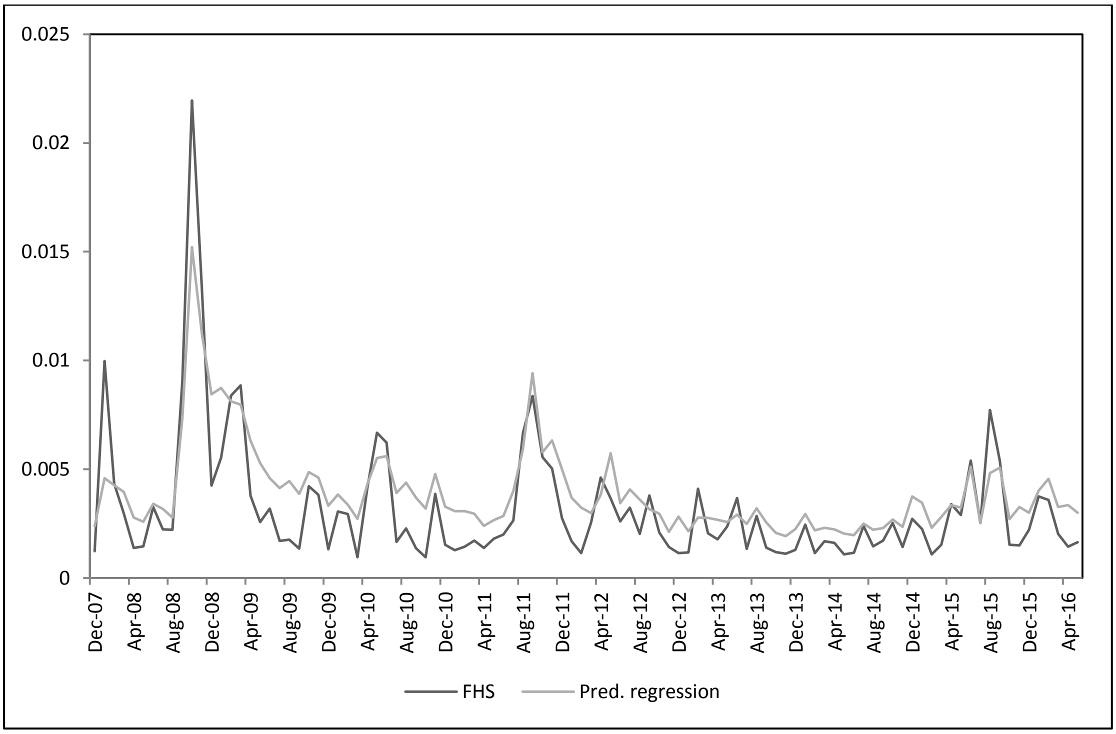


Figure 3: Risk aversion estimates. December 2007-June 2016.

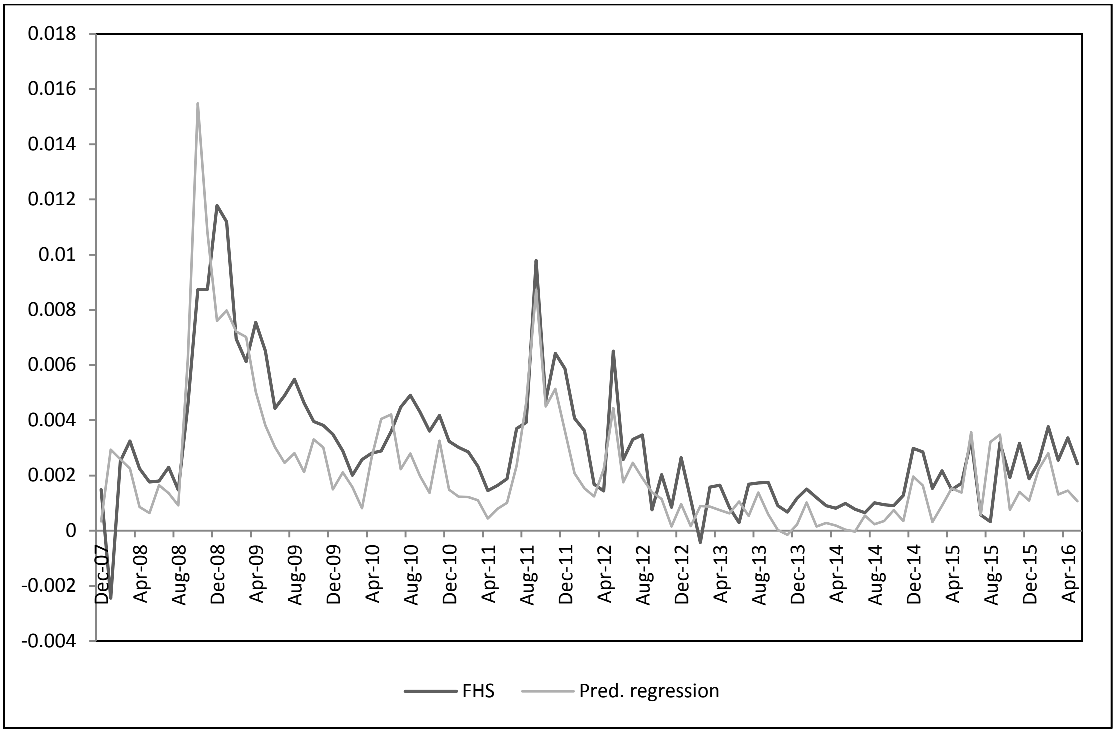


Figure 4: Times series of identified shocks along with the 68% upper and lower bounds.

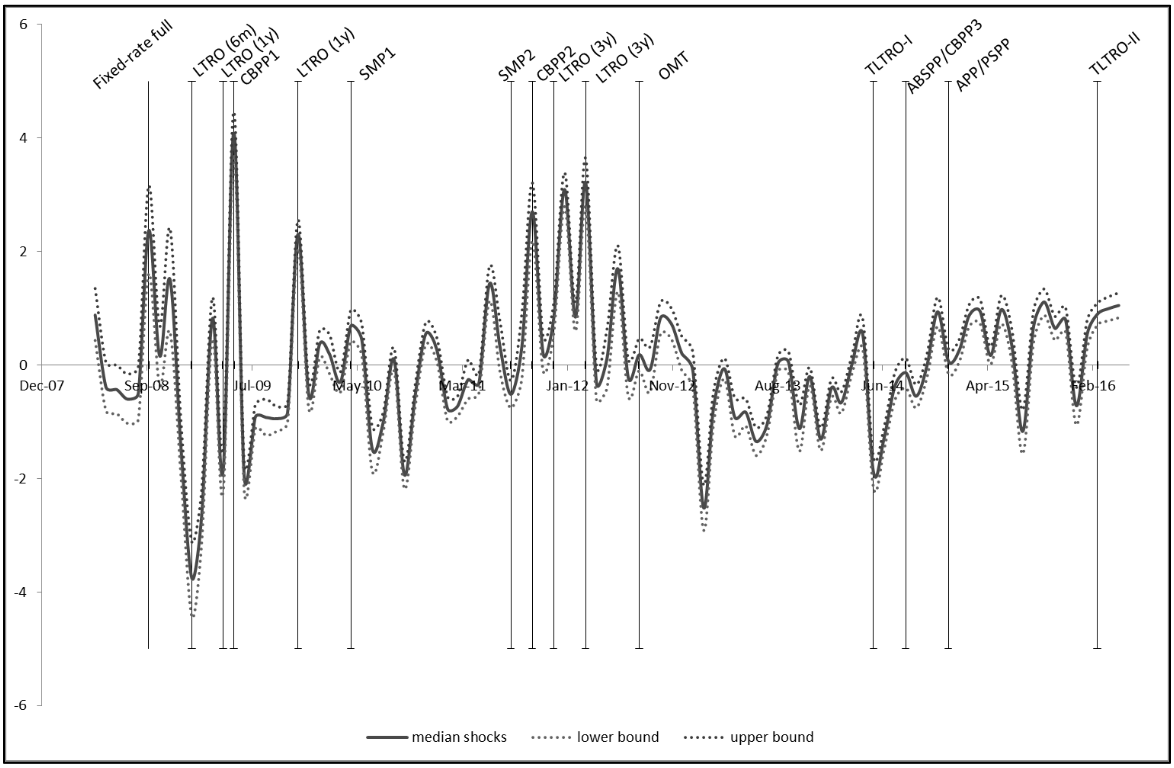


Figure 5: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

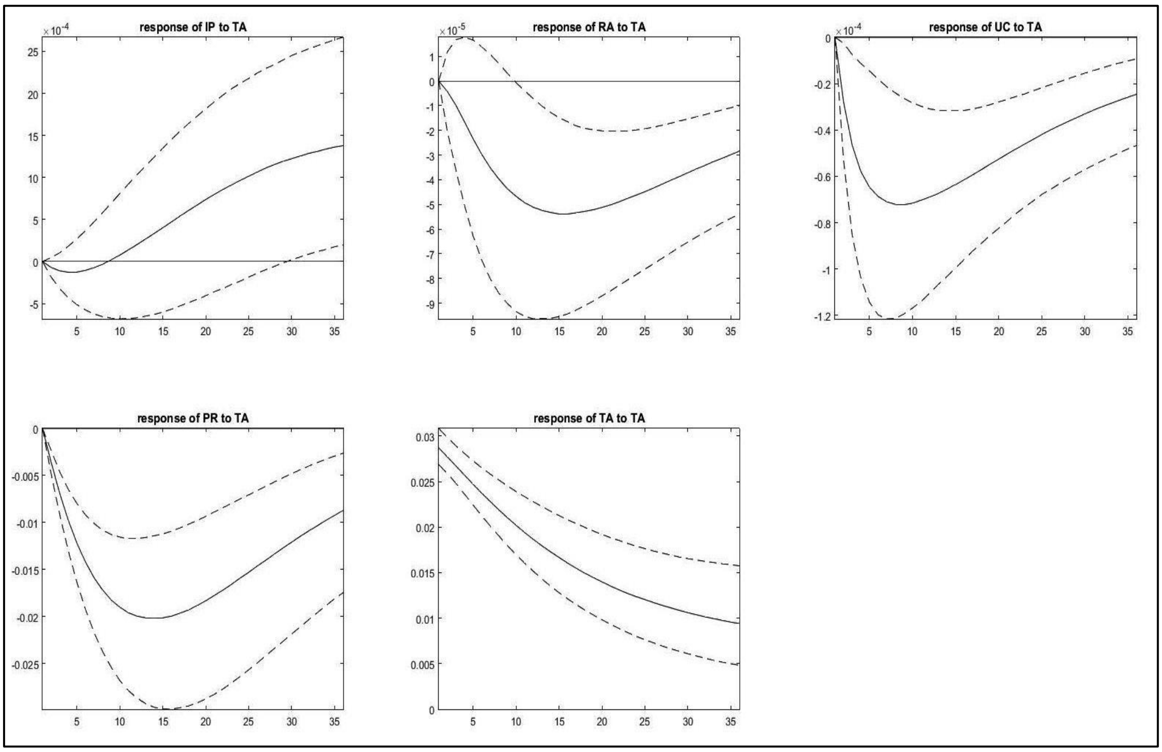


Figure 6: Median impulse responses to policy rate shock together with the 68% confidence bounds.

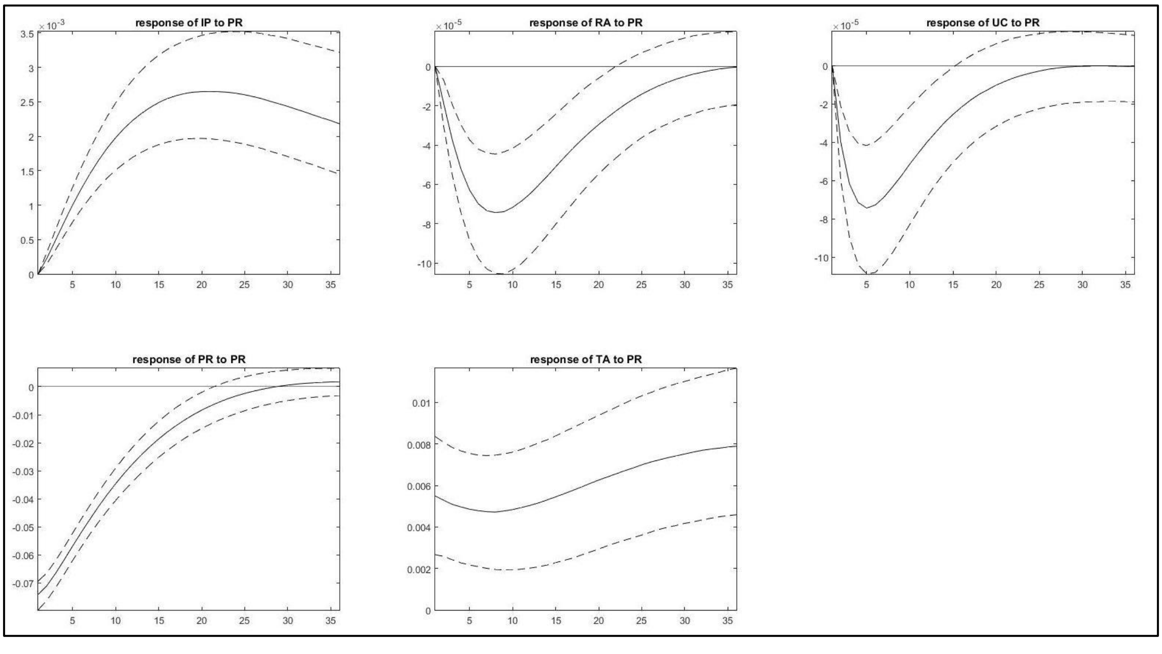


Figure 7: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

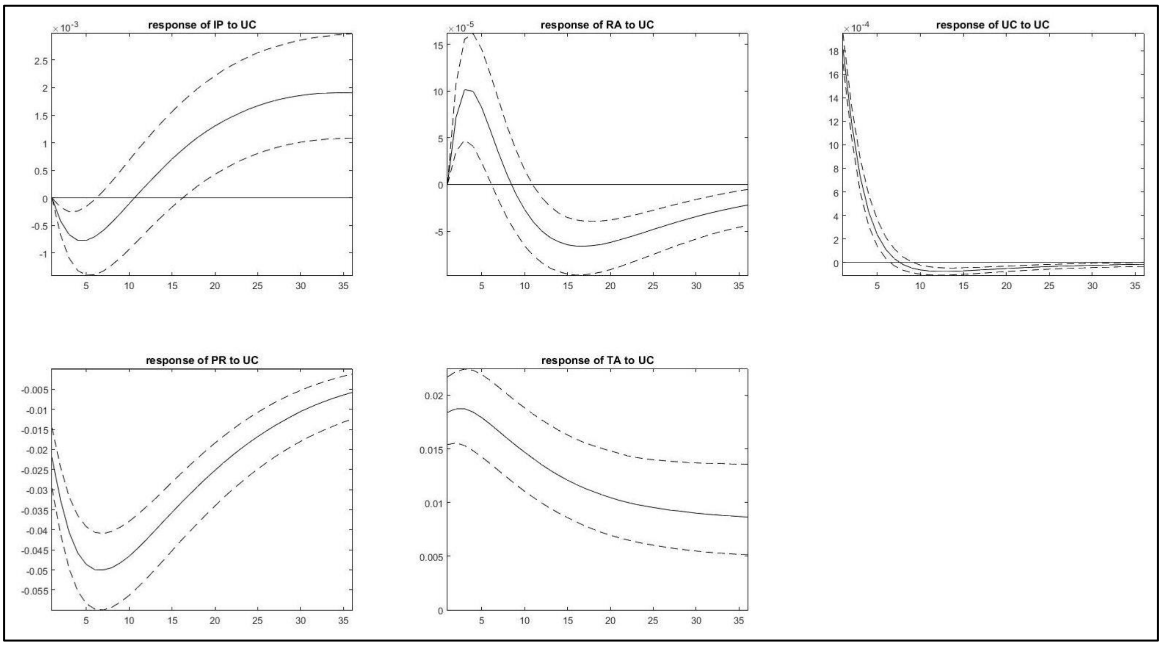


Figure 8: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

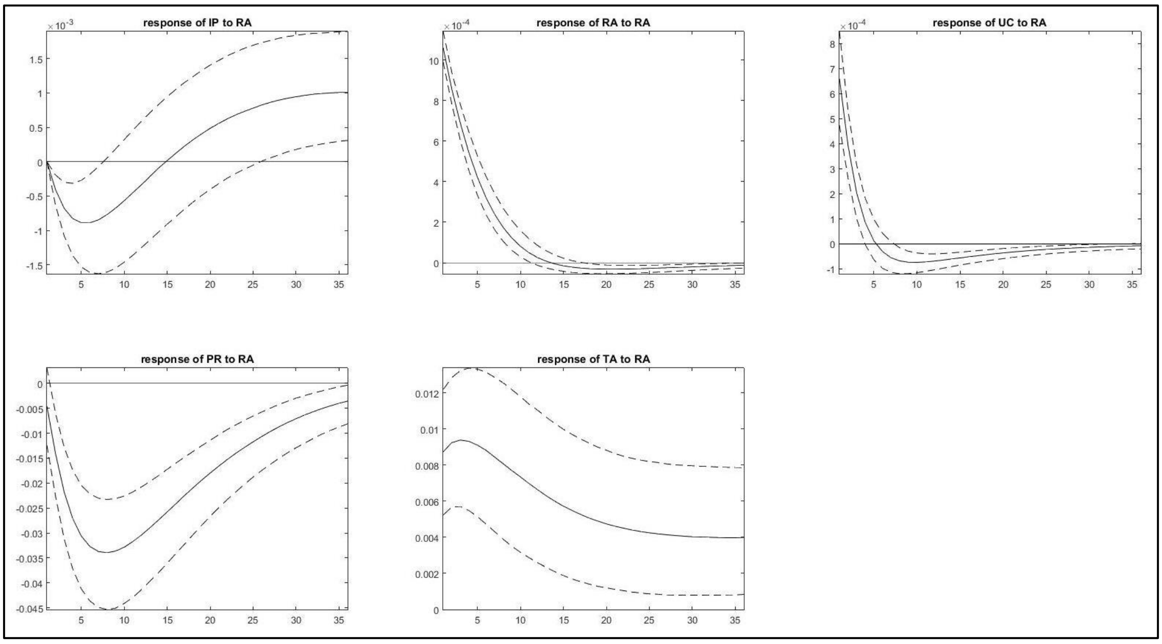


Figure 9: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

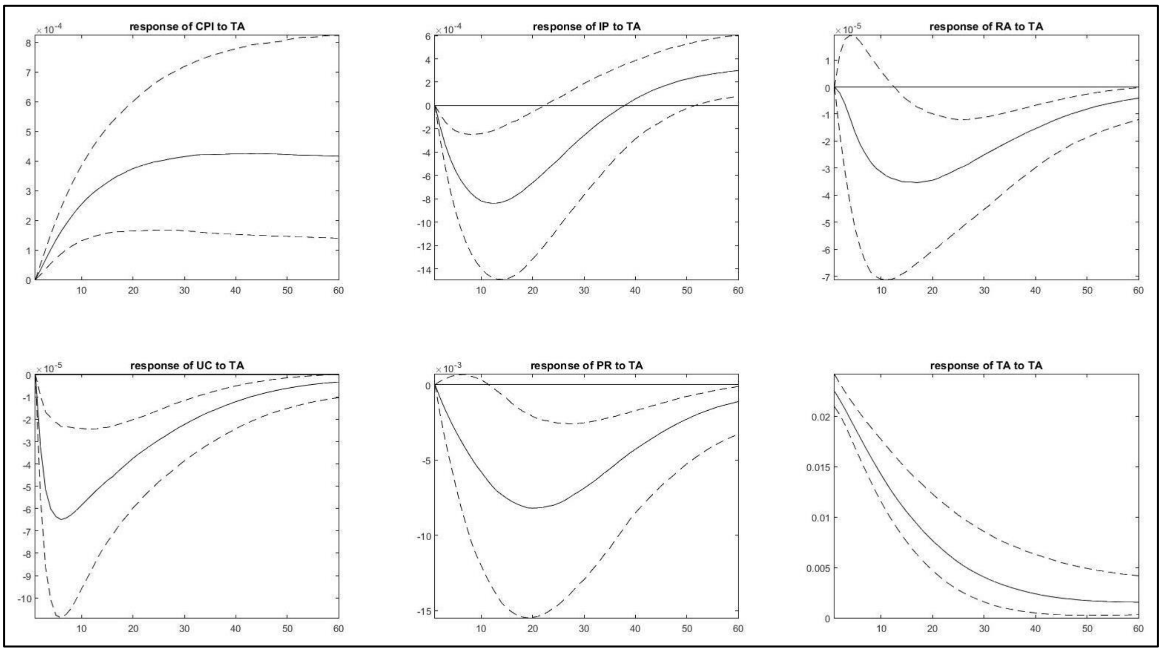


Figure 10: Median impulse responses to policy rate shock together with the 68% confidence bounds.

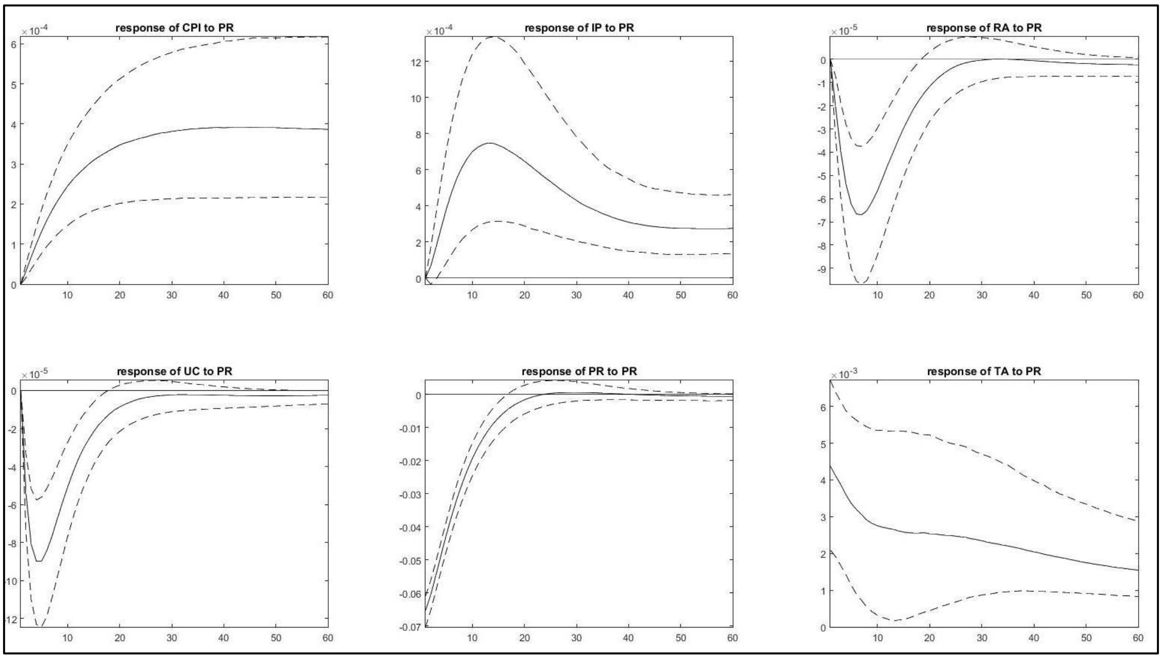


Figure 11: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

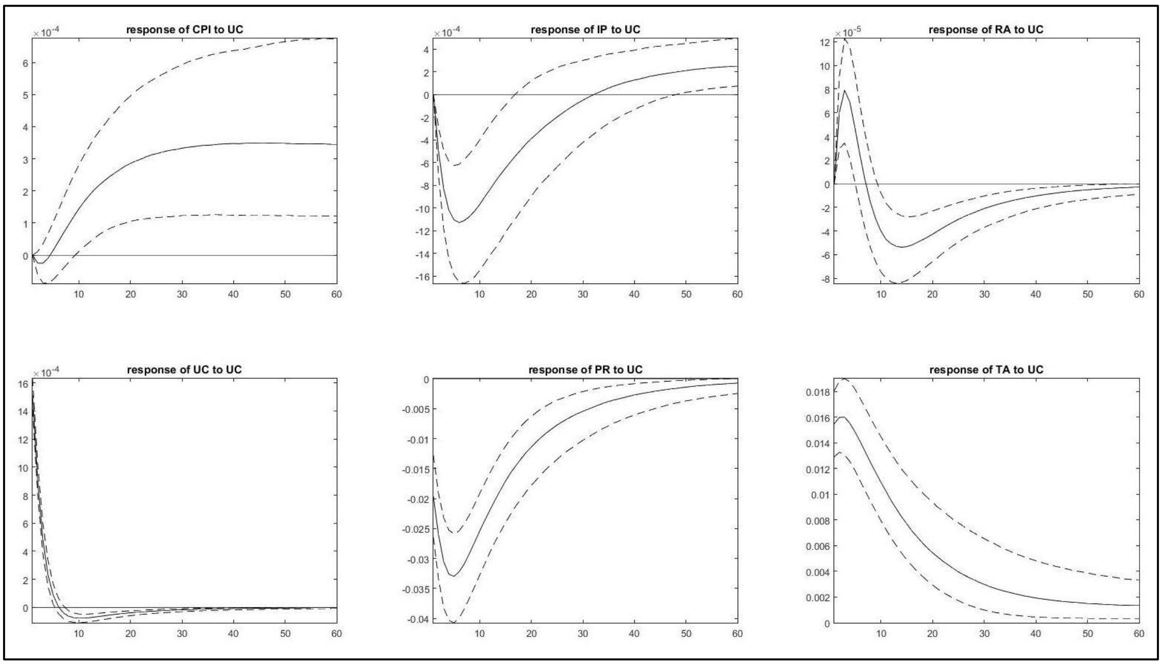


Figure 12: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

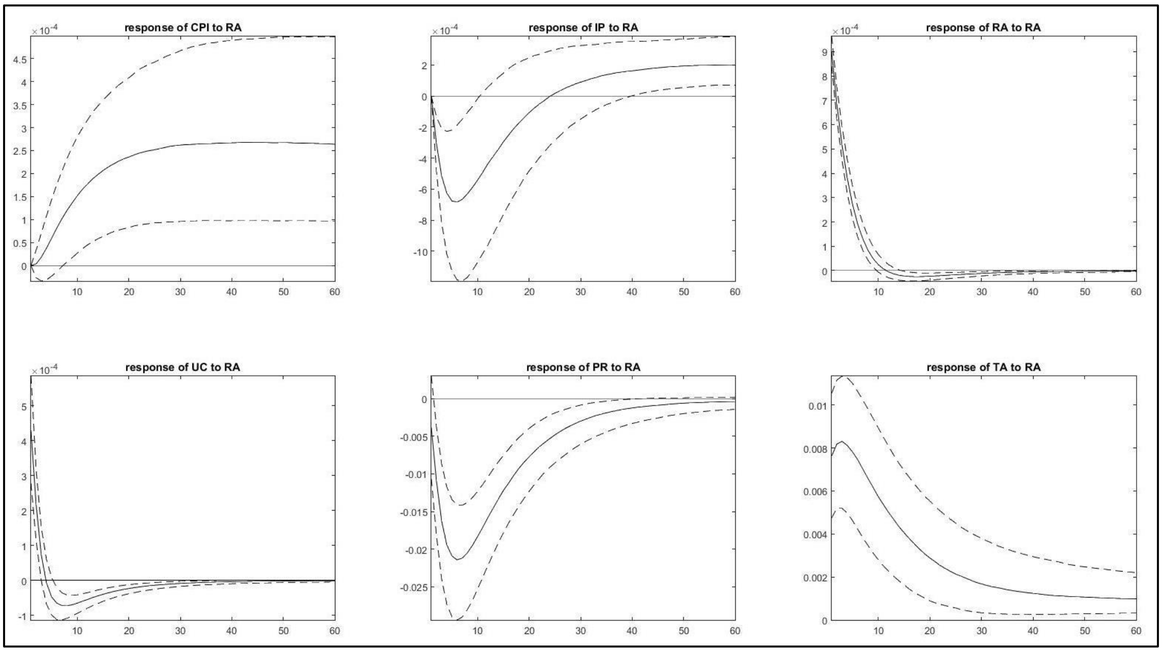
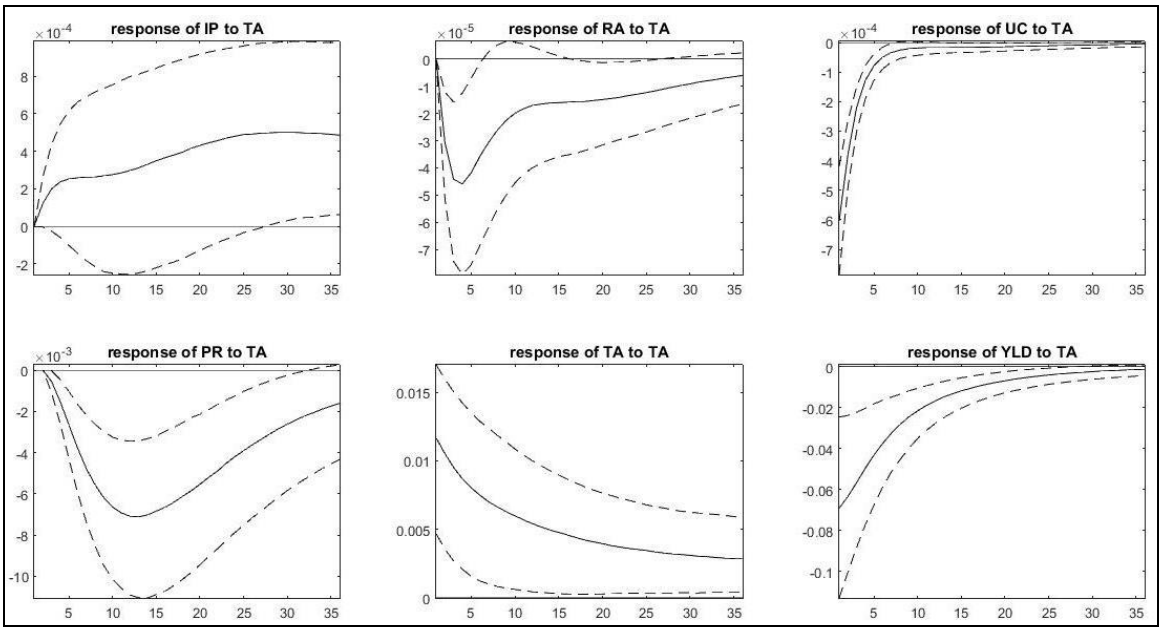


Figure 13: Median impulse responses to balance sheet shock using sign restrictions together with the 68% confidence bounds.



Supplementary Online Appendix

This appendix presents the details of the forecasting regressions approach and includes the results of the robustness analysis discussed in the main text of the paper.

A1. Forecasting regressions results

This appendix reports the results on the predictive regressions. Table A.1 summarizes the models examined. We compare the out-of-sample performance of these 27 models. For estimated models we perform recursive estimations starting in December 2007, after having 40 months of data going back to September 2004, and adding one observation at a time. We then compute the root mean squared error (RMSE), the mean absolute error (MAE) and the mean percentage error (MPE). Our sample period includes dates with extreme realized variance observations that could dramatically influence the ranking of the models. To this end, we winsorize the top 5% of the realized variance observations in our sample, and perform regressions using the winsorized sample. These results are reported in Table A.2.

The results of this table indicate that model 2 has the lowest RMSE and MAE. In terms of the MPE, the three-variable model 21 outperforms all others. We evaluate whether the forecast error measures are significantly different among competing models through the Diebold & Mariano (1995) test. We find that the RMSE and the MAE criteria have little power to distinguish among alternative models, while the MPE is the most distinguishing one. To this end, we choose model 21 as our forecasting regression model to estimate expected variance. For robustness we also perform the empirical analysis using the expected variance estimated from model 2. The results are similar to those reported in the paper and can be provided upon request.

A2. Alternative uncertainty and risk aversion estimates

This appendix reports the IRFs of the 5-variable VAR model in which risk aversion and uncertainty are estimated from the predictive regression approach. Figure A.2.1 presents the responses to a unit shock in total assets together with the 68% confidence bounds. Figures A.2.2, A.2.3 and A.2.4 present the IRFs to a shock in the MRO rate, uncertainty and risk aversion, respectively. These results are discussed in Section 4.2.1 of the main text of the paper.

A3. OLS estimates

This appendix reports the IRFs of the 5-variable VAR model which is estimated using the OLS procedure. The lag length of the VAR is set equal to 4. Figure A.3.1 presents the responses to a unit shock in total assets together with the 68% confidence bounds. Figures A.3.2, A.3.3 and A.3.4 present the IRFs to a shock in the MRO rate, uncertainty and risk aversion, respectively. These results are discussed in Section 4.2.2 of the main text of the paper.

A4. Alternative ordering of risk aversion and uncertainty

This appendix reports the IRFs of the 5-variable VAR model in which uncertainty is ordered before risk aversion. Figure A.4.1 presents the responses to a unit shock in total assets together with the 68% confidence bounds. Figures A.4.2, A.4.3 and A.4.4 present the IRFs to a shock in the MRO rate, uncertainty and risk aversion, respectively. These results are discussed in Section 4.2.3 of the main text of the paper.

A5. Alternative ordering of financial and monetary policy variables

This appendix reports the IRFs of the 5-variable VAR model in which industrial production is ordered first, followed by the MRO rate and ECB's total assets. Risk aversion and uncertainty are ordered last. Figure A.5.1 presents the responses to a unit shock in total assets together with the 68% confidence bounds. Figures A.5.2, A.5.3 and A.5.4 present the IRFs to a shock in the MRO rate, uncertainty and risk aversion, respectively. These results are discussed in Section 4.2.3 of the main text of the paper.

A6. 7-variable VAR model

This appendix reports the results of the 7-variable VAR model with the following vector of endogenous variables $y_t = (CPI_t, IP_t, VIX_t, RA_t, UC_t, PR_t, TA_t)'$. This model is estimated using the same Bayesian approach used for the 5-variable VAR. To identify the structural shocks we use Cholesky decomposition. The order of the seven endogenous variables of the VAR model is exactly the order that these variables appear in vector y_t. Figure A.6.1 presents the responses to a unit shock in total assets together with the 68% confidence bounds. Figures A.6.2, A.6.3 and A.6.4 present the IRFs to a shock in the MRO rate, uncertainty and risk aversion, respectively. Finally, Figure A.6.5 reports the IRFs to a shock in the VIX index. These results are discussed in Section 4.2.5 of the main text of the paper.

Table A.1: Models for predictive regressions

Variables	RV	RNV	DP	IR	$R^{(22)-}$
Estimated models					
Model 1	X				
Model 2		X			
Model 3	X	X			
Model 4	X	X	X		
Model 5	X	X		X	
Model 6	X	X			X
Model 7	X	X	X		X
Model 8	X	X	X	X	
Model 9	X	X		X	X
Model 10	X	X	X	X	X
Model 11	X		X		
Model 12	X			X	
Model 13	X				X
Model 14	X		X	X	
Model 15	X		X		X
Model 16	X			X	X
Model 17	X		X	X	X
Model 18		X	X		
Model 19		X		X	
Model 20		X			X
Model 21		X	X	X	
Model 22		X	X		X
Model 23		X		X	X
Model 24		X	X	X	X
Non-estimated models					
Model 25	X				
Model 26		X			
Model 27	0.5*X	0.5*X			

This table presents the variables included in the estimated and non-estimated models. RV denotes the lag realized variance of the previous month, RNV denotes the lag risk-neutral variance calculated from the VSTOXX index, DP denotes the log dividend-price ratio of the previous month, IR denotes the lag 3-month yield of the AAA-rated bonds and $R^{(22)-}$ is a dummy variables that takes the value of 1 if the lag realized month return of the index is negative.

Table A.2: Volatility forecasting results

Variables	$RMSE$	MAE	MPE
Estimated models			
Model 1	0.2583	0.1795	65.08
Model 2	**0.2545**	**0.1690**	61.02
Model 3	0.2550	0.1714	63.20
Model 4	0.2610	0.1750	63.76*
Model 5	0.2568	0.1729	62.77
Model 6	0.2586	0.1733	63.27
Model 7	0.2661	0.1772	63.81*
Model 8	0.2626	0.1753	61.36
Model 9	0.2613	0.1758	63.00
Model 10	0.2677	0.1779	61.51
Model 11	0.2598	0.1753	63.72
Model 12	0.2595	0.1818	66.71*
Model 13	0.2616	0.1819	64.99
Model 14	0.2612	0.1752	60.89
Model 15	0.2642	0.1779	63.70
Model 16	0.2628	0.1844	66.54*
Model 17	0.2654	0.1778	60.92
Model 18	0.2599*	0.1733*	62.25*
Model 19	0.2562	0.1706	60.02
Model 20	0.2572	0.1705	61.05
Model 21	0.2617*	0.1733	**59.05**
Model 22	0.2649	0.1754	62.11*
Model 23	0.2595	0.1719	60.04
Model 24	0.2663*	0.1758	59.17
Non-estimated models			
Model 25	0.3071*	0.2108*	72.58*
Model 26	0.3448*	0.2654*	108.62*
Model 27	0.2986*	0.2197*	84.74*

This table reports out-of-sample performance statistics. $RMSE$ denotes the root mean squared error, MAE denotes the mean absolute error and MPE is the mean absolute percentage error. The minimum values of these criteria are reported with bold. * indicates that the Diebold-Mariano (1995) test rejects the hypothesis that the respective model has equal forecasting performance (according to the relavant criterion) with the “best” ranking model at the 10% singificance level.

Figure A.2.1: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

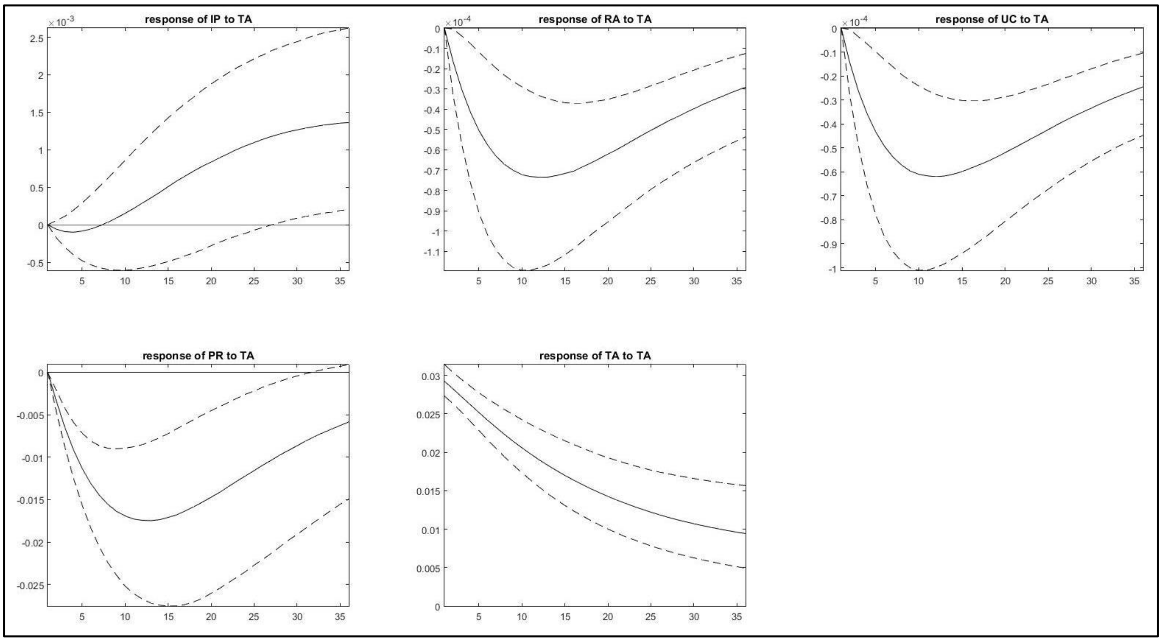


Figure A.2.2: Median impulse responses to policy rate shock together with the 68% confidence bounds.

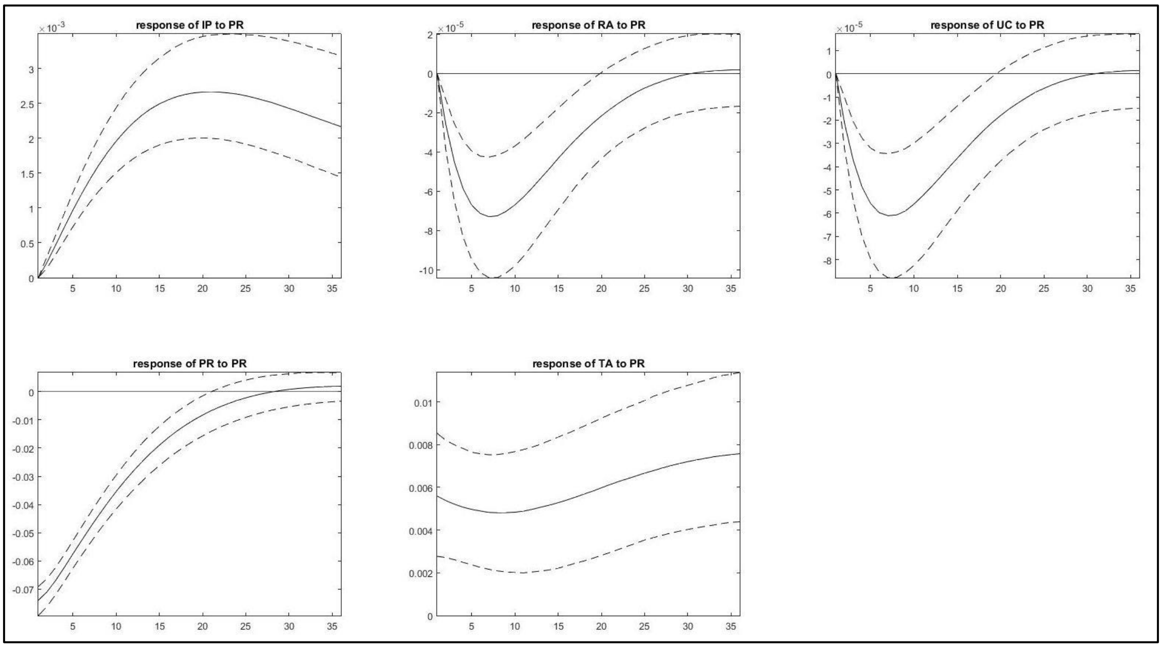


Figure A.2.3: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

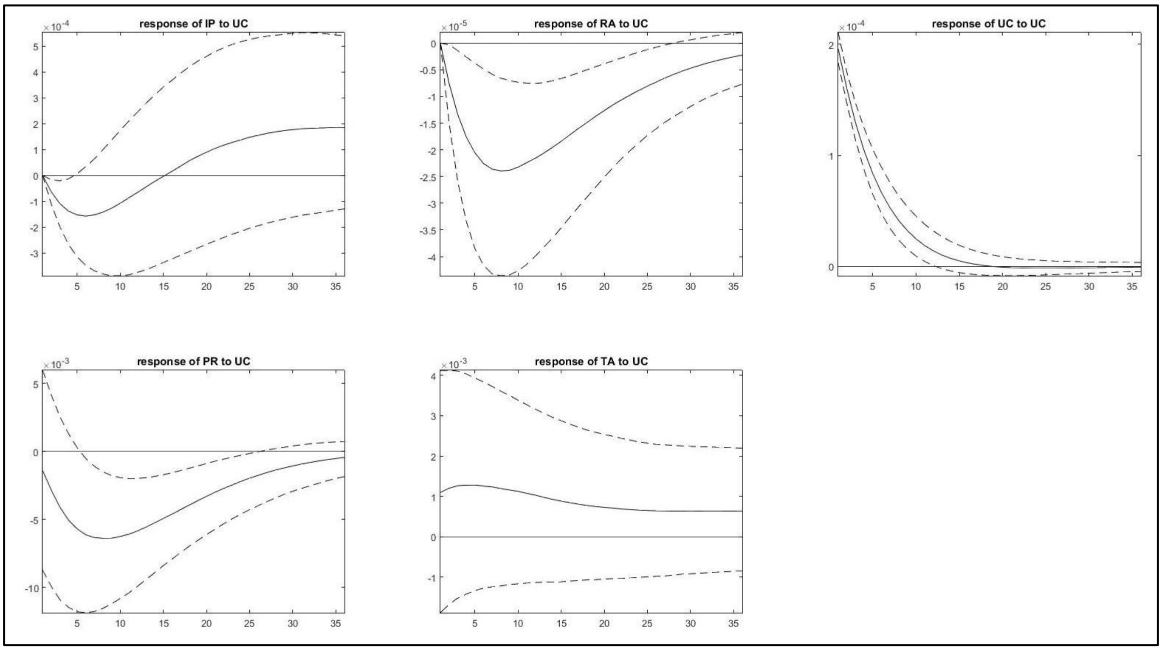


Figure A.2.4: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

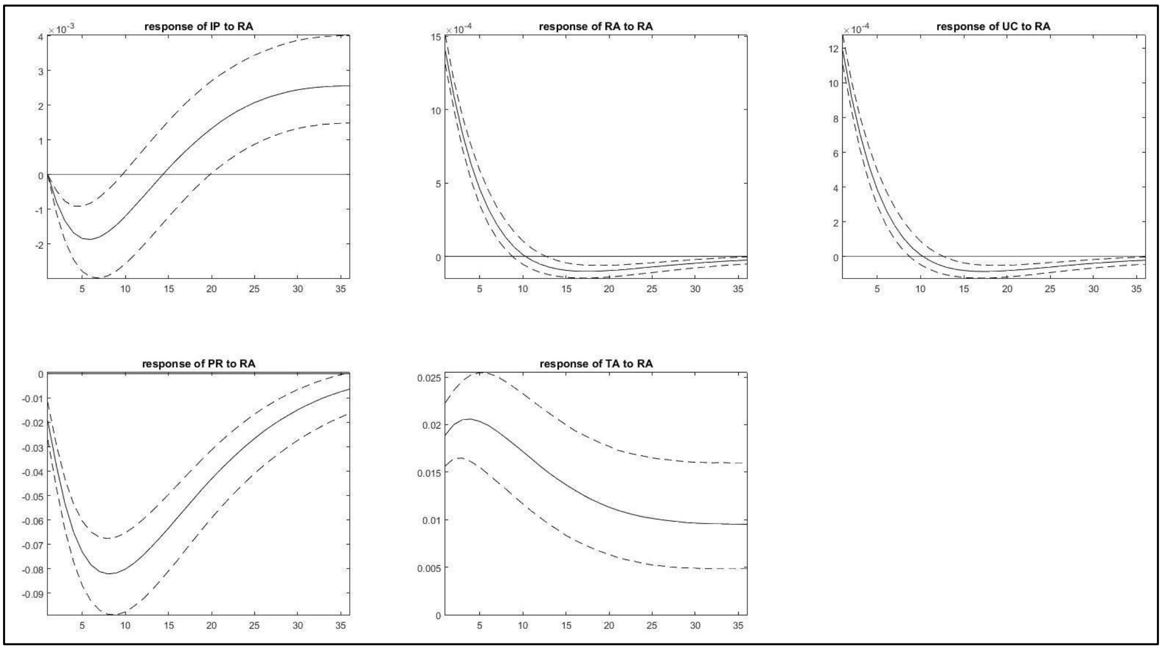


Figure A.3.1: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

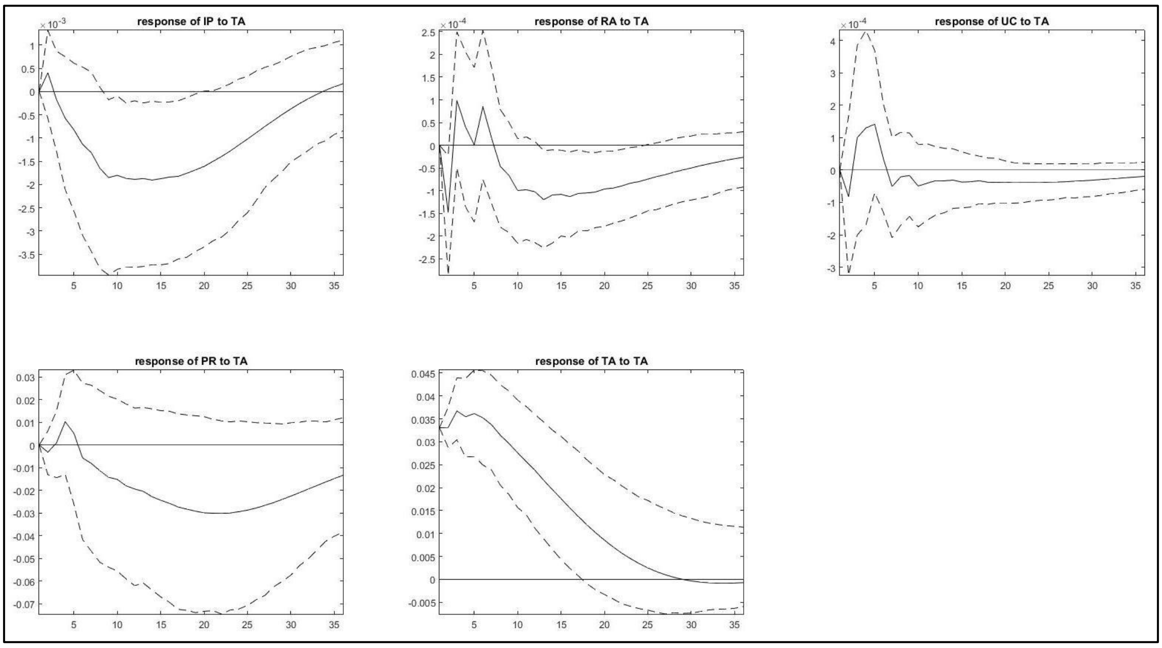


Figure A.3.2: Median impulse responses to policy rate shock together with the 68% confidence bounds.

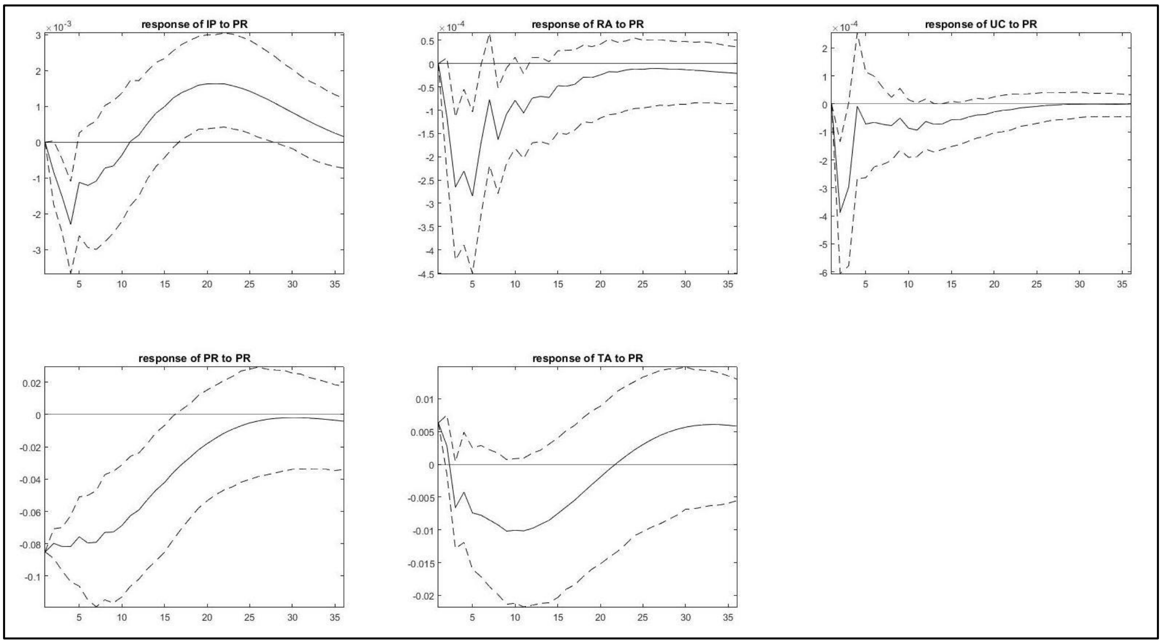


Figure A.3.3: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

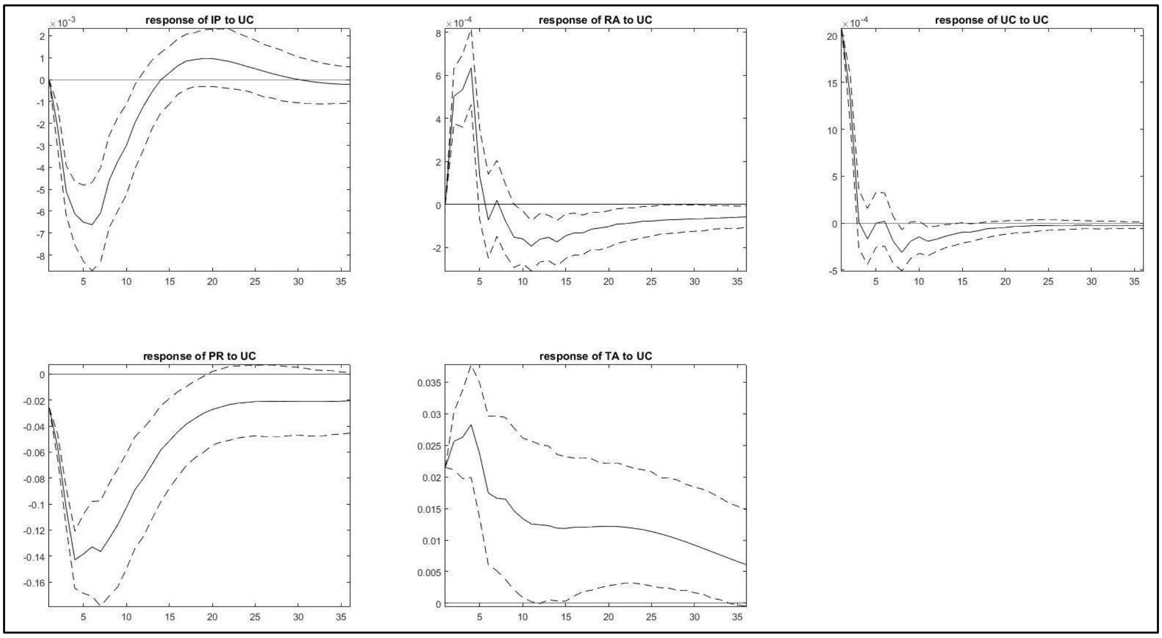


Figure A.3.4: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

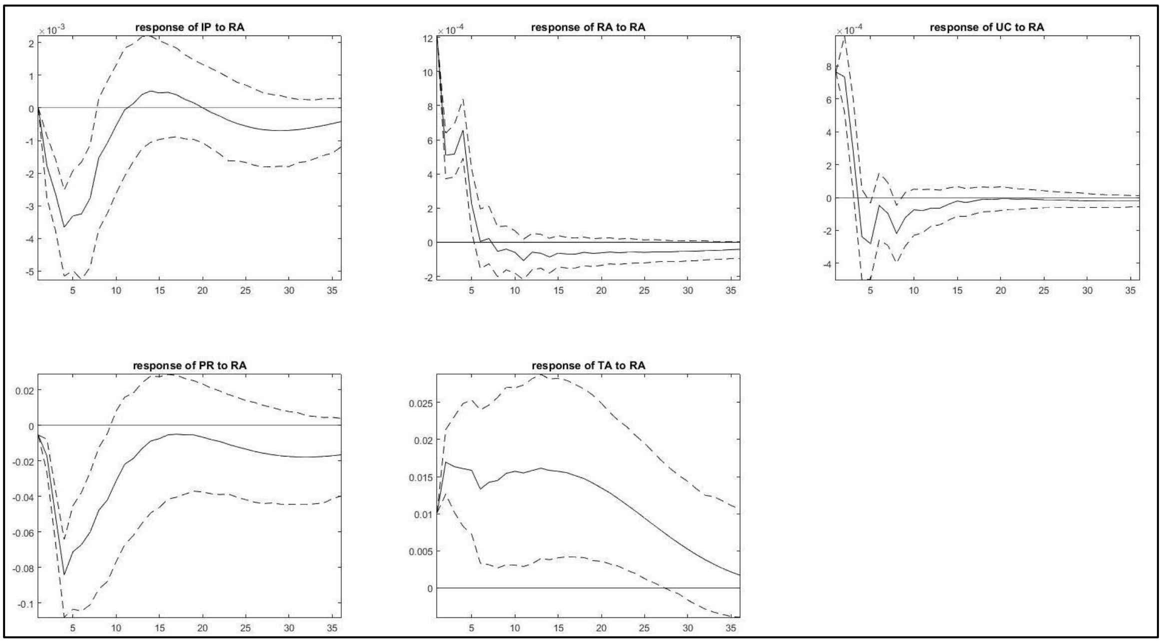


Figure A.4.1: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

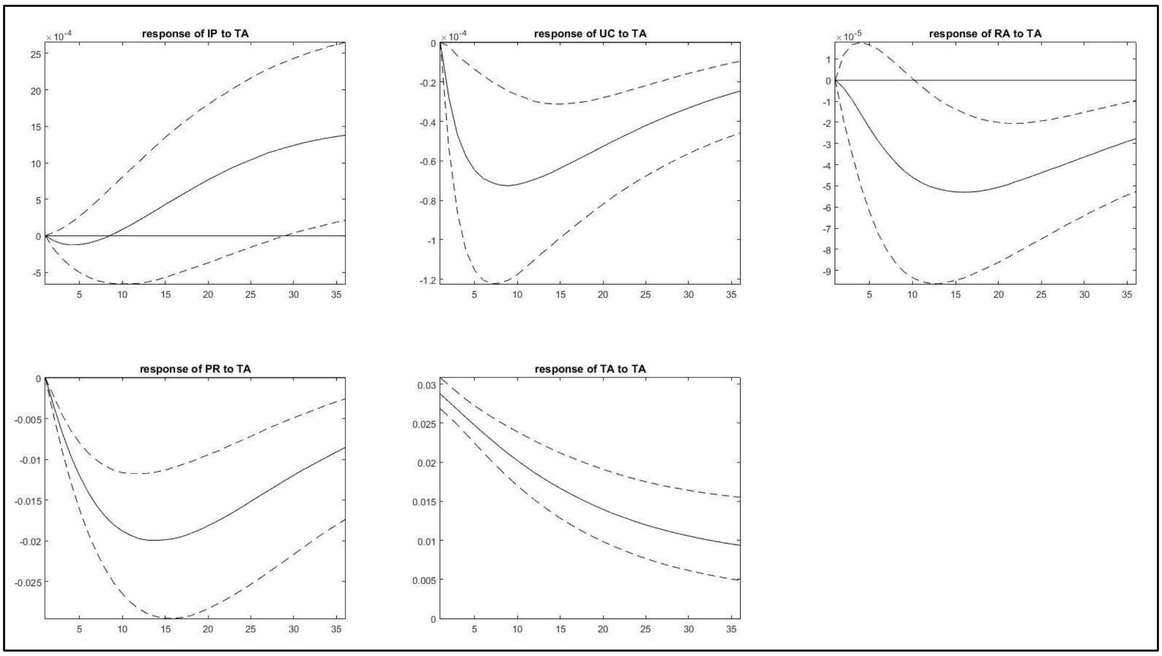


Figure A.4.2: Median impulse responses to policy rate shock together with the 68% confidence bounds.

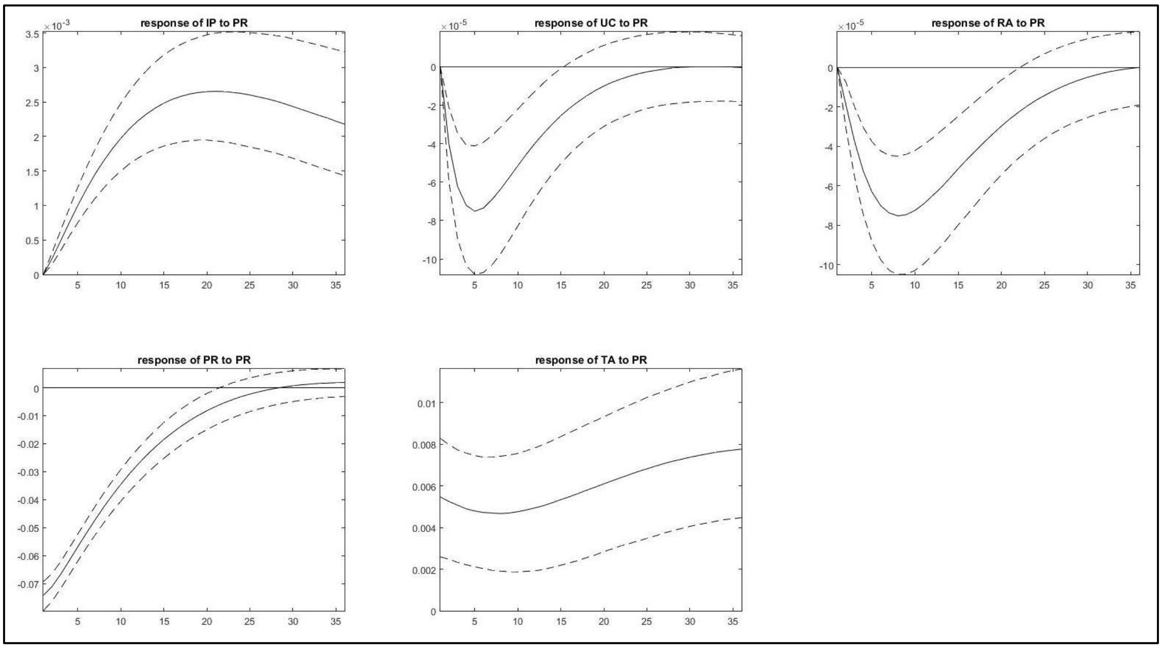


Figure A.4.3: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

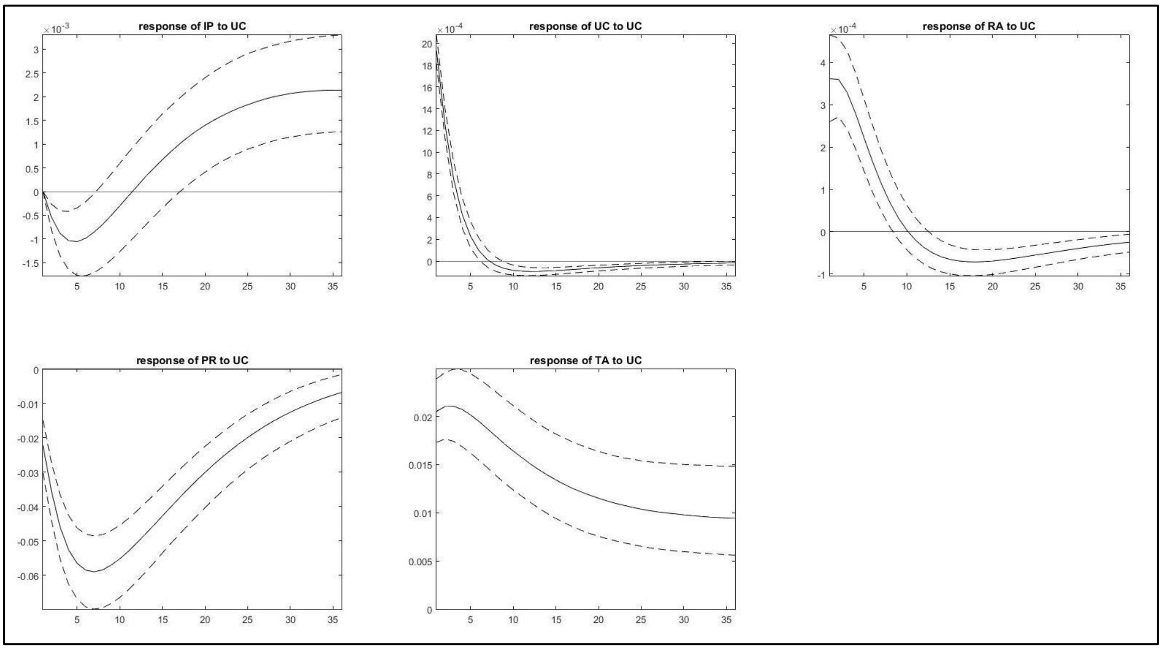


Figure A.4.4: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

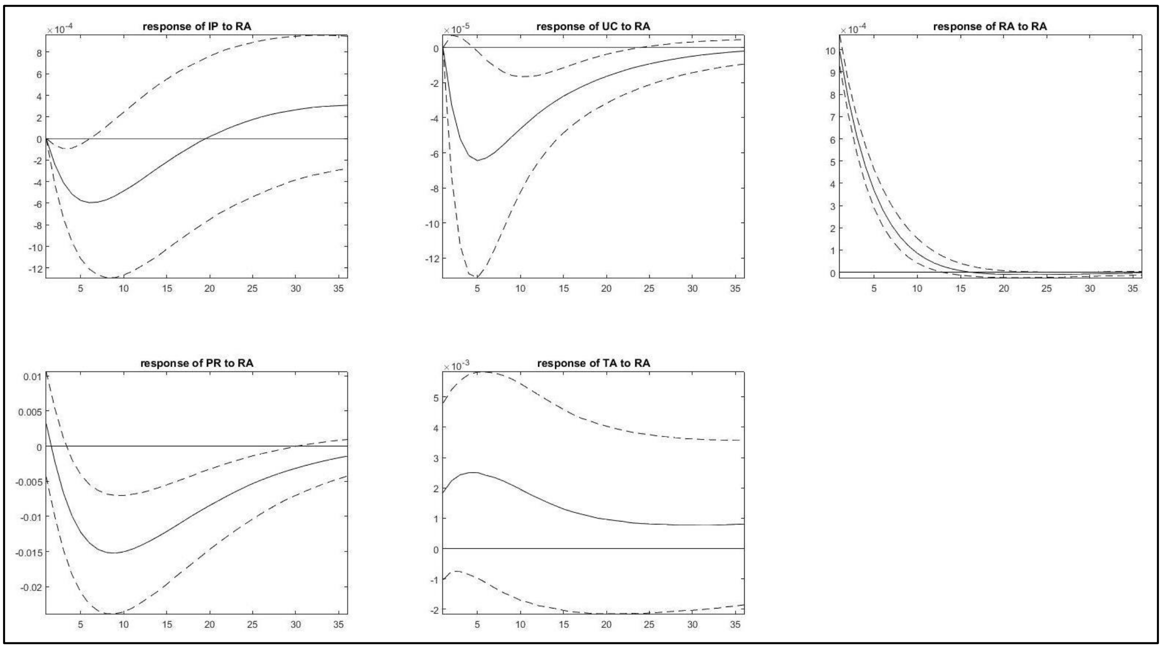


Figure A.5.1: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

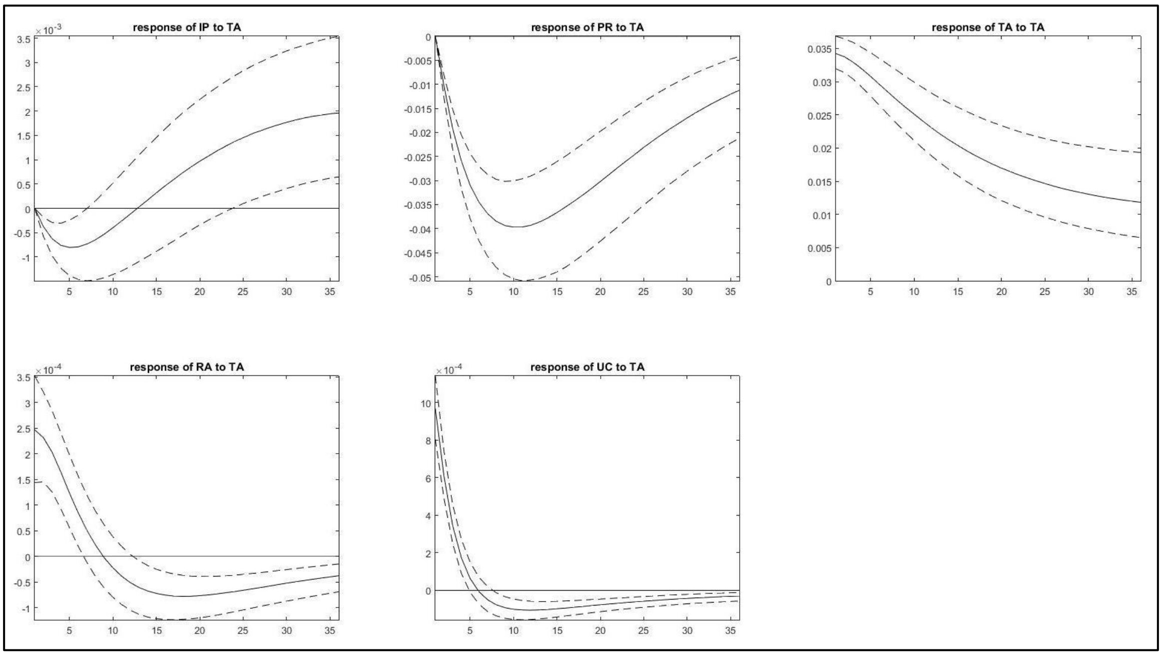


Figure A.5.2: Median impulse responses to policy rate shock together with the 68% confidence bounds.

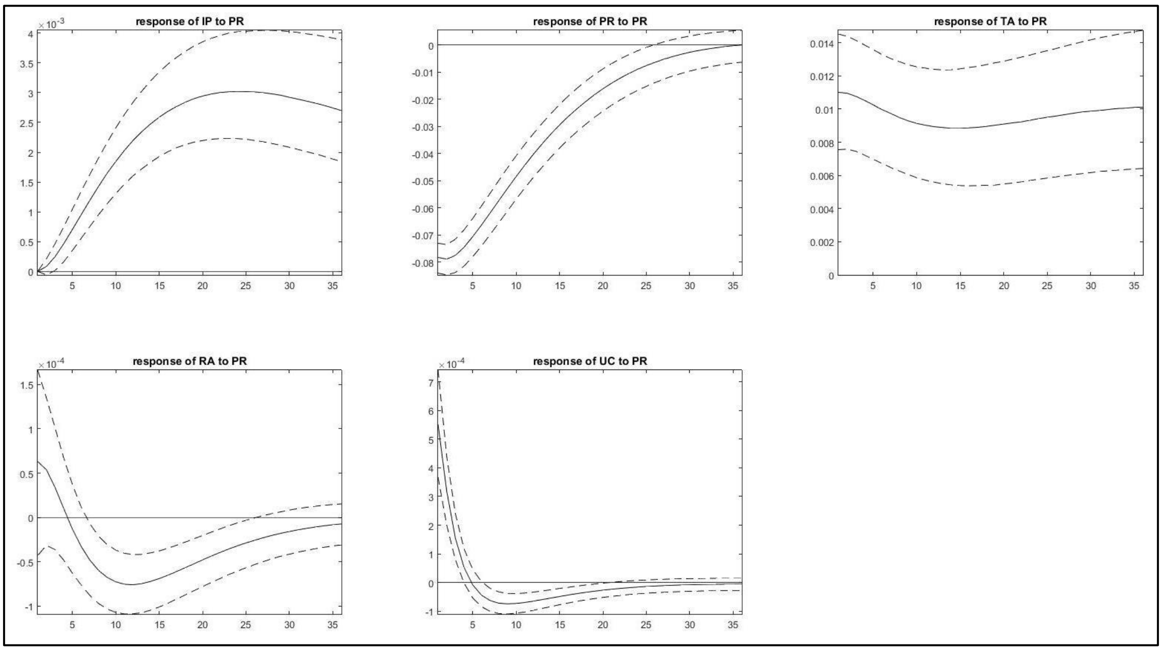


Figure A.5.3: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

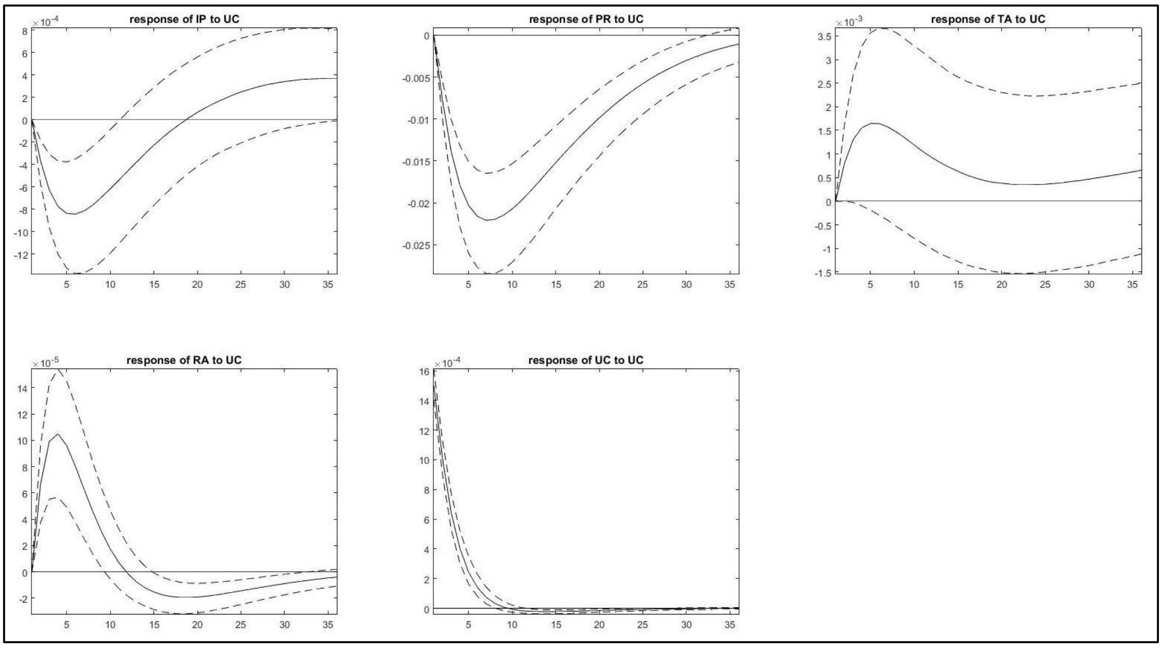


Figure A.5.4: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

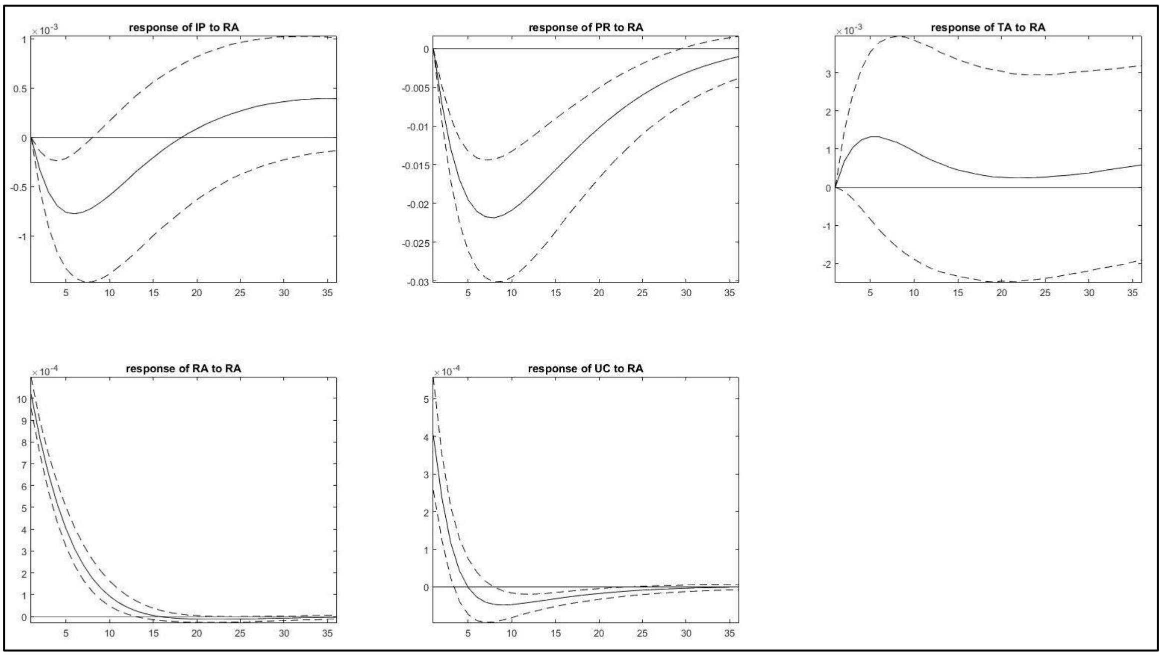


Figure A.6.1: Median impulse responses to balance sheet shock together with the 68% confidence bounds.

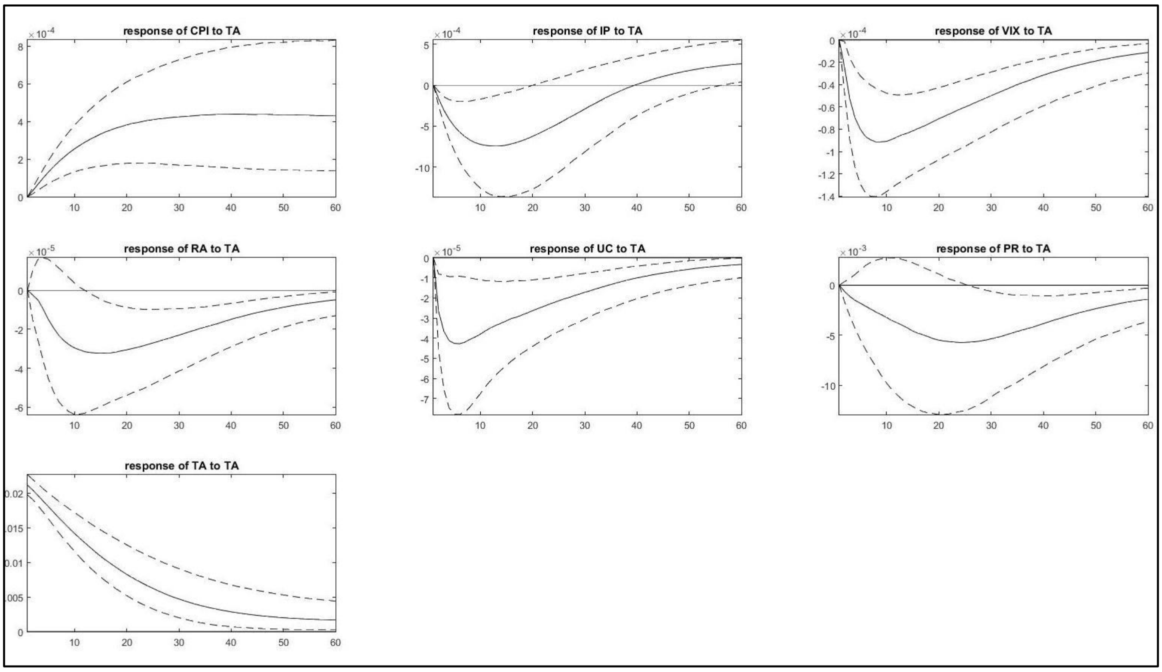


Figure A.6.2: Median impulse responses to policy rate shock together with the 68% confidence bounds.

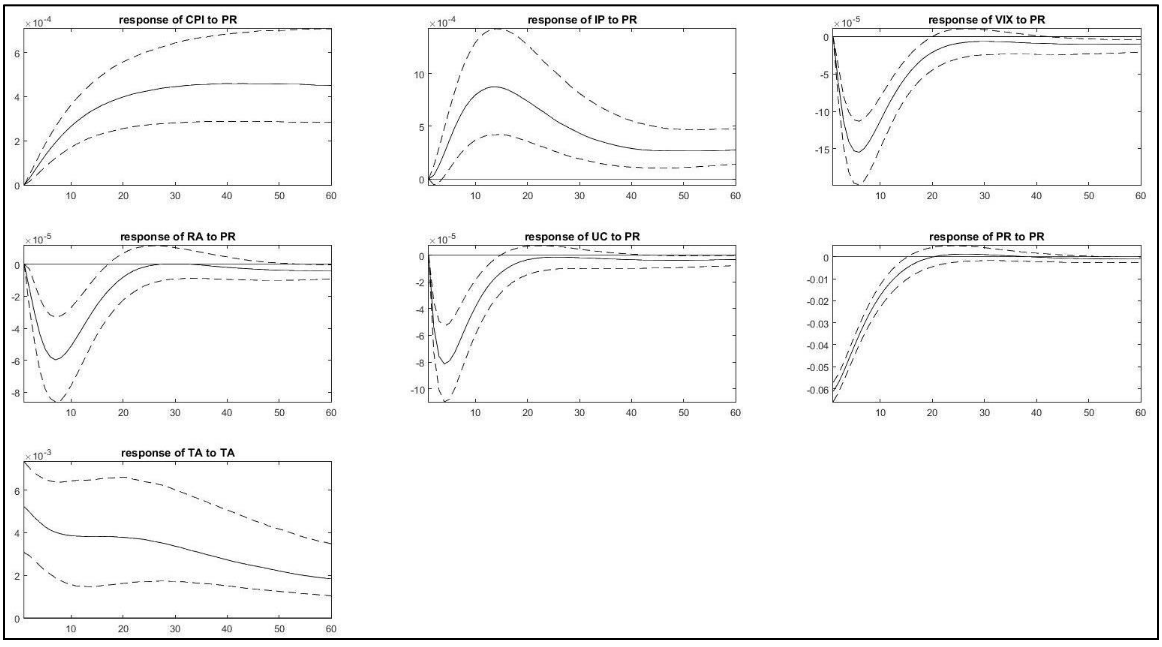


Figure A.6.3: Median impulse responses to uncertainty shock together with the 68% confidence bounds.

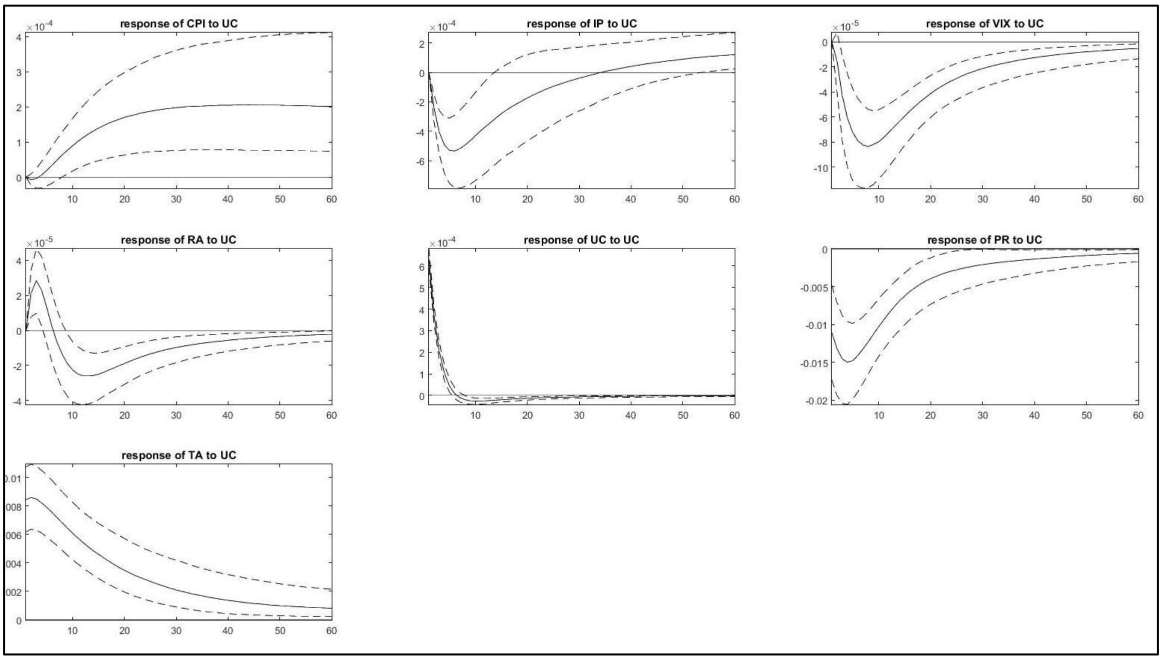


Figure A.6.4: Median impulse responses to risk aversion shock together with the 68% confidence bounds.

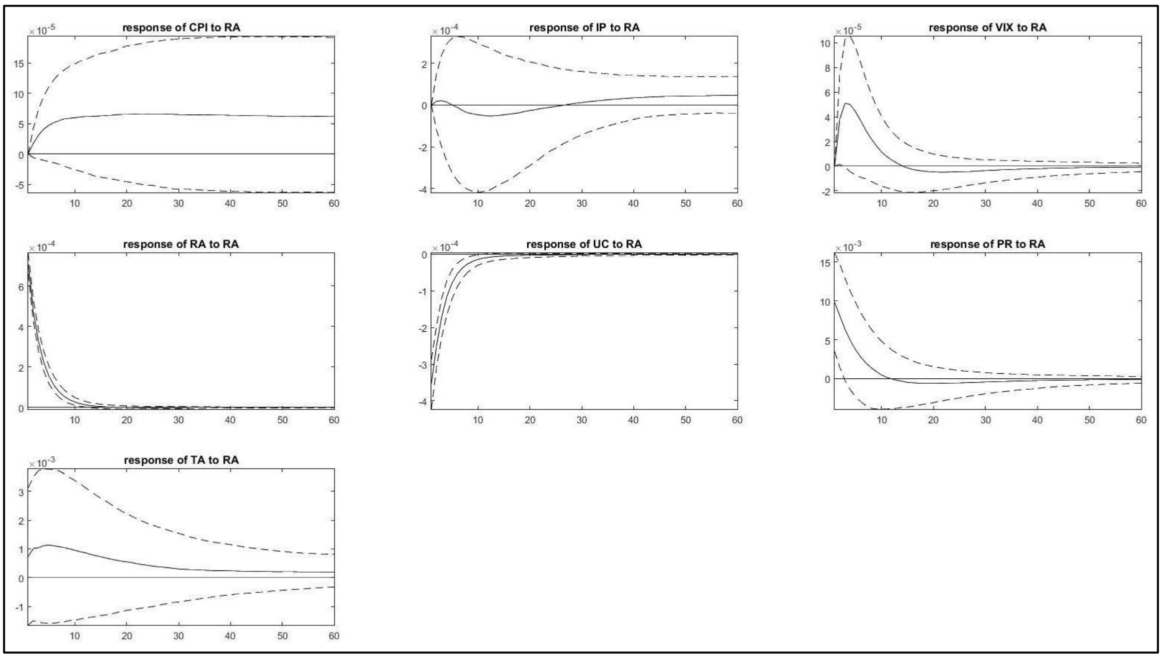
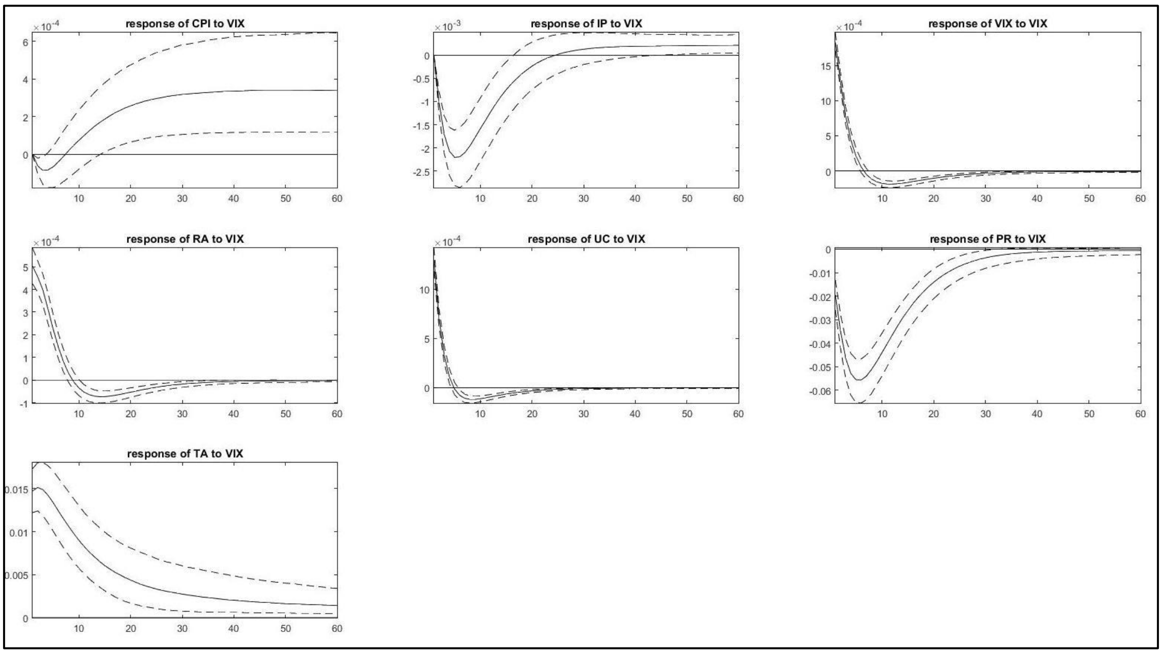


Figure A.6.5: Median impulse responses to VIX shock together with the 68% confidence bounds.



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