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Abstract

This article analyzes the impact of the unconventional monetary policies (UMPs) of four major central banks (the Fed, ECB, BoE and BOJ) on the probability of future market crashes. We exploit the heterogeneity of different UMP actions to disentangle their influence on reducing the ex ante perception of extreme events (tail risks) using the information contained in risk-neutral densities from the most liquid stock index options. The empirical findings show that the announcement of UMPs reduces the risk-neutral probability of extreme events across various horizons and thresholds, supporting the hypothesis of the risk-taking channel. Interestingly, foreign UMP actions also prove to be significant variables affecting domestic tail risks, mainly at longer horizons. These results reveal a cross-border effect of foreign UMPs on domestic tail risks. Finally, the dynamics of the UMPs are captured by a structural model that confirms a transitory impact of UMPs on market tail risk perceptions.

Keywords: unconventional monetary policy, risk-neutral density, tail risk, event study, SVAR.

JEL classification: E44, E58, G01, G10, G14.

Resumen

Este documento evalúa el impacto de los anuncios de medidas de política monetaria no convencionales de cuatro grandes bancos centrales (la Reserva Federal, el Banco Central Europeo, el Banco de Inglaterra y el Banco de Japón) sobre las probabilidades de futuras caídas bursátiles. Estas percepciones de eventos extremos o riesgos de cola se extraen utilizando la información contenida en las densidades neutrales al riesgo de las opciones de los índices bursátiles más líquidos. Las conclusiones empíricas sugieren que el anuncio de medidas monetarias no convencionales reduce la probabilidad de eventos extremos a diferentes vencimientos y umbrales de riesgo, apoyando la existencia del canal de asunción de riesgos *(risk-taking channel).* Asimismo, los efectos de desbordamiento de medidas no convencionales sobre los riesgos de cola son relevantes, en particular a vencimientos a más largo plazo. Por último, un modelo estructural, que captura la dinámica de las medidas no convencionales de política monetaria, confirma el impacto transitorio de dichas medidas sobre las percepciones de riesgo de cola.

Palabras clave: política monetaria no convencional, densidades neutrales al riesgo, riesgo de cola, eventos extremos, VAR.

Códigos JEL: E44, E58, G01, G10, G14.

1. Introduction

Central banks of major economies enacted a wide array of unconventional policy measures (UMPs) to influence monetary and financial conditions. Originally implemented by the Bank of Japan (BoJ) in 2001 to address the country's persistent deflation and banking crisis, UMPs were eventually adopted in other countries in the aftermath of the global financial crisis with the objective, among others, of reducing market uncertainty. These "nonstandard" measures go far beyond conventional monetary policy and include balance sheet policies, forward guidance and even negative interest rates. The existing variety of UMP actions and countries constitutes a valuable source of heterogeneity for analyzing the potential of unconventional policies. Is there a collection of UMP measures that were systematically effective at reducing market uncertainty? Did they exhibit a similar influence in all regions? How successful have they been at lowering the probability of extreme events? Understanding the impact of UMPs is essential to identify the influence of central banks on financial markets, especially during distressed periods such as the past financial crisis or the recent Covid-19 pandemic, where UMPs are the first economic measures implemented in many countries.

The aim of this paper is to evaluate the effectiveness of diverse UMP actions at reducing the perception of extreme market movements, or tail risks. In particular, we exploit the available heterogeneity of UMP measures from four major central banks – the Federal Reserve (Fed), European Central Bank (ECB), Bank of England (BOE) and Bank of Japan (BoJ) – to discern their impact on the risk-neutral probability of market crashes. These anticipated probabilities of extreme events are measured through the information contained in the risk-neutral densities (RNDs) of option prices from the main stock market indexes. Contrary to the real-world probability densities, which refer to the dynamics of actual prices based on historical data, option prices are forward looking because their payoffs depend on future states of the underlying asset. The indexes selected for analysis are the most representative, liquid and diversified in the various economies considered in this article; therefore, the future states of the indexes are related to the future states of the economy. Risk-neutral probabilities incorporate the subjective probability of occurrence of a state and the risk aversion adjustment of investor preferences.

The implications of using risk-neutral probabilities of extreme events are more profound than they may appear at first glance: an infinitesimal area of the RND at a given (expected) return is directly related to the price of an Arrow-Debreu asset providing a positive payoff in this particular state of nature. Thus, an increase in the size of this area reflects the interest of investors to hedging this particular scenario. The methodology employed in this article permits the measurement of the changes in the RNDs – and, consequently, the value of Arrow-Debreu assets – before and after UMPs are announced, providing a complete picture of the hedging demand of investors during central bank interventions. The foundations of RNDs were settled by Breeden and Litzenberger (1978) and employed in, for instance, Bliss and Panigirtzoglou (2004) and Hattori, Schrimpf and Sushko (2016). Recently, Martin (2017) and Martin and Wagner (2019) have revitalized the literature on using option prices as estimates of expected returns.

The main contribution of this paper is twofold. First, we dig deeper into the variety of UMP measures implemented by central banks. Our work is innovative not only in examining the heterogeneous UMP actions pursued by various central banks but also in analyzing the effectiveness of comparable announcements at reducing market uncertainty (tail risk hereafter), measured by the risk-neutral probability of tail events. In this way, we shed light on how investors react to similar UMP attempts implemented by central banks in different countries; see, for instance, Hattori et al. (2016). The monitoring of tail risks is key from a policy perspective. In high-volatility scenarios, it is essential to reduce uncertainty to avoid adverse feedback loops between the financial system and the real economy.[1]

Our main empirical finding suggests that UMP announcements mitigate the probability of (expected) sharp market declines for various thresholds of a given loss and across different horizons in the four areas analyzed. Specifically, UMP measures reduce the perception of extreme events by 14 percent in the U.S, 9 percent in the euro area, 10 percent in the UK, and 7 percent in Japan. An interesting heterogeneity is found when comparing the measures. The most effective measures seem to be the announcement of forward guidance, particularly in the US and Japan (where it reduces tail risk perceptions by 27 %) and liquidity announcements. These results highlight the relevance of communication and credibility of central banks as a monetary policy tool. According to our results, unsterilized measures are also more effective than sterilized interventions. To the best of our knowledge, this is the first attempt at comparing the effectiveness of the heterogeneous measures of the four major central banks at reducing extreme market movement. However, one needs to be cautious when comparing these disaggregated results across different areas. A concerning fact is that different types of measures are announced on the same day and the overall number of announcements of the different measures is limited and sometimes uneven across the four central banks, making it difficult to disentangle the relative effectiveness of different UMP measures. Additionally, the timing and the circumstances in which they were announced, such as the underlying financial and economic conditions, may play a relevant role. Finally, these results do not incorporate the effects of more recent announcements of unconventional monetary policies in the wake of the COVID-19 crisis (such as the pandemic emergency purchase programme (PEPP) in the case of the ECB or the resumption of asset purchases of the Fed).

[1] As O. Blanchard notes, "So what are policymakers to do? First and foremost, reduce uncertainty. Do so by removing tail risks, and the perception of tail risks.", The Economist, January 31, 2009.

A second contribution of this article is the testing of cross-border effects arising from the nonconventional monetary policy actions of foreign central banks. The comprehensive dataset employed in this paper, consisting of option prices from the most liquid stock indexes around the world, places us in a privileged position for analyzing this issue. The empirical evidence provided here demonstrates the role of the Fed in *increasing* the perception of risk for overseas investors when contractionary measures are suggested. The announcement of contractionary UMPs in the US increases tail risk perceptions in other areas – mainly the euro area and UK – but their effects appear in the long term, suggesting the existence of a term structure of UMPs' impacts on tail risks.

To further provide evidence of the impact of UMPs on tail risks, we carry out a structural vector-autoregressive (SVAR) analysis. The SVAR confirms the main result of this article: expansionary UMP shocks reduce tail risk perceptions in the four areas under study, leading to a decrease of approximately two percentage points. However, the UMP shock has only a temporary effect on tail risk perceptions, fading out after a year. As an additional output of the model, the macroeconomic impact of an expansionary UMP is found to be positive. All these results are corroborated with an exhaustive battery of robustness checks that corroborate our main findings.

The methodology employed in this paper relies on two main sources of information: UMP announcements by central banks and data from financial markets. On the one hand, a comprehensive database tracking the UMP actions of different central banks has been built for our research. This dataset comprises more than 160 events for the four major central banks (the FED, ECB, BoE and BOJ), and it distinguishes among types of measures: liquidity, forward guidance and asset purchases (both sterilized and unsterilized). In our view, each of these groups has a different goal, and their effect on financial variables and market expectations deserves a particular analysis. On the other hand, the information about RNDs is extracted from equity options written on the most liquid and representative stock indexes of each economic region: S&P500 (US), the EuroStoxx50 (Eurozone), FTSE100 (UK) and Nikkei225 (Japan).

Thus, this article analyzes the effects of UMPs on market uncertainty using the information of future states of the economy embedded in broad index option prices. The remainder of the paper is organized as follows. Section 2 presents the contribution of this article to the literature. Section 3 explains the methodology used to extract risk-neutral densities and their estimation. Section 4 develops the static event-study analysis. The dynamic effects of UMPs using a SVAR approach are reported in Section 5. Section 6 performs a series of robustness checks. Finally, Section 7 concludes the paper.

2. Contribution to the literature

The development of unconventional policy measures has expanded the transmission mechanisms of monetary policy to new channels broadly analyzed by the literature, such as the liquidity, signaling and portfolio rebalancing channels.[2] This article examines a broader transmission mechanism of monetary policy: the risk-taking channel, in which monetary policy actions can affect other assets and markets via their impact on risk perceptions and financial sector risk-taking; see Borio and Zhu (2012) and Bruno and Shin (2015). Specifically, we focus on the impact of UMP announcements on tail risk perceptions in representative market equity indexes. In this way, we contribute by testing the transmission mechanism of Brunnermeier and Sannikov (2013), who suggest that central bank purchases can serve as insurance against tail events.

This paper is related to different lines of the burgeoning research on the effects of UMPs. First, this article belongs to the stream of literature analyzing the relationship between monetary policy and financial markets and, specifically, its interaction with market uncertainty. Concerning conventional monetary policies, Birru and Figlewski (2010) find that these types of measures are associated with "greater resolution of uncertainty". Nave and Ruiz (2015) confirm that an expansionary monetary policy of the ECB reduces risk aversion in Eurozone financial markets. Maio (2014) also studies the effect of monetary policy actions on the cross-section of equity returns, concluding that the impact of monthly changes in the Federal funds rate is greater for the returns of more financially constrained stocks. Rompolis (2017), using a SVAR strategy, concludes that an expansionary ECB balance sheet shock decreases both risk aversion and uncertainty at least in the medium term. Finally, Bekaert, Hoerova and Duca (2013) propose a decomposition of the VIX index into its risk aversion and uncertainty constituents, showing that expansionary monetary policy significantly reduces these two components. In contrast to the methodology of Bekaert et al. (2013), we employ the full information provided by the RNDs and focus on tail risks.

The interaction of UMPs and financial market uncertainty is a field that has experienced increasing interest in recent years, and it has mainly focused on fixed income markets. For instance, Gagnon, Raskin, Remache, Sack et al. (2011) is one of the earliest event studies with US data reporting how LSAP announcements reduce long term yields; see also Meyer and Bomfim (2010) and D'Amico and King (2013). Similar con-

[2]Within the liquidity channel, UMPs can affect portfolio decisions and asset prices by altering the liquidity premia. Large-scale asset purchases are credited as increased reserves on the balance sheets of private banks. Since such reserves are more easily traded in secondary markets than long-term securities, there is a decline in the liquidity premium, enabling liquidity-constrained banks to extend credit to investors. The signaling channel highlights that UMP announcements may reveal to market participants that the central bank has changed its view on future economic conditions, for instance that it plans to hold policy rates lower than previously expected. On the other hand, the portfolio rebalancing channel, or QE, involves the purchase of long-term assets, reducing the term premium and increasing the demand for risky assets.

clusions are obtained by Krishnamurthy, Nagel and Vissing-Jorgensen (2018) for the ECB and Joyce, Tong and Woods (2011) for the Bank of England. Bauer, Rudebusch and Wu (2014) conclude that changes in expected short rates are also associated with changes in the term premia of long-term rates, and Meaning and Zhu (2011) document decreasing marginal effects of UMP on long yields. Articles examining the impact of UMPs on market uncertainty using information from the option markets are even scarcer. For instance, Olijslagers, Petersen, de Vette and van Wijnbergen (2019) find that only UMPs that change the relative asset supplies seem to reduce perceived crash risks using information from option prices for the euro-dollar exchange rate. Our article is closely related to Hattori et al. (2016), who quantify the impact of the UMPs of the Fed in RNDs from stock and bond market options. These authors find that "nonstandard" announcements reduce the risk-neutral implied probability of extreme events affecting interest rates and equity markets. This article extends their study to other economic areas, comparing the effectiveness of UMPs from the four major central banks and accounting for the heterogeneity of the different UMP actions.

Second, this article also belongs to another strand of literature interested in the potential spillovers of monetary policy. Empirical work has mainly focused on the global monetary spillovers of the Fed's actions, concluding that US monetary policy has sizable spillover effects on both advanced and emerging economies.[3] For instance, Fratzscher, Lo Duca and Straub (2018) highlight the procyclicality of flows in the wake of UMP, in particular in emerging economies. Chen et al. (2016) also find that the effects of Fed's quantitative easing are even larger and more heterogeneous in emerging economies than in advanced countries. Related papers have dug deeper into the so-called global financial cycle. Rey (2015) and Miranda-Agrippino and Rey (2018) suggest that there is a common comovement in asset prices, capital flows and credit growth that seems to be driven by monetary conditions in core economies, particularly the US, affecting domestic policy makers' decisions and risk aversion. Some papers have also compared the spillover effects of conventional and unconventional monetary policies and obtained mixed results. While a large part of the literature highlights the strengthening of spillovers under quantitative easing programs (e.g., Rogers, Scotti and Wright (2018), Yang and Zhou (2017) and Neely (2015)), new evidence such as that in Curcuru, Kamin, Li and Rodriguez (2018) challenges these results using a term structure model to distinguish between conventional and unconventional monetary policies.

Less attention, however, has been paid to the differential impact of the international spillovers from the UMPs of central banks other than the Fed. Rogers et al. (2014) compare the spillovers of quantitative easing measures implemented by the Bank of England,

[3] See, among others, Chen, Filardo, He and Zhu (2016) Rogers, Scotti and Wright (2014), Bhattarai, Chatterjee and Park (2018), Tillmann (2016) and Moore, Nam, Suh and Tepper (2013).

the ECB, the Federal Reserve and the Bank of Japan, concluding that these measures contributed to easier global conditions, particularly those policies implemented by the Fed. Similar results are obtained by Chen, Lombardi, Ross and Zhu (2017) and Apostolou and Beirne (2019) when comparing Fed and ECB spillovers. Our article contributes to this literature by assessing the differential cross-border effects of the UMP of major central banks on market risk uncertainty.

This article continues the extensive literature analyzing the informative content of option-implied RNDs, which traces its roots back to the original work of Breeden and Litzenberger (1978). A significant part of this research has focused on the methodological issues for estimating RNDs using parametric and nonparametric techniques. Jackwerth (2004) and Figlewski (2009) provide a good review of these methodological issues. Another part of the literature on RNDs has also examined their behavior during periods of financial stress. One of the first such studies was Bates (1991), who concluded that the 1987 crash was possibly anticipated in the options markets as much as two months in advance. In a later work, Jackwerth (2000) derives risk-aversion functions from option prices and shows that risk aversion significantly changes around the 1987 crash. Lynch and Panigirtzoglou (2008) extract RNDs from S&P index options and conclude that RNDs respond to market events but are not very useful for forecasting them. In a seminal work, Birru and Figlewski (2012) also examine RNDs in the fall of 2008, finding a strong pattern in the RND's responses to stock index movements.

Finally, several articles have mined the macroeconomic information content of option prices. Almeida, Ardison, Garcia and Vicente (2017) introduce an option-based tail risk measure that provides meaningful information about aggregate macroeconomic conditions, and Faccini, Konstantinidi, Skiadapoulos and Sarantopulou-Chiourea (2019) analyze the properties of S&P 500 option-implied risk aversion as a predictor of US real economic activity. Along these lines, we are not aware of papers other than Hattori et al. (2016) dealing with the impact of UMPs in risk-neutral distributions from option prices.

3. RNDs and their estimation

Option prices contain a significant amount of information about expected returns; see Martin (2017) and Martin and Wagner (2019). Because options are written as the discounted expectation of future payoffs, investors voice their views about future asset prices by taking positions in those options that match their prospects. The information about the entire distribution of a later asset price from several observed option prices crystallizes in the implied risk-neutral density (Breeden and Litzenberger, 1978). Therefore, RNDs include information about the probability of extreme adverse movements of prices, or tail risks.

To assess the impact of UMPs on market tail risk perceptions, we first need to compute the RNDs from equity option contracts. For the sake of exposition, a full description of the methodology for estimating the RNDs is included in Appendix A, while the main results are provided here.

3.1. Estimated RNDs

The RNDs are estimated using options from the most representative liquid stock market indexes from the US (S&P500), the euro area (EuroStoxx50), UK (FTSE100) and Japan (Nikkei225). The data are taken from Option Metrics IvyDG Global, a comprehensive database with historical information about option prices and implied volatilities from index option markets. The sample period spans from January 2007 to December 2016, when the main UMP measures were announced. The data frequency is daily, and it comprises more than 2,500 observations for each index. RNDs are estimated for each day using the cross-section of option prices available on that day and reported at three different horizons, 30, 60 and 91 days, although other maturities are also attainable.

[FIGURE 1 ABOUT HERE]

RNDs are computed following the procedure described in Appendix A. To illustrate the results, Figure 1 depicts the shape of RNDs for different option indexes in selected days around UMP announcements. The different lines represent the RNDs for the day of the announcement (solid line) and days before (dashed) and after (dotted).[4]. For the sake of exposition, RNDs have been computed for a 30-day horizon, though other tenors provide similar results.

Some interesting conclusions arise from Figure 1. For instance, graph (a) exhibits the changes in markets' tail risk perceptions due to the Security Market Programme (SMP) announcement by the ECB in May 2010, which involved the purchase of sovereign bonds in the secondary markets of the so-called "dysfunctional markets" in the Eurozone. Here, we clearly observe a reduction in the tails of the RND when the action is announced. In economic terms, the hedging demand of investors for extreme wealth declines, crystallizing in a lower price of the Arrow-Debreu asset for that state.

Another example is graph (b) in Figure 1, which exhibits the S&P500's reaction to the announcement by the Fed of an additional $600 billion purchase of longer term Treasuries (LSAP2) on November 3, 2010. As shown, the mode of the RND clearly increases its level when the measure is announced. Moreover, the weight on the tails is reduced, especially in the upper tail. Similar reductions in tail risks are observable in graph (c) for the

[4]The x-axis represent future states of the indexes (the underlying asset of the options) for a certain time horizon. It is usual to normalize the future value of index states using the moneyness, so the current value of index is equal to one.

FTSE100 with the purchase by the BoE of nonfinancial investment-grade corporate bonds of up to £10 billion (CBPS) and increase the stock of purchased UK government bonds by £60 billion (APF 3); graph (d) reflects the results for the Nikkei225 following the announcement of the Quantitative and Qualitative Easing (QQE) program with yield curve control scheme by the BoJ in September 2016. In all cases, a major repricing occurred on the same day and the day following the relevant UMP announcement, suggesting that UMP was successful at taming risk tail perceptions.

To offer a different perspective on the results, we compute the option-implied probability of a given percentage decline in the stock market at a given time horizon. This statistic can be interpreted as a proxy for tail risk, and it informs about the probability of incurring (expected) market losses of a certain level at a given time horizon. In this way, we calculate the probabilities[5] of market losses less than or equal to 5% or 10% and at three different maturities: 30, 60 and 91 days.

Figure 2 depicts the time series of these option-implied likelihood for the indexes under study. For the sake of exposition, this figure shows the evolution of the probabilities for expected equal to or less than 10% for 1-month (gray line) and 3-month (black line) maturities. The different UMP announcements are displayed as vertical lines.

[FIGURE 2 ABOUT HERE]

Some interesting conclusions arise from the inspection of Figure 2. First, the probability of a 10% drop in the market index is systematically higher for longer than shorter horizons, as expected. However, this distance clearly decreases during stress periods.[6] Second, there is an interesting source of commonality among the different economic areas. For instance, market tail risk perceptions significantly worsened and increased in the aftermath of the Lehman collapse on September 15, 2008. The probability of a 10% drop in the index levels systematically spiked in all the economies under study; see, for instance, the case of the S&P500 and the Eurostoxx50, which showed increases of 35% and 40%, respectively, in their tail probabilities.

Third, it seems that most announcements from central banks have been successful at calming the markets; see, for instance, Hattori et al. (2016). At the expense of a formal test further developed, a visual inspection of Figure 2 suggests that the level of tail risk decreases after the UMP announcements of central banks. This result is observable regardless of the index under consideration. For instance, the deterioration of market perceptions in the US only eased after the announcement of the first UMP program (LSAP1).[7] The

[5]Recall that these probabilities are, in fact, the price of (Arrow-Debreu) assets providing a positive payoff in the event of a market loss less than or equal to 5% and 10%.

[6]Left-tail probability spikes are more pronounced during stress periods for short-term RNDs.

[7]Specifically, on November 25, 2008, the FOMC announced the purchase of $100 billion in agency debt and $500 billion in agency mortgage-backed securities.

posterior LSAP1 announcements also seem to have had an effect on option-implied tail risks. Posterior events such as the deterioration of the European debt crisis and the worse-than-expected macroeconomic scenario in the US provoked a worsening in market tail risks apparently mitigated by a second round of LSAP2 by the Fed in August 2010. This second phase also seems to have been successful, as market perceptions of risky events significantly declined from 24 percent to approximately 14 percent. Other subsequent announcements, such as the Maturity Extension Program (MEP) and LSAP3, also affected the probability of a 10 percent drop.

Similar conclusions arise for other economic areas in which, according to Figure 2, UMP measures seem to have calmed the markets. For example, the famous “whatever it takes” speech by former ECB President Mario Draghi and the announcement of Outright Monetary Transactions (OMT) taken by the ECB in August 2012 appeared to reduce the market perceptions of risky events by approximately 10 to 15 percentage points in the following months. In the same vein, the UK’s central bank announced in January 2009 the beginning of a program of large-scale purchases of public and private assets using central bank money, and as a result, financial tensions started to ease and market perceptions to improve[8]. Market expectations of risky events declined to approximately 15-20 percent. Finally, the implementation of the Comprehensive Monetary Easing (CME) by the BoJ on October 5, 2010, resulted in a positive impact on market perceptions.

Overall, the examples above indicate a relationship between UMP actions and reductions in market uncertainty that is formally tested in the next section.

4. Event-study analysis

4.1. Generalities

To assess the impact of UMP announcements on tail risk perceptions, we first perform an event-study analysis. This methodology has been broadly used for estimating the impact of UMP on financial markets, such as bond yields and exchange rates; see, among others, Gagnon et al. (2011) and Neely (2015).

The event-study methodology presents several advantages for our purposes. Probably the most interesting is how this technique permits us to identify a causal impact of UMP announcements on tail risk perceptions under certain strong conditions. These conditions include a suitable choice of the time window[9]; the assumption that the unique drivers af-

[8]The first round was announced in March 2009 and amounted in total to 200 billion pounds of purchases until January 2010.

[9]The time window of events should be narrow to avoid capturing other effects but large enough to measure the full impact of UMP announcements. Our baseline estimation considers one-day windows. This choice is appropriate for financial indicators when capital markets are efficient because, given the efficient market hypothesis, financial variables quickly price in new relevant information due to their forward-looking nature. As a robustness check, we also enlarge this time window to two days. The results of this specification can be found in Appendix E.1.

fecting financial variables are the UMP announcements themselves; and the developments of financial markets are assumed not to affect monetary policy decisions. In addition, another interesting advantage of the event-study methodology is that it enables us to disentangle the effects of heterogeneous UMP measures.

In spite of its advantages, the event-study approach also suffers from some limitations. For instance, because financial variables are only affected by the unexpected component of news due to their forward-looking nature, one needs to be able to estimate the "surprise component" of the UMP announcements, a difficult task to achieve. Thus, some authors only consider QE decisions covered in the Financial Times as "announcement effects"; see Fratzscher, Duca and Straub (2014). In the same vein, Altavilla, Giannone and Lenza (2014) extract the average surprise variation in government bond yields on announcement days. In addition to this complexity, major central banks have implemented quite heterogeneous UMPs, with substantial differences in their amounts. An even more concerning fact for such estimation is that different measures were announced on the same day and the overall number of announcements is limited, making it difficult to disentangle the relative effectiveness of different UMP measures. Therefore, to relate the unexpected component of UMP announcements to their overall volume and to compare the relative effectiveness of different forms of UMP is a limitation imposed by the methodology. Finally, we cannot assess the persistence of the effects of these measures in the long term.[10]

4.2. Baseline specification

We denote by $F_{i,t,n}^{\alpha\%}$ the risk-neutral probability on day t of index i experiencing a decline of size $\alpha\%$ for a period of n months (the risk-neutral cumulative density function). Following Hattori et al. (2016), the baseline regression model for each economic area i is stated as

$$\Delta F_{t,i,n}^{\alpha\%} = \beta_i A_{i,t}^{UMP} + \sum_{j=1}^{J} \gamma_{i,j} News_{i,j,t} + \varepsilon_{i,t}, \text{ with } \alpha = 5\%, 10\%, \ n = 1,2,3 \text{ months.} \quad (1)$$

where $\Delta F_{t,i,n}^{\alpha\%}$ stands for the change in the expected probability (in logs) of an $\alpha\%$ decline in the stock market for a period of n months for each area i; $A_{i,t}^{UMP}$ is a dummy variable equal to one on the day of the UMP announcement, zero otherwise; and *News* is a vector of control variables that accounts for macroeconomic releases affecting each of the areas under study, based on the Bloomberg economic surprise monitor (ECSU) and reported in Appendix D. In addition to this set of controls, we also control for UMP announcements in

[10]The efficient market hypotheses also implies that announcements will affect long-term financial indicators in a similar way as they do short-term indicators. However, this hinges on a strong assumption.

the rest of the areas considered. Finally, OLS estimates are calculated using Newey-West standard errors to control for heteroskedasticity and serial correlation. [11]

Table 1 reports the estimated effects of UMP announcements made by the different central banks under study on one-month option-implied tail risks, as described in equation (1). As expected, the announcement of UMP reduces the market perceptions of the probability of risky events in the four equity markets. Indeed, all the coefficients are statistically significant with a negative sign. For instance, estimates demonstrate that UMPs are successful at revising down the 5th percentile of tail risk probabilities by approximately 3 to 5 percent. When moving to the 10th percentile, these tail risk likelihoods decline by between 7 and 14 percent. These estimates are consistent with those reported by Hattori et al. (2016) for the US market, who find an impact of 13.6 on tail risks for a 20 percent decline in the S&P 500 over a month. The control variable *News* does not have a statistically significant impact on tail risk perceptions.

[TABLE 1 ABOUT HERE]

Notably, Table 1 also provides some interesting features. For example, UMP measures have a stronger impact on sizable downside risks. The estimated coefficients are more negative for the 10th than the 5th percentile, suggesting that UMPs mitigate larger tail risks. Additionally, the Fed seems to have been more successful at reducing tail risks than other central banks. Certainly, the impact of Fed measures is larger than the results found in other areas, which suggests that the risk-taking channel could have worked better in the US than in other areas. Various factors may explain the relatively greater success of the Federal Reserve. First, together with the United Kingdom, the US system is less dependent on the banking system and more capital-intensive. Second, the Fed's measures were also more aggressive from the beginning. Finally, a larger number of policies were announced in periods of heightened financial stress. All these factors have been suggested to be relevant by the literature, but our analysis does not shed light on them.

4.3. A term structure of UMP announcements

The characteristics of our option dataset permit us to examine the impact of UMP measures on tail risk perceptions at different horizons. Taking advantage of this feature, we repeat the baseline model estimation using one-, two- and three-month option maturities. Table 2 presents the estimated coefficients of tail risk percentiles. For the sake of concision, other macroeconomic releases and UMP announcements in the rest of the areas have also been controlled for but are not reported in this table.

[11] Despite the fact that we use the most liquid index options, such as the S&P500, the Eurostoxx50, the FTSE100 and the Nikkei225, we run a robustness check to this baseline specification to control for liquidity risks, which are a common source of concern in option markets. This exercise can be found in Appendix E.3.

[TABLE 2 ABOUT HERE]

The estimates reported in Table 2 confirm the reduction in market tail risk perceptions across different horizons and loss thresholds. In general, the estimated coefficients are statistically significant with a negative sign. Once again, the coefficients are larger for extreme events, suggesting that UMP measures are perceived as hedging mechanisms against (stock) market crashes. Interestingly, Table 2 reveals that the tail risk impact is stronger for shorter maturities: UMP announcements result in a clear, strong signaling mechanism for mitigating current tail risk, but their effects dilute as time passes.

These results draw a (downward-sloping) term structure of UMP effects on reducing market tail risk. A possible explanation for this decreasing monotone relationship is that monetary policy is conditional on the state of the world and therefore can vary in the medium and long term depending on the economic and financial situation. The longer the term is, the greater the uncertainty and the larger the possibility of external shocks affecting the economic and financial conditions of countries that can even lead to a readjustment of monetary policy. [12]

4.4. Disentangling the effects of heterogeneous measures

The exceptional variety of UMP measures implemented during the period 2007-2016 constitutes a relevant source of information for disentangling which types of announcements were successful at mitigating tail risks. Interested in exploiting this source of heterogeneity, we classify all the announcements around three major types of measures: liquidity, forward guidance, and asset purchases. In our view, each of these groups has a different goal, and their effects on financial variables and market expectations may differ.[13]

In the wake of the global financial crisis, central banks focused on providing liquidity to unblock interbank markets and ease funding conditions. We use a broad definition of liquidity measures that also includes measures to support bank lending, including the ECB's LTROs and TLTROs, the BOE's Funding for Lending Scheme (FLS), and the BOJ's Growth Supporting Funding Facility (GSFF).

Forward guidance measures are signals about future policy actions. There are two different types of forward guidance: Delphic or Odyssean. While the former predicts future economic conditions, the latter only commits to a future course of action. Forward

[12] Examples of such external shocks are regulatory changes, changes in the outlook for the global economy, political changes affecting fiscal policy and changes in commodities prices.

[13] Alternative classifications were also considered. A candidate was to gather the UMP measures around forward guidance, credit easing and QE policies. While credit easing refers to measures targeting a specific market (e.g., to reduce specific interest rates or restore market functions), QE policies reflect any course that unusually increases the size of central bank liabilities. However, the distinction between credit easing and quantitative easing policies is still open to debate, so we prefer to keep this classification as simple as possible.

guidance actions have evolved over time from open-ended guidance to time-contingent and state-contingent guidance.[14] The Federal Reserve, the ECB, the Bank of England and the Bank of Japan have all provided forward guidance about future policy rates in various forms. In this analysis, we do not distinguish among different forms of forward guidance due to the limited number of events.

Additionally, we distinguish between asset purchases that increase the size of the balance sheet of central banks, named *unsterilized* asset purchases, and asset purchases that only change the composition but not the size of the balance sheet, named *sterilized* asset purchases. This distinction is of interest since it is linked to the debate on whether unsterilized interventions are more effective than sterilized operations (Hamada, 1999).

To assess the differential impact of heterogeneous UMP actions, we thus extend the event study in equation (1) for each economic area i as follows:

$$\begin{aligned} \Delta F_{t,i,n}^{\alpha\%} &= \beta_{1,i} A_{i,t}^{Liquidity} + \beta_{2,i} A_{i,t}^{SterilizedAP} + \beta_{3,i} A_{i,t}^{UnsterilizedAP} \\ &\quad + \beta_{4,i} A_{i,t}^{FG} + \sum_{j=1}^{J} \gamma_{i,j} News_{i,j,t} + \varepsilon_{i,t}, \text{ with } \alpha = 5\%, 10\%,\ n = 1,2,3 \text{ months.} \end{aligned} \tag{2}$$

Table 3 reports the estimated coefficients of expression (2) using options with a maturity of one month. For the sake of concision, results for other controls and time horizons are available upon request. According to the estimates in Table 3, the most effective measures for reducing tail risks seem to be forward guidance (*FG*) and liquidity (*Liquidity*) announcements. Interestingly, these sets of measures exhibit a systematic reduction of tail risk across economies. All the estimated coefficients are negative and statistically significant for different thresholds, and in general, the sizes of the coefficients are higher for forward guidance than liquidity. For instance, forward guidance (liquidity) lowers the probability of a 10 percent crash over one month by 27 (9) percent in the case of the Fed; 13 (9) percent in the euro area; 10 (11) percent in the UK; and 27 (6) percent for the Bank of Japan.

[TABLE 3 ABOUT HERE]

Forward guidance measures also exhibit a statistically significant impact on reducing the likelihood of a 5 percent stock market slump. Again, these announcements seem to be more effective in the US and Japan than in the euro area or UK. Consistent with previous results, the impact of forward guidance measures on reducing tail risk seems to be greater than that of liquidity measures. Swanson (2017) also finds that forward guidance has been

[14] Open-ended guidance only provides qualitative information about the future path of monetary policy, which results in a high degree of flexibility to respond to unanticipated shocks. In contrast, time-contingent kind provides an indication of when monetary policy is likely to vary. Similarly, state-contingent guidance produces an indication of the economic conditions that might lead to a change, such as the unemployment rate.

more effective in the short run in the US in the ZLB period, but he also claims that asset purchases are preferable for reducing longer term Treasury and interest rate uncertainty.

Other interesting results are also provided in Table 3. Regarding the debate on whether unsterilized interventions are more effective than sterilized operations, our results are consistent with the existing evidence (Hamada, 1999). Unsterilized measures are statistically significant and negative for the Fed and ECB, and their impact is higher for (expected) larger market declines. Finally, news releases also reduce the expected market tensions, although their effect is limited.

These results are in line with the literature highlighting the importance of communication as a monetary policy tool (Neuenkirch, 2013), since regular information releases about monetary policy can affect rate expectations before any actual rate change. In particular, the central bank must be transparent and credible to be effective.

One needs to be cautious when comparing results across different areas. The effectiveness of UMP can be affected not only by the financial structures and central bank operating procedures in place but also by the heterogeneity of measures. [15] Nevertheless, we cannot control for these specificities. Additionally, the circumstances in which they were announced, such as the underlying financial and economic conditions, may play a relevant role. For instance, it is said that during periods of financial stress, UMP tends to have a greater impact on asset prices. However, this result has been challenged by Altavilla, Carboni and Motto (2015).Finally, these results do not incorporate the effects of more recent announcements of unconventional monetary policies in the wake of the COVID-19 crisis (such as the Pandemic emergency purchase programme in the case of the ECB or the resumption of asset purchases of the Fed).

4.5. Cross-border effects

Although central bank balance sheet policies have been primarily designed to address domestic economic issues, the increasing degree of financial integration and trade openness among economies results in a more closely interwoven and interdependent world. Thus, recent empirical evidence suggests the existence of cross-border effects of monetary policies. For instance, Ammer, Vega and Wongswan (2010) show that foreign stocks show stronger responses to interest rate surprises from the Fed. Groba and Serrano (2020) also document that foreign central bank actions have an effect on the default probability of nonfinancial firms between the US and EMU. More recently, Gourinchas, Rey and Sauzet (2019) emphasize the importance of international monetary spillovers due to the role of a

[15] The number of announcements of the different measures (liquidity, asset purchases and forward guidance) across the four central banks are also uneven as can be seen in D.13. For instance, the Bank of Japan announced much more assets purchases than the Bank of England. Moreover, the number of observations for forward guidance and unsterilized asset purchases announcements is relatively small.In addition, as already mentioned, different types of measures were announced on the same day, making it difficult to disentangle the relative effectiveness of different UMP measures.

dominant international currency. These results are consistent with an international transmission of monetary policy, where international firms whose cash flows depend on a foreign economic area would be influenced by that area's monetary decisions and financial intermediation plays a key role (Miranda-Agrippino and Rey, 2018).

The international sample of option prices used in this article places us in a privileged position to examine the existence of monetary policy spillovers, in particular by examining whether there is an impact of foreign UMP shocks on national tail risks. A first approach to this question is provided in Figure 3, which depicts the RNDs of international indexes registered on the dates of arrival of the announcements. [16] The figure shows the RNDs in two groups, expansionary (Panel A) and contractionary (Panel B) measures, according to the nature of the action taken. In particular, the announcements shown in Figure 3 correspond to i) the purchase of $500 billion in agency mortgage-backed securities (LSAP1) on November 25, 2008 (upper-left graph); ii) Fed Chairman Ben Bernanke's speech at Jackson Hole on August 26, 2011 (upper right); iii) the taper tantrum, that is, Bernanke's allusion to "drawbacks of persistently low rates..." on May 22, 2013 (bottom left); and iv) the FOMC press conference where the Fed sketched an end to its stimulus on June 19, 2013 (bottom right).

[FIGURE 3 ABOUT HERE]

Figure 3 suggests some interesting features of the data. The first aspect is the remarkable change in the shape of the RNDs on the days surrounding the announcement of contractionary measures, in contrast to expansionary measures. Although the RND's shape changes in all cases from one day to another, this change seems to be more significant for contractionary actions. Notably, the direction of this shift in RNDs is a second characteristic of the figures: RNDs move to the right region of the moneyness axis in expansionary announcements and *to the left* in the case of contractionary announcements. Interestingly, the effect of contractionary Fed actions suggests an increase of the tail risk in other economies such as Japan (bottom-left graph) and Europe (bottom right).

Of course, previous speculation about the existence of cross-border spillovers is not conclusive. To conduct a formal test, we modify the baseline specification in expression (1) as follows:

$$\Delta F_{t,i,n}^{\alpha\%} = \beta_{1,i} A_{i,t}^{UMP_i} + \beta_{2,i} A_{i,t}^{UMP_{-i}} + \sum_{j=1}^{J} \gamma_{i,j} News_{i,j,t} + \varepsilon_{i,t}, \qquad (3)$$

with $\alpha = 5\%, 10\%$ and $n = 1, 2, 3$ months. The variable $\beta_{1,i}$ stands for the estimated impact of idiosyncratic UMP on tail risks, and $\beta_{2,i}$ represents the estimated spillover effect. For the rest of the specification, refer to equation (1).

[16] Different time zones and the stock market hours should be considered.

[TABLE 4 ABOUT HERE]

Table 4 presents a formal test for the existence of cross-border effects between areas. The main conclusion of this table is the relevance of the Fed in leading international monetary spillovers: contractionary UMP measures from the Fed have a negative impact on the tail risks of the euro area (Panel B) and UK (Panel C). The estimates at the two- and three-month horizons are statistically significant and positive. Indeed, a contractionary announcement in the US leads to an increase in the perceived likelihood of tail risks by 4 and 6 percent in euro area equity markets and by between 5 and 9 percent in UK equity markets. These results are not only driven by the "taper tantrum" but also by other announcements of the Fed's exit strategy. This asymmetric impact of Fed announcements on other countries has already been suggested by the literature, and it can be explained by the hegemonic role of the US dollar in global financial markets; see, for instance, Gourinchas et al. (2019). As shown in Figure 3, the Fed's expansionary unconventional monetary policy also tends to reduce market tail risk perceptions in other areas, but the effect is not statically significant. Finally, we also observe spillovers from other areas, such as the BOE or BOJ but of lesser intensity, and the results are less robust. In the case of the ECB, the OMT and TLTRO announcements had a strong impact in the other areas [17].

In addition to the relevance of the US, and even more relevant, cross-border announcements seem to affect market perceptions in the long term, which could suggest the existence of a term structure of UMPs' impacts on tail risks. Indeed, in the previous subsection, we concluded that the idiosyncratic contributions of each area have an impact across different horizons, somewhat similar to a level effect. However, external announcements of monetary policy, i.e., spillovers, only affect tail risks in the long term, analogous to a slope effect. Market participants perceive that spillovers might take time to materialize and therefore might affect their economy in the medium term but not in the short term.

5. The dynamic effects of UMPs on tail risk perceptions

This section develops a structural vector-autoregressive model (SVAR) model to explore the dynamic effects of UMPs on market risk perceptions. The SVAR methodology permits the further examination of the existence of an impact of UMPs on tail risks and its persistence over time, constituting an interesting approach to assessing the effectiveness of the policy actions.

SVAR models have been extensively used to analyze the macroeconomic effects of conventional monetary innovations; see, for instance, Christiano, Eichenbaum and Evans (1999), Peersman and Smets (2003) and Uhlig (2005). More recently, UMP innovations

[17] These results are available upon request.

have also been studied through the lens of SVAR models, as done by Boeckx, Dossche and Peersman (2014) and Burriel and Galesi (2018).

5.1. Variable description

The SVAR analysis developed in this article is structured around four economic variables that characterize each economic area: aggregate supply and demand, domestic (unconventional) monetary policy, and financial risk. We detail here the set of proxies used for these components.

As is commonly in the literature, we employ standard macroeconomic variables as proxies for aggregate demand and supply: monthly real GDP and inflation. Monthly real GDP is constructed using a Chow-Lin decomposition where monthly industrial production is the reference series. The data are taken in logs of seasonally adjusted real GDP. On the other hand, we employ the log of seasonally adjusted consumer prices for inflation. The data were been downloaded from FRED Economic Data, Eurostat for the data on the Eurozone and Datastream.

The effective stance of UMP is proxied through the shadow rates of Wu and Xia (2016). The shadow short rate (SSR) is the interest rate of the shortest maturities from an estimated shadow yield curve of sovereign bonds according to the approach of Wu and Xia (2016) and Krippner (2015).[18] As argued by Elbourne, Ji, Duijndam et al. (2018), several reasons support the selection of shadow rates as proxies for the UMPs. First, the forward-looking nature of financial markets motivates the analysis of announcements of policy changes, rather than the implementation of the measure itself. The shadow rate has the advantage of including announcement effects of nonstandard monetary policy measures whenever they affect bond yields. This is consistent with the empirical evidence shown in Section 4, where UMP announcements do have an impact on tail risks. Second, shadow rates reflect both forward guidance and quantitative easing policies; however, central bank assets fail to take into account forward guidance measures and the announcement impact of nonstandard monetary policies. Once again, this argues in favor of shadow rates since, in light of our results, forward guidance announcements seem to be more relevant than asset purchase announcements. Thus, we use the shadow rates of Wu and Xia (2016) as indicators of UMPs, since they seem to better track our a priori beliefs about significant monetary

[18]Shadow rates are obtained by modeling the term structure of the yield curve; these models have been adjusted to take into account the zero lower bound (ZLB). Specifically, Wu and Xia (2016) and Krippner (2015) decompose the short rate process into a shadow rate, which can be negative, plus a call option accounting for the possibility of holding cash at the ZLB, as proposed by Black (1995). The differences between the two approaches are mainly methodological. While Wu and Xia (2016) use a three-factor model to estimate the shadow rates, Krippner (2015) develops a two-factor model that claims to be more correlated with unconventional monetary measures implemented in the US. The Wu and Xia (2016) method faces the risk of overfitting the data but better fits the yield curve, especially at the short end. Several papers have concluded that shadow rates are a good proxy for measuring the overall monetary policy stance in a ZLB environment; see, for instance, Damjanović and Masten (2016), Wu and Xia (2016) and Krippner (2015).

policy episodes. In particular, we employ the short-term rate of Wu and Xia (2016) for the US, UK and the euro area. For Japan, we use the shadow rates of Krippner (2015), as Wu and Xia (2016) do not calculate the corresponding rates for this country.

Finally, financial risk is captured by the probability of a 10 percent drop in the representative stock market index of each economic area over a one-month period. These time series were previously applied in Section 3. In the baseline specification, we employ the last observation of each month for the sake of consistency. As robustness checks, we also use the monthly median of daily data. Additionally, other percentiles of the RNDs and VaR measures are also employed. The results are robust to these alternatives, as shown in Section 6.

5.2. *Methodology and identification strategy*

This article employs a monthly Bayesian structural vector autoregression (SVAR) approach for each economic area under analysis. The benchmark VAR model considered has the following structural form representation:

$$A_0 Y_t = k + B(L) Y_{t-1} + \varepsilon_t, \tag{4}$$

where Y_t is the vector of endogenous economic variables; A_0 is a matrix of the contemporaneous reactions of the variables to the structural shock; parameter k is the intercept; B(L) is a matrix polynomial of structural coefficients; and ε_t is a vector of structural innovations. Following Uhlig (2005), a time trend is not ultimately included in the model. The *reduced-form* representation of the model is as follows:

$$Y_t = \alpha + C(L) Y_{t-1} + u_t, \tag{5}$$

where $u_t = A_0^{-1} B(L)$, and $C(L) = A_0^{-1} B(L)$. The reduced-form residuals have a full rank covariance matrix, $\Sigma = A_0^{-1} A_0^{-1\prime} = DD'$. Structural shocks are identified through a combination of zero and sign restrictions on the columns of D following the methodology of Arias, Rubio-Ramírez and Waggoner (2018). Table 5 summarizes the restrictions imposed on the structural impact matrix D to identify structural shocks.

[TABLE 5 ABOUT HERE]

A brief discussion of the identification strategy follows. Although the shocks of interest are unconventional monetary innovations, we also identify demand, supply and uncertainty shocks.[19] In this way, the expansionary UMP shock is identified by restricting the shadow

[19] Canova and Paustian (2011) demonstrate that sign-identified VAR models improve the recovery of true structural responses when, for a given number of variables, more shocks are identified and more variables are restricted.

rates to decrease. Following most of the literature on monetary policy, we assume that output and prices only react with a lag; see, for instance, Christiano, Eichenbaum and Evans (2005) and Elbourne et al. (2018). Therefore, the contemporaneous impacts of output and prices are restrained to react positively with a certain lag. This identification strategy is related to that employed in, for instance, Uhlig (2005), Baumeistera and Benatib (2013), Weale and Wieladek (2016) and Schenkelberg and Watzka (2013).

Aggregate demand and supply shocks are also identified to capture business cycle disturbances and ensure that UMP shocks are exogenous responses to macroeconomic conditions. While the aggregate demand shock is identified by restricting output and prices to move in the same direction, supply shocks are characterized by both variables moving in opposite directions; see Peersman and Straub (2009) and Yano (2009). Additionally, given that policy makers do not observe aggregate demand and supply within a month – due to the publication delay of official statistics – we assume that monetary policy does not react immediately to unexpected changes in output growth and inflation. The imposition of a zero contemporaneous reaction of shadow rates to aggregate demand and supply shocks is also used by Elbourne et al. (2018). Other authors also impose a zero restriction using balance sheet data instead of shadow rates, qualifying it as "realistic" (Weale and Wieladek, 2016).

Finally, our variable of interest, tail risk, is left unrestricted in the SVAR specification, since the central question of the paper is to assess how UMPs affect market risk perceptions. Unlike macroeconomic indicators, financial variables are observed in real time. Because a rise in risky events and a decline in shadow rates have the opposite impacts on macroeconomic variables, we opt to leave unrestricted output and inflation. Additionally, this uncertainty shock allows us to ensure that we capture a UMP shock exogenous to unexpected changes in market perceptions.[20]

The VAR model is estimated using Bayesian methods from the BEAR Toolbox of Matlab® developed by Dieppe, Legrand and Van Roye (2016). The data sample is monthly, and it spans from January 2007 to December 2016, a period in which UMPs were implemented. For robustness, we also restrict the estimation period to run from 2008 to 2016. To avoid tight priors that dominate information from the data, we impose an agnostic normal inverse-Wishart prior, similar to Uhlig (2005). Six lags of endogenous variables are estimated, which seem to capture well the dynamics of the model. The model is estimated in

[20]To the best of our knowledge, this is the first time that SVAR models with tail risk proxies have been used to explore UMPs. This identification strategy is inspired by Elbourne et al. (2018), who also employ shadow rates to proxy for unconventional monetary measures in a somewhat similar framework. In contrast to Elbourne et al. (2018), we opt for parsimonious models that ensure the comparison of the results, given the exceptional heterogeneity of the economic areas involved. In this vein, we exclude some indicators – e.g., the interbank market's liquidity — that work differently in each area. Our approach is possibly closer to the identification scheme of Weale and Wieladek (2016), whose most relevant differences are the use of the balance sheet as a proxy for UMPs and equity prices instead of tail risk perceptions.

logs, allowing for implicit cointegration relationships in the data (Sims, Stock and Watson, 1990).

5.3. Results

One output of the estimation procedure is the impulse-response functions (IRFs) from SVAR models. Figure 4 depicts the response of the economic variables under study to an (expansionary) UMP shock of one standard deviation. Each row corresponds to an economic variable, and the different economic areas are organized in columns. Each chart displays the median of the posterior distribution (solid line) and the 68 percent credibility interval (shaded area).

[FIGURE 4 ABOUT HERE]

Some interesting conclusions emerge from Figure 4. First, we focus on the impact of a UMP shock on our variable of interest, tail risk. The UMP shock crystallizes in a decline of shadow rates by 5-10 basis points at the moment of impact, and its effect fades out gradually – except in the case of Japan. In the euro area and the UK, the impact is much shorter and becomes positive on account of the increase in output and inflation. As advanced in the event-study section, an (expansionary) UMP shock reduces tail risk perceptions in the four areas under study, leading to a decrease of approximately two percentage points. In general, the impact of UMP shocks is transitory and fades out after a year. In light of these results, it seems that UMP measures have been successful at temporarily reducing market tail perceptions. Moreover, the response of tail risk perceptions to an UMP shock is relatively homogeneous across areas.

An additional byproduct of our procedure is the assessment of UMP shocks on macroeconomic variables. For example, the output growth response to an expansionary UMP shock is significant and positive in the four areas. An expansionary one-standard-deviation UMP shock leads to a gradual increase in output that reaches a peak at approximately 0.05 and 0.3 percent after a year. This response is similar in the US, euro area and Japan. In the UK, the effect is much smaller, as the output growth response reaches 0.05 percent after 10 months. This can be explained by the smaller and shorter impact of the shock on the shadow rate, and the risk-taking channel could have been less relevant. While the impact found in our specification is smaller than that reported in Weale and Wieladek (2016) using balance sheet data – an unexpected 1 percent asset purchase announcement has a maximum impact on GDP of 0.58% (US) and 0.25% (UK) – our results are closer to those of Gambacorta, Hofmann and Peersman (2014) and higher than Elbourne et al. (2018). Gambacorta et al. (2014) conclude that a 3 percent increase in the central bank balance sheet has a positive impact on output of approximately 0.04% and 0.10%, and Elbourne et al. (2018) suggest that an expansionary UMP shock that lowers the shadow rate by approximately 20 basis points on impact increases GDP by 0.05 percent after 20 months.

Regarding inflation, the UMP shock increases inflation in the four areas under study. However, its impact is stronger in the US since the monetary shock increases inflation by 0.25 percent within a year, while in the rest of areas, its impact is smaller (0.05 percent in the euro area and the UK). Similar results are obtained by Gambacorta et al. (2014), who claim that a 3% increase in the balance sheet leads to an increase in inflation of between approximately 0.06% and 0.11%, and Burriel and Galesi (2018), who conclude that a 25 bps decrease in shadow rates increases inflation by 0.1 percent. Again regarding Figure 4, Japan exhibits a remarkable positive impact on inflation of approximately 0.1 percent, but the estimation is noisy. Finally, and for the sake of concision, the remaining IRFs (shocks to demand, supply and uncertainty) are relegated to Appendix F.

6. Robustness checks

This section presents the results from various robustness checks to the SVAR estimation grouped into two main categories that are presented in the next subsections. In Section 6.1., we discuss alternative specifications regarding some technical aspects of the main identification of the SVAR, such as variations in the sign restrictions imposed in the baseline model and whether a Cholesky decomposition of the estimates of the variance-covariance matrix affects the baseline results. In Section 6.2., we investigate whether alternative data characteristics could lead to substantial changes in the main results discussed previously.

The main conclusion remains valid after all this analysis: expansionary UMPs reduce expectations of future tail risks for all economies studied. As shown, this result is robust to alternative SVAR identification schemes and different data characteristics.

6.1. Robustness to different identification schemes

6.1.1. Alternative specification of sign restrictions

The choice of sign restrictions in structural VAR models is not without criticism, even in cases supported by the literature. For this reason, we propose an alternative scheme of sign constrains for the baseline model where the contemporaneous impact of output and prices is zero. Accordingly, we assume that output and prices only react with a lag, following most of the literature on monetary policy; see, for instance, Christiano et al. (2005), Boeckx et al. (2014) and Burriel and Galesi (2018). The expansionary UMP shock is still identified by a reduction in the shadow rates but unidentified afterwards. Finally, the variable of interest, the probability of a market drop, is left unrestricted. This alternative identification scheme is summarized in Table 6.

[TABLE 6 ABOUT HERE]

Figure 5 depicts the IRFs to a UMP shock under this new identification scheme. As shown, results are mainly robust to this specification: A one percent standard deviation in the UMP shock temporarily reduces the probability of a market decline in an interval of one (BoE) to 2.50 (BoJ) percentage points – depending on the economic area – and its effect fades out after a year.

[FIGURE 5 ABOUT HERE]

The macroeconomic benefits of UMPs also spread to the real economy. Under this new specification, the SVAR results suggest that UMPs have been effective from a macroeconomic perspective. An expansionary UMP shock of one standard deviation increases output by between 0.05 (BoE) and 0.20 (BoJ) percent, depending on the area under study. Inflation is also positively affected, increasing by approximately 0.04 (ECB, BoE) and 0.20 (Fed) percent as a result of the UMP shock, although the dispersion of these estimates remains large. In essence, the results of this exercise remain qualitatively and quantitatively similar to those of the baseline specification.

6.1.2. Cholesky decomposition

Some authors emphasize the vulnerability of SVAR models to sign restriction identification. Indeed, Elbourne et al. (2018) suggest that some UMP identifications "fail to plausibly recover true unconventional monetary policy shocks". To overcome this critique, we carry out a SVAR with the same variables as in the baseline model but identified via a standard Cholesky decomposition of the estimates of the variance-covariance matrix, which is a clear and convenient way of identifying structural shocks.

The Cholesky decomposition imposes restrictions on the contemporaneous matrix A of equation (4), so the order of the variables becomes essential. To this end, we first order the so-called "slow-moving" variables that only adjust with a lag to monetary policy shocks, on the grounds that prices are sticky; see, among others, Nave and Ruiz (2015) and Bekaert et al. (2013). Inflation and output are then followed by the shadow rates, as policymakers tend to react to changes in macroeconomic variables. Last are market risk perceptions, which react instantaneously to economic news and, therefore, within the same month. According to this configuration, we assume that policymakers do not respond to changes in risk perceptions. This choice is especially suitable to our analysis, since our objective is to distinguish between UMPs and uncertainty shocks, usually driven by a period of heightened volatility in markets.

[FIGURE 6 ABOUT HERE]

Figure 6 reports the IRFs of a one-standard-deviation shock in the UMP for the areas analyzed. As shown, the results are qualitatively robust to this new specification. Indeed, risk perceptions react positively in the wake of a contractionary policy shock. As expected, inflation and output react negatively to this shock. From a quantitatively point of view, the results are also similar to those from the baseline model in Section 5, with the sole differences being observed for the Fed and BOJ, where the impact of an unexpected UMP shock on tail risk perceptions is somewhat smaller – approximately 0.4 and 0.5 percent for the Fed and BoJ, respectively.

6.2. Robustness to data characteristics

6.2.1. SVAR with balance sheet data

We propose an alternative specification of the baseline SVAR model of equation (4) using balance sheet data instead of shadow rates. This novel proposal includes a vector of endogenous variables Y_t comprising consumer prices (in logs, seasonally adjusted); real GDP (in logs, seasonally adjusted); central banks' total assets (in logs); the level of tail risk perceptions; and the effective interest rate. As in the baseline model, structural shocks are identified through a combination of zero and sign restrictions following the methodology of Arias et al. (2018) and summarized in Table 7. Finally, the model is estimated by means of Bayesian methods using monthly data from 2007 to 2016.

[TABLE 7 ABOUT HERE]

A brief discussion of this alternative specification follows. The UMP shock is identified through an expansion of the balance sheet that increases inflation and output with a lag, similar to the baseline specification. To identify an exogenous UMP shock, we impose a zero impact effect on effective interest rates to impose orthogonality between unconventional and conventional monetary policy shocks. Policy rates are restrained to be zero at impact and left unidentified afterwards. Additionally, we identify aggregate demand, supply and uncertainty shocks to ensure that unconventional monetary innovations are exogenous to macroeconomic and financial conditions. These three shocks are identified in the same way as in the baseline model (4), except for the zero restriction imposed on the effective rate.

Figure 7 reports the IRFs for a one-standard-deviation UMP shock in the sample analyzed. The results show that a one-percent increase in central bank assets leads to an approximately one- or two-percent decline in risk perceptions, depending on the area considered. The most marked impact of UMPs was, once again, observed for the US. However, it is important to note that i) these results are not directly comparable with the output of the baseline model (4), and ii) the balance sheet data do not capture forward guidance measures or announcement effects.

[FIGURE 7 ABOUT HERE]

Turning to the macroeconomic variables, inflation and output react positively to an expansionary balance sheet shock. A one-percent increase in total assets leads to an increase of approximately 0.05 to 0.10 percent in inflation. Similarly, a shock to total assets results in an approximately 0.10 to 0.20 percent increase in aggregate output, although the estimates exhibit high variance. Comparing these results with those in the literature, our findings are in line with those of Gambacorta et al. (2014), who report that a 3.00% increase in the balance sheet is associated with an increase in inflation of between 0.06 and 0.11% and an increase in output of between 0.06 and 0.15%. Weale and Wieladek (2016) also report increases in GDP and inflation in response to increases in asset purchases, but their estimates are smaller than ours: a 1% increase (in terms of GDP) in asset purchase announcements leads to a maximum impact on GDP of 0.58% in the US and 0.25% in the UK. For inflation, a 1% increase (in terms of GDP) in asset purchase announcements results in increases of 0.6% (US) and 0.32% (UK).

6.2.2. SVAR with different subsamples

Some criticism could arise when using the shadow rates to proxy for UMP shocks during the period 2007-2016. This concern is mainly based on the difficulty of disentangling a conventional from an unconventional monetary policy shock within our sample period. To confirm that our results are driven by UMP measures, we re-estimate the baseline SVAR specification over the period 2008-2016. Then, the year 2007 is discarded because all the central banks under study cut interest rates in response to market turmoil. The results, not presented here but available in Figure 8 in Appendix F, show that the main conclusions of this article remain unaltered: the results are robust to this subsample period, even though some uncertainty is found in the estimates of the results regarding the ECB.

[FIGURE 8 ABOUT HERE]

6.2.3. Other robustness checks

We conduct additional robustness checks of the baseline model under alternative specifications of the tail risk variable. The list of analyses comprises the use of the monthly median observation of the RND distribution, instead of the last monthly observation; the application of different percentiles of the RND; and the utilization of value-at-risk (VaR) measures. Again, our main findings are robust to all these alternatives. These results are available upon request.

7. Conclusions

Unconventional monetary policies (UMPs) affect perceived market uncertainty. The event study developed in this article shows that UMP announcements mitigate the tail risk perceptions of stock market investors. These results are consistent across monetary areas, loss thresholds and time horizons. Specifically, the impact seems to be stronger for sizable and near-term downside risks.

The detailed database of UMP announcements constructed in this article permits us to identify the efficacy of the measures taken. The empirical findings show that the most effective measures at reducing tail risks are forward guidance and liquidity announcements. In addition, unsterilized interventions are better than sterilized operations at calming markets. These results are in line with the literature highlighting the importance of communication as a monetary policy tool (Neuenkirch, 2013), since regular information releases about monetary policy can affect rate expectations before actual rate changes. In particular, this information must be transparent and credible to be effective.

An original finding provided by this article is that spillover effects between areas are relevant and should be considered. The estimations indicate that the Fed's contractionary actions lead to an increase in tail risk in other economies, mainly in European and UK markets. Interestingly, cross-border announcements seem to affect market perceptions in the long term, which could suggest the existence of a term structure of UMPs' impact on tail risks. This result is probably explained by the relevance of the Federal Reserve as a global liquidity provider, due to the importance of the US dollar in global financial markets.

The results of the event-study exercise are confirmed by a SVAR model. The estimates confirm that UMP announcements temporarily reduce tail risk perceptions, and their effect seems to fade out after a year. Moreover, UMP measures seem to have had a positive impact on output and inflation. A series of robustness checks reinforces the main conclusion of this article: the impact of heterogeneous UMPs lowers the probability of market downturns.

From an academic perspective, the empirical findings support the risk-taking channel of Borio and Zhu (2012), in which monetary policy affects other markets and assets via its impact on risk perceptions and financial sector risk-taking. In this vein, the results can be interpreted in different ways. First, announcements can reduce the level of uncertainty since they can have an insurance effect on tail risks, as suggested by Figlewski (2009). Second, UMP measures can relax the balance sheet constraints of leveraged investors, reducing the risk of exceeding the VaR limits if these risk management models are based on them. Finally, UMP announcements might constitute a channel that influences aggregate risk aversion, as highlighted by Bekaert et al. (2013).

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Table 1: UMP announcements and option-implied tail risks in the short run

Area	Fed		ECB		BOE		BOJ	
Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$
UMP	-0.05***	-0.14***	-0.03***	-0.09***	-0.04***	-0.10***	-0.04***	-0.07**
	[0.012]	[0.032]	[0.011]	[0.028]	[0.009]	[0.029]	[0.012]	[0.035]
News	0	-0.01*	0	-0.01	-0.01**	-0.03**	0	-0.02
	[0.002]	[0.007]	[0.010]	[0.021]	[0.003]	[0.011]	[0.007]	[0.022]
Obs.	2,517	2,517	2,541	2,541	2,552	2,552	2,447	2,447

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decrease in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1 month. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in each area; see D.13 for more information. UMP announcements in the rest of the areas are also controlled for. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Table 2: UMP and option-implied tail risks across different horizons

Area	Fed		ECB		BOE		BOJ	
Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$
1-month	-0.05***	-0.14***	-0.03***	-0.09***	-0.04***	-0.10***	-0.04***	-0.07**
	[0.012]	[0.032]	[0.011]	[0.028]	[0.009]	[0.029]	[0.012]	[0.035]
2-month	-0.03***	-0.06***	-0.01*	-0.03**	-0.02***	-0.04***	-0.01	-0.03**
	[0.007]	[0.012]	[0.008]	[0.014]	[0.006]	[0.011]	[0.013]	[0.014]
3-month	-0.02***	-0.04***	-0.01	-0.02	-0.02***	-0.03***	0.01	-0.01
	[0.005]	[0.009]	[0.009]	[0.012]	[0.006]	[0.008]	[0.013]	[0.012]
Obs.	2,517	2,517	2,541	2,541	2,552	2,552	2,447	2,447

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decline in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1, 2 or 3 months. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details about the list of events included are provided in Appendix C. In all the regressions, other relevant macroeconomic releases ("News") and other UMP announcements in other areas have been controlled for, even if not reported in this table. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Table 3: Heterogeneous UMP and option-implied tail risks in the short run

Area	**Fed**		**ECB**		**BOE**		**BOJ**	
Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$
Liquidity	-0.04	-0.09**	-0.03**	-0.09**	-0.04***	-0.11***	-0.04***	-0.06**
	[0.024]	[0.037]	[0.014]	[0.038]	[0.011]	[0.035]	[0.014]	[0.029]
Sterilized AP	0.02	-0.03	0.02	-0.01	0	0.01		
	[0.017]	[0.107]	[0.021]	[0.051]	[0.016]	[0.026]		
Unsterilized AP	-0.03**	-0.08***	-0.04**	-0.08*	-0.03	-0.09	-0.01	-0.03
	[0.014]	[0.029]	[0.020]	[0.048]	[0.021]	[0.070]	[0.020]	[0.069]
FG	-0.09***	-0.27***	-0.03***	-0.13***	-0.05***	-0.10***	-0.10***	-0.27***
	[0.012]	[0.051]	[0.013]	[0.029]	[0.017]	[0.024]	[0.018]	[0.040]
News	0	-0.01*	0	0	-0.01**	-0.03***	0	-0.02
	[0.002]	[0.007]	[0.002]	[0.005]	[0.003]	[0.011]	[0.007]	[0.022]
Observations	2,517	2,517	2,541	2,541	2,552	2,552	2,447	2,447

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decline in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1, 2 or 3 months. UMP announcements are disaggregated into liquidity, sterilized asset purchases, unsterilized asset purchases and forward guidance. Further details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in each area; see D.13 for further information. UMP announcements in the rest of the areas are also controlled for. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Table 4: Spillovers between areas

Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,2}$	$\Delta F^{10\%}_{t,2}$	$\Delta F^{5\%}_{t,3}$	$\Delta F^{10\%}_{t,3}$
Panel A: Spillover to the US						
BOE UMP	-0.01	0	-0.01*	-0.01	-0.01*	-0.01
	[0.011]	[0.035]	[0.006]	[0.013]	[0.004]	[0.008]
ECB UMP	0	0.01	0	0	0	0
	[0.015]	[0.046]	[0.008]	[0.018]	[0.006]	[0.012]
BOJ UMP	-0.01	-0.03	0	-0.01	0	0
	[0.010]	[0.030]	[0.005]	[0.011]	[0.004]	[0.007]
Panel B: Spillover to the Euro Area						
Fed's expansionary UMP	-0.01	-0.02	0.01	0	0.01	0
	[0.016]	[0.040]	[0.010]	[0.018]	[0.010]	[0.014]
Fed's contractionary UMP	0.04	0.04	0.04**	0.06*	0.04**	0.06**
	[0.026]	[0.087]	[0.018]	[0.031]	[0.018]	[0.024]
BOJ UMP	-0.01	-0.04*	0	-0.01	0	0
	[0.008]	[0.020]	[0.006]	[0.010]	[0.006]	[0.008]
BOE UMP	0	-0.01	0	0	0	0
	[0.010]	[0.021]	[0.008]	[0.011]	[0.008]	[0.010]
Panel C: Spillover to UK						
Fed's expansionary UMP	-0.01	-0.04	0.01	0	0.01*	0.01
	[0.018]	[0.057]	[0.008]	[0.017]	[0.008]	[0.011]
Fed's contractionary UMP	0.05	0.17	0.05**	0.09*	0.05*	0.08**
	[0.051]	[0.186]	[0.027]	[0.055]	[0.028]	[0.040]
ECB UMP	-0.01	-0.02	0	-0.02	0	-0.01
	[0.014]	[0.042]	[0.007]	[0.017]	[0.006]	[0.010]
BOJ UMP	-0.01	-0.04	-0.01*	-0.02*	-0.01*	-0.02*
	[0.011]	[0.036]	[0.006]	[0.013]	[0.006]	[0.009]
Panel D: Spillover to Japan						
Fed's expansionary UMP	0	-0.06	-0.02	-0.01	-0.01	-0.01
	[0.023]	[0.048]	[0.017]	[0.024]	[0.016]	[0.022]
Fed's contractionary UMP	-0.02	-0.02	0.03	0.01	0.01	0.01
	[0.030]	[0.085]	[0.022]	[0.034]	[0.013]	[0.021]
ECB UMP	-0.01	-0.01	0	0	0.01	0.01
	[0.015]	[0.038]	[0.012]	[0.019]	[0.010]	[0.014]
BOE UMP	0.01	0.02	-0.01	0.01	0.01	0.01
	[0.014]	[0.033]	[0.011]	[0.017]	[0.010]	[0.014]

The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decline in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1, 2 or 3 months. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details about the list of events included are provided in Appendix C. We also control for relevant macro releases in each area, even if not reported; see D.13 for additional information. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Table 5: Identification restrictions

Variables/Shocks	Monetary policy	Demand	Supply	Uncertainty
Inflation	+	+	-	
Output	+	+	+	
Shadow rates	-	0	0	-
Risk				+

Notes: Zero restrictions are imposed on impact, while sign restrictions are imposed on impact and the first month after the shock, except for the case of inflation and output for the UMP shock. In this specific case, sign restrictions are imposed on the first and second month after the shock.

Table 6: Alternative identification restrictions

Variables/Shocks	Monetary policy	Demand	Supply	Uncertainty
Inflation	0	+	-	
Output	0	+	+	
Shadow rates	-	0	0	-
Risk				+

Notes: Zero restrictions are imposed on impact, while sign restrictions are imposed on impact and the first month after the shock.

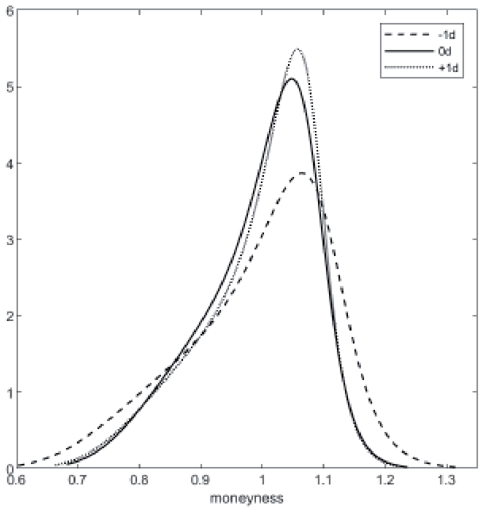
Table 7: Alternative identification restrictions

Variable/Shocks	Monetary policy	Demand	Supply	Uncertainty	Undefined
Inflation	+	+	-		
Output	+	+	+		
CB total assets	+			+	
Risk				+	
Policy rate	0	0	0		

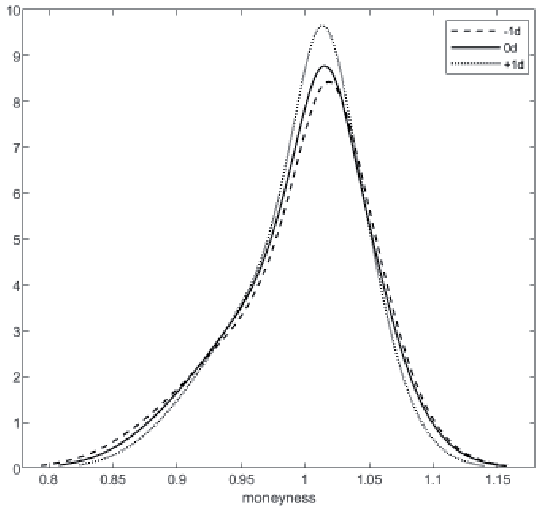
Notes: Zero restrictions are imposed on impact, while sign restrictions are imposed on impact and the first month after the shock, except for the case of inflation and output for the UMP shock. In this specific case, sign restrictions are imposed on the first and second month after the shock.

Figure 1: RNDs on relevant UMP announcement dates

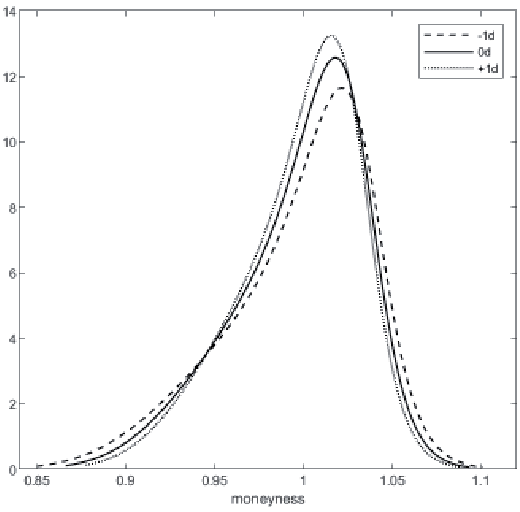
(a) EuroStoxx50 - May 10, 2010



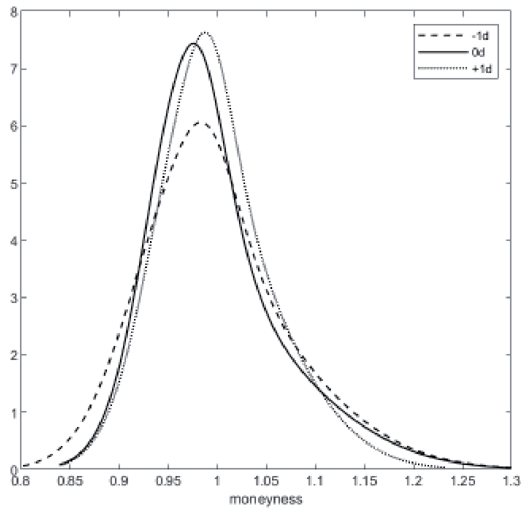
(b) S&P500 - November 3, 2010



(c) FTSE100 - August 4, 2016

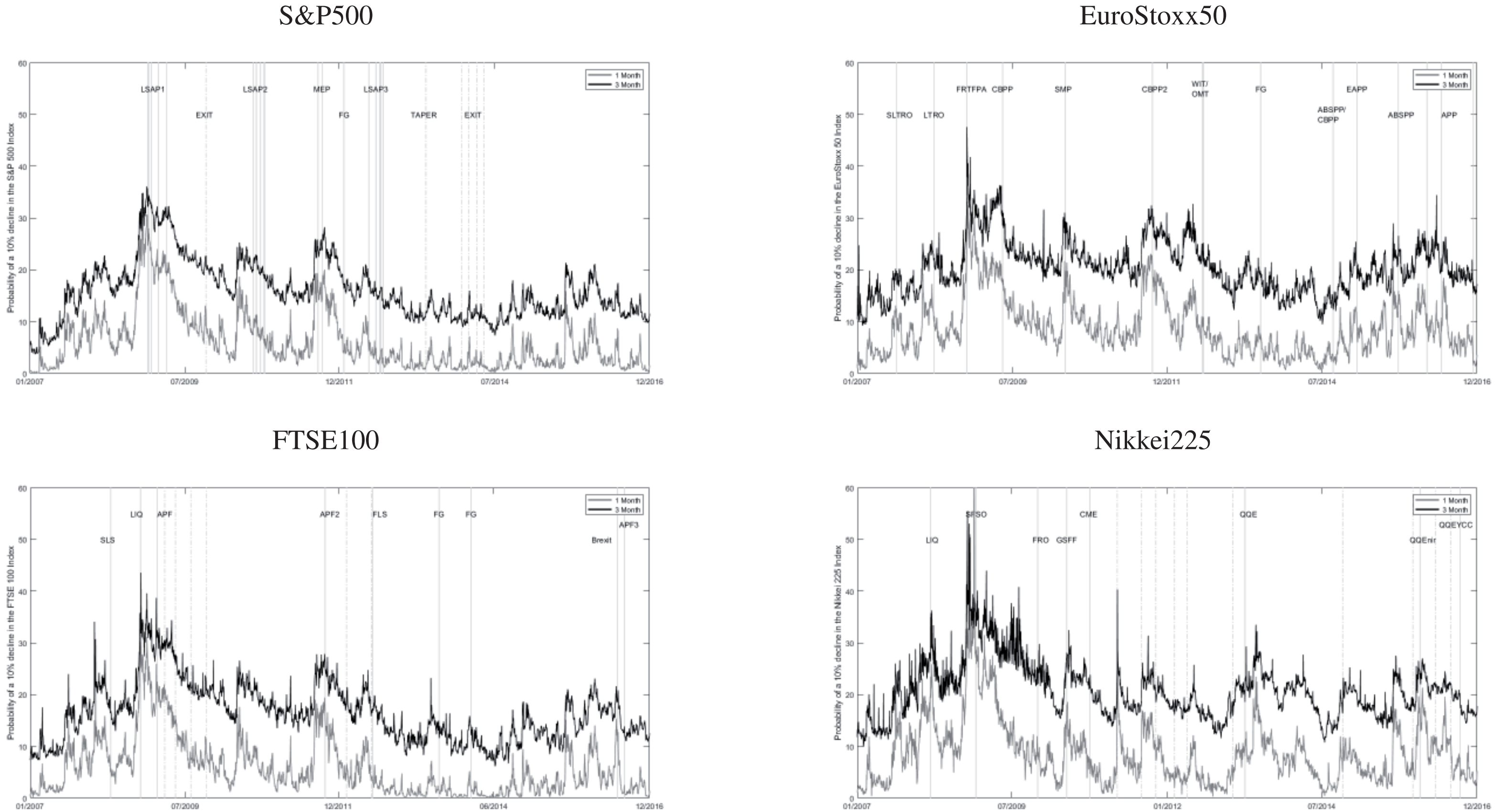


(d) Nikkei225 - September 21, 2016



Changes in RNDs on given UMP announcement dates by moneyness degree. The figures show the corresponding stock index implied RND on the date of the announcement (solid line) and the days before (dashed) and after (dotted). Graph (a) corresponds to the SMP announcement by the ECB on May 10, 2010; graph (b) represents the notification of the LSPA2 program by the Fed on November 3, 2010; graph (c) corresponds to the communication of CBPS and APF3 programs by the BoE on August 4, 2016; and graph (d) represents the QQE program of the BoJ announced on September 21, 2016. All program acronyms are provided in Appendix B.

Figure 2: Option-implied probabilities of a 10% decline in stock index at different horizons

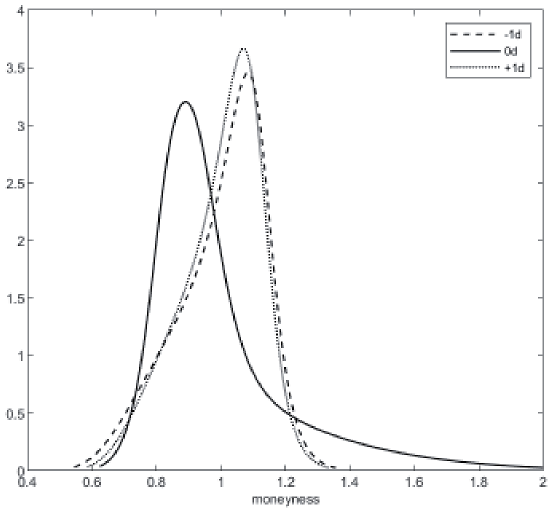


Time series of option-implied probabilities of a 10% decline in the stock market index at the 1-month (gray line) and 3-month (black line) horizon. Vertical lines represent UMP announcements of their respective central banks. The data frequency is daily and spans from January 2007 to December 2016. See Appendix B for acronyms.

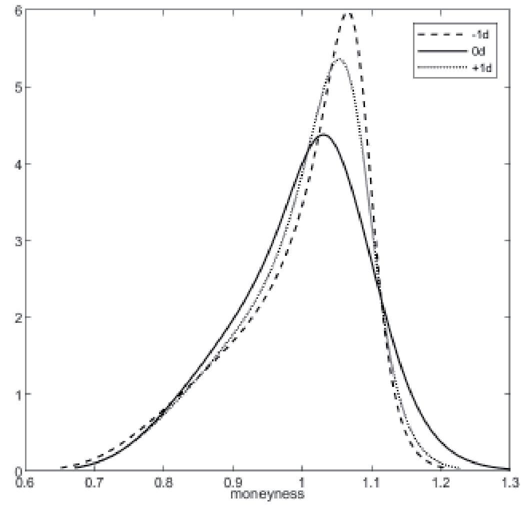
Figure 3: RNDs of different indexes to Fed announcements

Panel A.- Expansionary UMPs

EuroStoxx50 - November 26, 2008

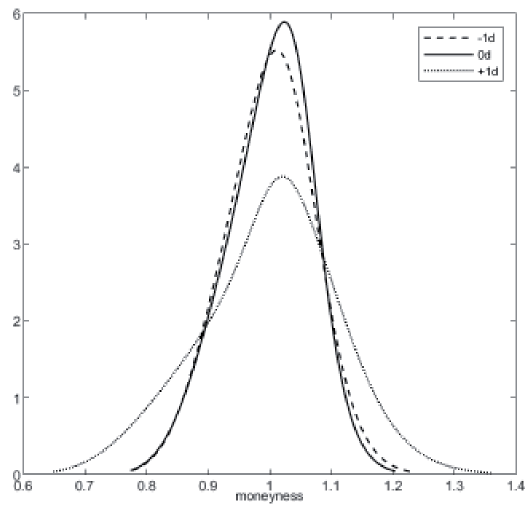


EuroStoxx50 - August 29, 2011

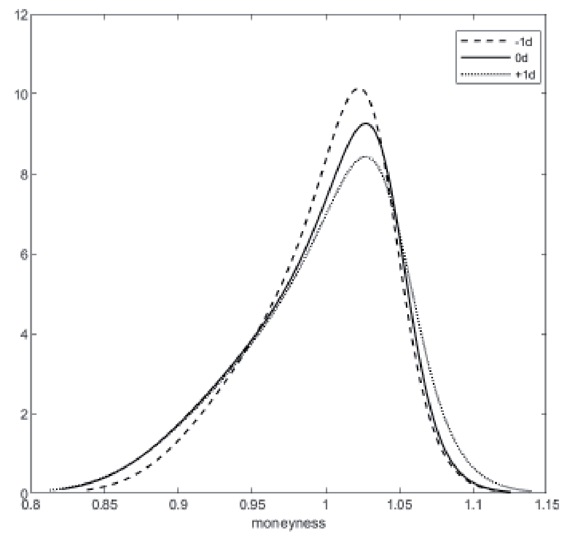


Panel B.- Contractionary UMPs

Nikkei 225 - May 22, 2013

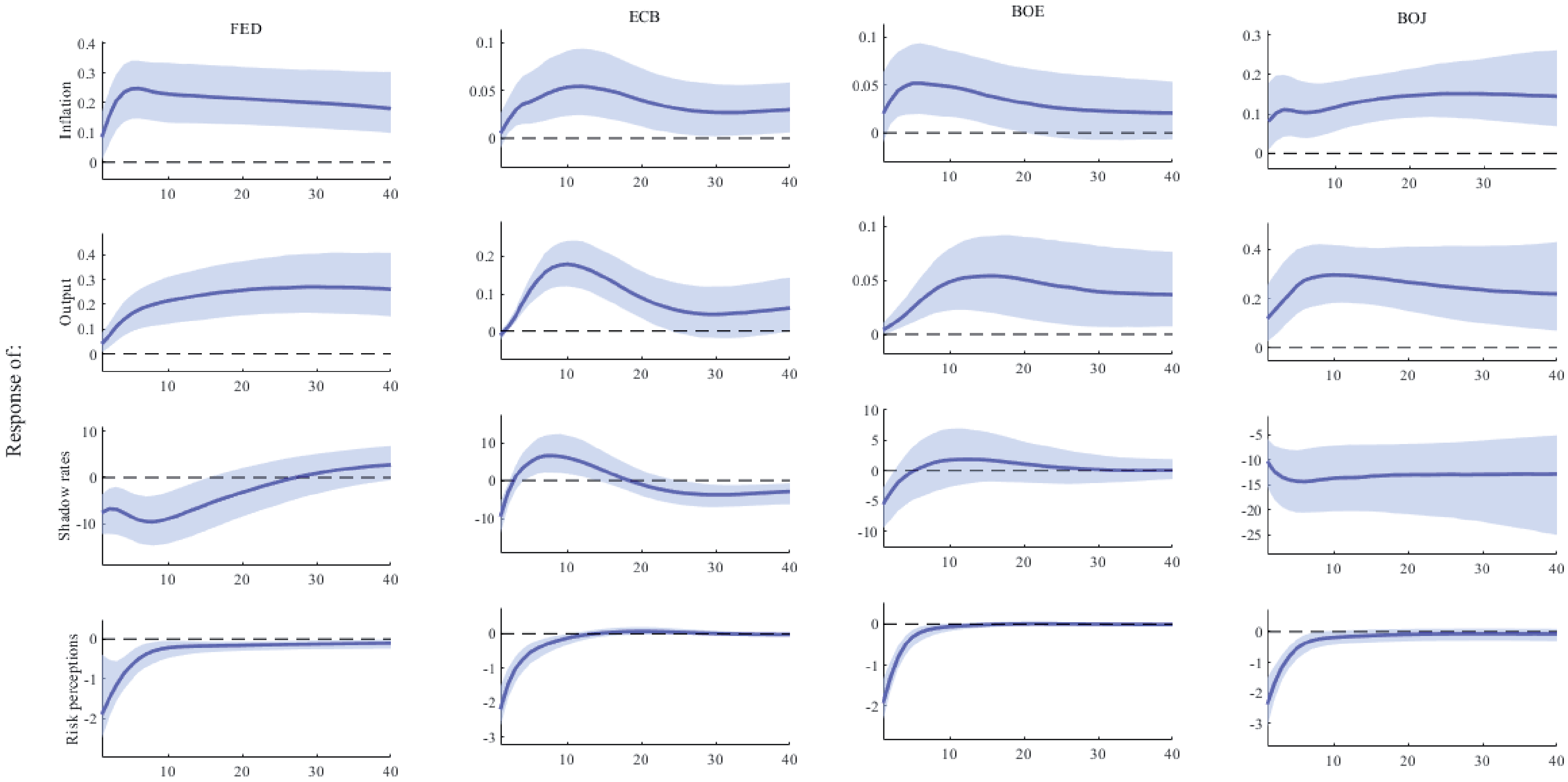


EuroStoxx50 - June 19, 2013



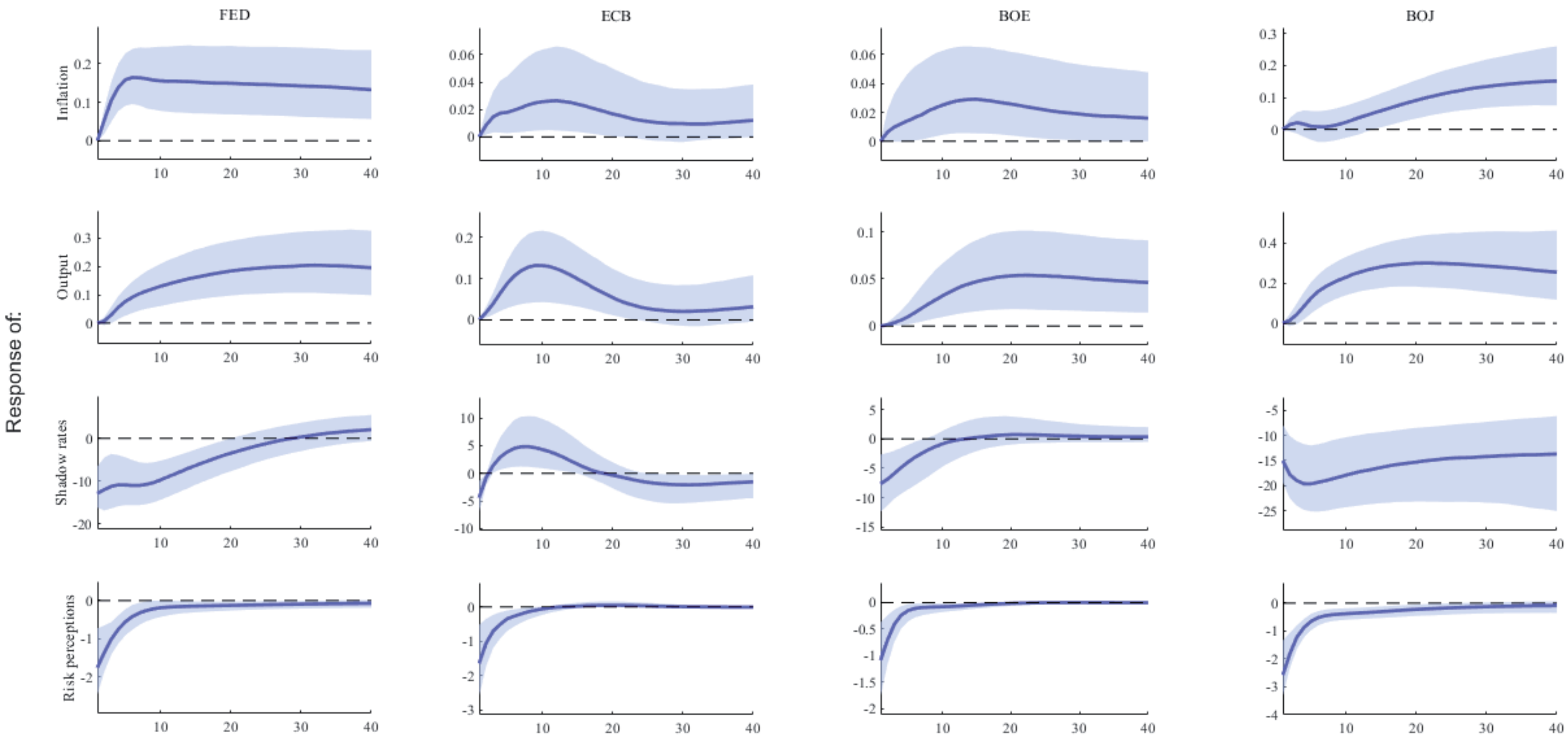
Changes in RNDs on given Fed UMP announcement dates. The figures show the corresponding stock index's implied RND on the date of the arrival of the announcement (solid line) and the days before (dashed) and after (dotted). The figures are grouped according to the nature of UMP measure taken: expansionary (Panel A) and contractionary (Panel B). The graphs corresponds to the following: i) the purchase of $500 billion in agency mortgage-backed securities (LSAP1) on November 25, 2008 (upper-left graph); ii) Fed Chairman Ben Bernanke's speech at Jackson Hole on August 26, 2011 (upper right); iii) Bernanke's allusion to "drawbacks of persistently low rates..." on May 22, 2013 (bottom left); and iv) the FOMC press conference where the Fed sketched an end to its stimulus on June 19, 2013 (bottom right). All program acronyms are provided in Appendix B.

Figure 4: Impulse-response functions to UMP shocks



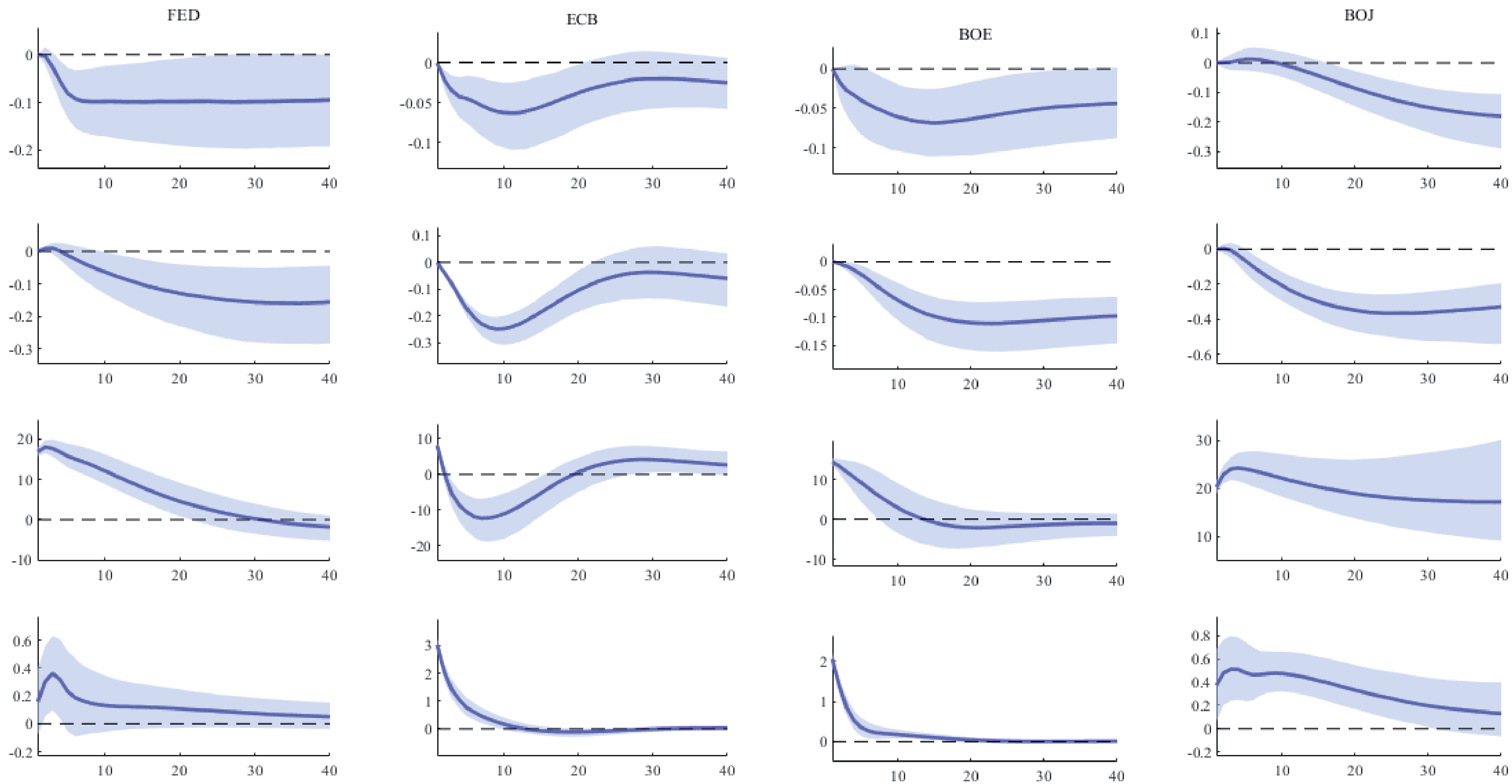
Impulse-response functions (IRFs) to expansionary UMP shocks. The figure depicts the response of the economic variables under study to an (expansionary) UMP shock of one standard deviation. Each row corresponds to an economic variable: inflation, output, shadow rates and risk perceptions. The different economic areas are organized in columns. Each chart displays the median of the posterior distribution (solid line) and the 68 percent credibility interval (shaded area).

Figure 5: Impulse-response functions to UMP shocks under alternative sign restrictions



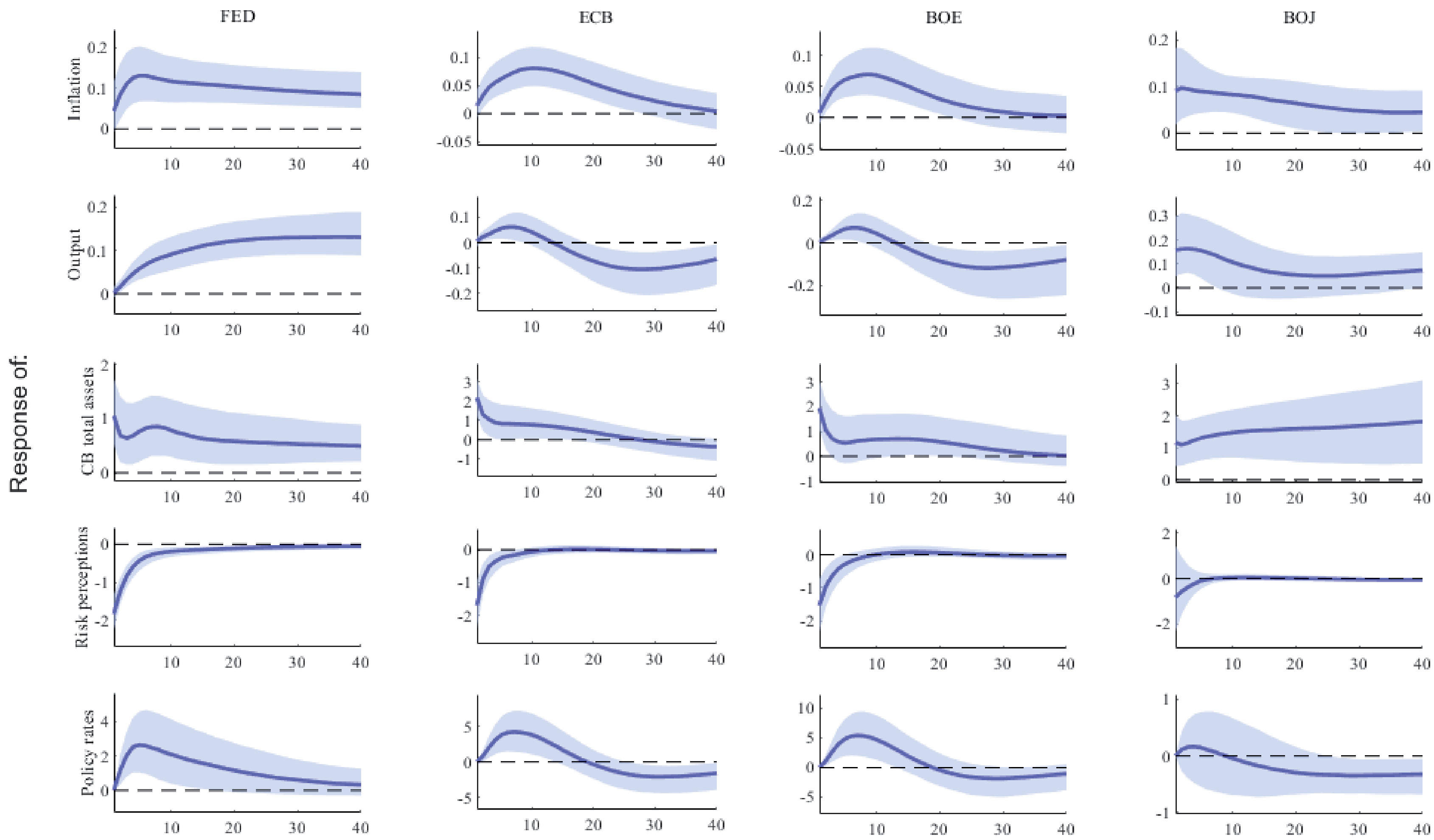
Impulse-response functions (IRFs) to expansionary UMP shocks under alternative sign restrictions. The figure shows the response of the economic variables under study to an (expansionary) UMP shock of one standard deviation. Each row corresponds to an economic variable: inflation, output, shadow rate and risk perceptions. The different economic areas are organized in columns. Each chart displays the median of the posterior distribution (solid line) and the 68 percent credibility interval (shaded area).

Figure 6: Impulse-response functions to UMP shocks under Cholesky decomposition



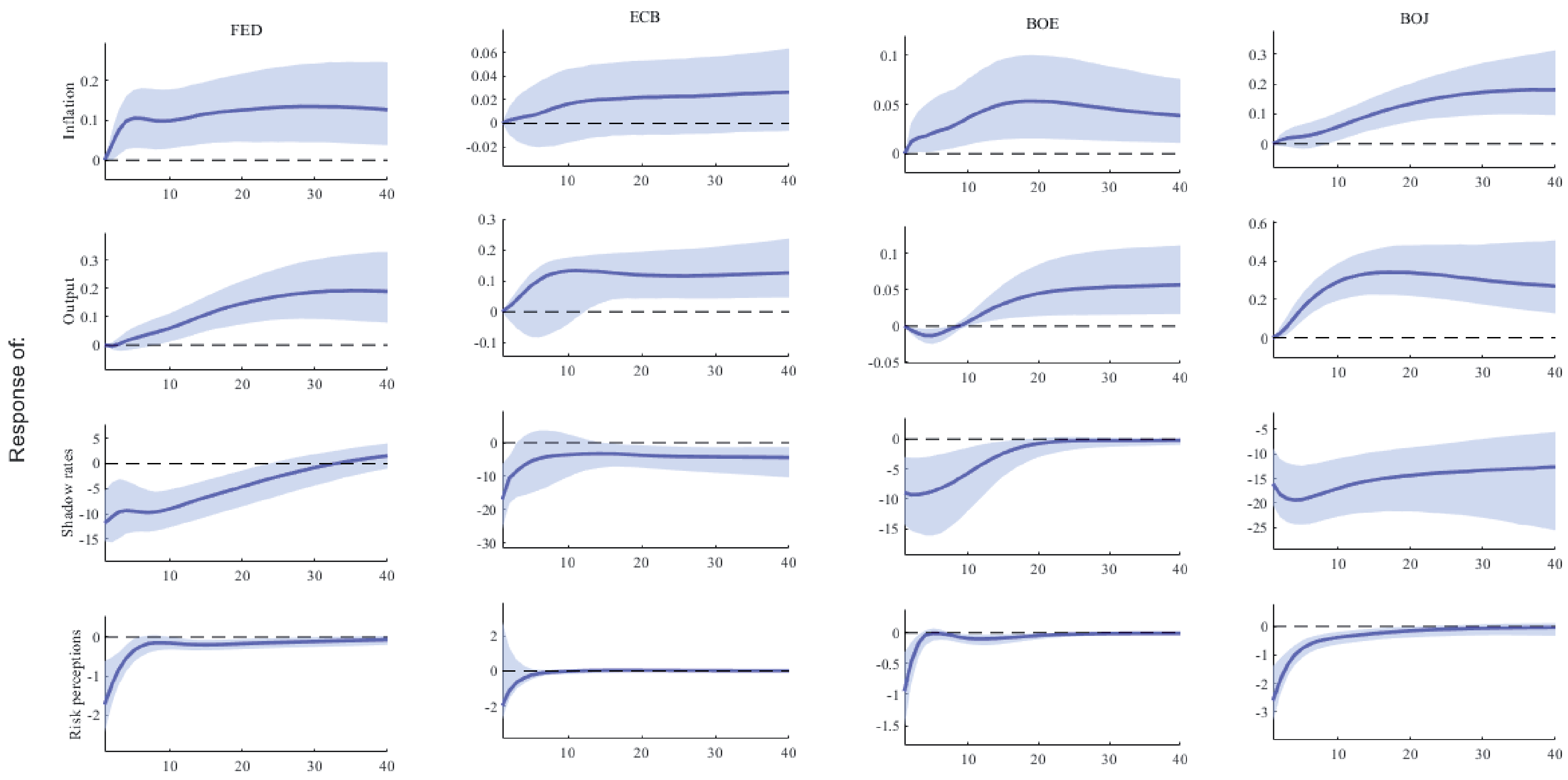
Impulse-response functions (IRFs) to contractionary UMP shocks under a Cholesky decomposition of the variance-covariance matrix of the SVAR model. The figure shows the response of the economic variables under study to a (contractionary) UMP shock of one standard deviation. Each row corresponds to an economic variable: inflation, output, shadow rates and risk perceptions. The different economic areas are organized in columns. Each chart displays the median of the posterior distribution (solid line) and the 68 percent credibility interval (shaded area).

Figure 7: Impulse-response functions to UMP shocks with balance sheet data



Impulse-response functions (IRFs) to expansionary UMP shocks using balance sheet data. The figure shows the response of the economic variables under study to an (expansionary) UMP shock of one standard deviation. Each row corresponds to an economic variable: inflation, output, shadow rates and risk perceptions. The different economic areas are organized in columns. Each chart displays the median of the posterior distribution (solid line) and the 68 percent credibility interval (shaded area).

Figure 8: Impulse-response functions to UMP shocks for the 2008-2016 subsample



Impulse-response functions (IRFs) to expansionary UMP shocks for the 2008-2016 subsample. The figure shows the response of the economic variables under study to an (expansionary) UMP shock of one standard deviation. Each row corresponds to an economic variable: inflation, output, shadow rates and risk perceptions. The different economic areas are organized in columns. Each chart displays the median of the posterior distribution (solid line) and the 68 percent credibility interval (shaded area).

Appendix A. Extraction of the RNDs

In this article, we use a nonparametric approach to extract RNDs from implied volatility surfaces provided by OptionMetrics. A clear advantage of the use of a nonparametric approach is that we avoid any restriction on the shape of the RND, a convenient feature for our analysis, which is focused on the left tail of the RND.

The seminal work of Breeden and Litzenberger (1978) shows that the second derivative of the price of a call with respect to the strike is equivalent to the risk-neutral probability.[21] The price of a call option is the discounted risk-neutral expectation of the payoff of the option on the expiration date T,

$$C = e^{-rT} E^{Q}[S_T - X] \,, \tag{A.1}$$

where C stands for the call price, S_T is the price of the underlying asset on the expiration date T and X represents the exercise price. Expression (A.1) can be written as follows:

$$C = e^{-rT} \int_X^{\infty} [S_T - X] f_Q(S_T) dS_T \,, \tag{A.2}$$

were f_Q is the risk-neutral probability density and F_Q stands for the risk-neutral distribution function. Taking the partial derivative with respect to the strike prices in equation (A.2) and solving for the risk-neutral distribution $F_Q(X)$, we obtain

$$F_Q(X) = e^{rT} \frac{\delta C}{\delta X} + 1 \,. \tag{A.3}$$

Finally, the derivative with respect to the strike price in expression (A.3) yields the risk-neutral density function:

$$f_Q(X) = e^{rT} \frac{\delta^2 C}{\delta^2 X} \,. \tag{A.4}$$

To construct a smooth RND according to equation (A.4), we ideally need a continuum of strike prices encompassing future payoffs. Unfortunately, option prices are discrete, and exercise prices for traded option contracts may be far apart. Then, some sort of interpolation is required to soften price noise.

As we have mentioned, in our estimations, we employ the implied volatility surfaces provided by OptionMetrics. For a certain date, these files consist of a grid of Black-Scholes-Merton implied volatilities (σ^{bsm}) for different standardized maturities (30, 60, 91 days, ...) and for different values of delta, Δ. The Δs range from 0.2 to 0.8, spaced in intervals of 0.05, resulting in approximately 13 points. We follow Malz (1997), who suggests to interpolate/extrapolate option prices (implied volatilities) in the Δ domain,

[21] See Jackwerth (1999) for a review of methodologies to extract risk-neutral densities from option prices.

instead of in the moneyness domain. The main advantage of this procedure is that the Δ domain for call options is bounded between 0 and 1, whereas moneyness is unbounded.

The first step consists of extrapolating the implied volatility function. Some valuable information in the extremes of the distribution could be lost by restricting the delta range; thus to address this potential scarcity of data, in line with Bliss and Panigirtzoglou (2004), we add two additional pseudo-points on both tails of the smile, with a space of 0.05 Δs, and assign to them the closest observed *delta*. As a result, the number of observations used for extracting RNDs increases from 13 to 17.

In the second step, given the 17 pairs $\left(\Delta_i,\ \sigma_i^{bsm}\right)$, we fit a cubic smoothing spline, and we evaluate it for a thinner range of 1,000 Δ points. The cubic smoothing spline is

$$S_\lambda = \sum_{i=1}^{n} m_i(\sigma_i^{bsm} - g(\Delta_i, \theta))^2 + \lambda \int_{-\infty}^{+\infty} p^{''}(x;\theta)^2 dx\,, \tag{A.5}$$

where m_i is a given weight of the squared error; σ_i^{bsm} and $g(\Delta_i, \theta)$ are the empirical and fitted implied volatilities of the ith option, respectively; θ is a parameter vector that defines the smoothing spline ($p(x, \theta)$) and whose coefficients are calculated by OLS without imposing any shape; and finally, λ is a smoothing parameter that balances the smoothness of the spline and its goodness-of-fit, and it is fixed to 0.9.

In the third stage of our procedure, *delta*s are converted into exercise prices (moneyness), and the interpolated volatilities are converted into call prices using the Black-Scholes-Merton formula.

Finally, equation A.4 is estimated by finite-differences using the interpolated values of moneyness and call prices.

Appendix B. Acronyms for UMP programmes

Table B.8: Acronyms for UMP programmes

Acronym	Definition
Liq	Liquidity
LSAP	Large Scale Asset Purchases
MEP	Maturity Extension Programme
FG	Forward Guidance
TAPER	Taper Tantrum
SLTRO	Supplementary Longer-term Refinancing Operations
LTRO	Long-term Refinancing Operations
FRTFA	Fixed-rate Tenders with Full Allotment
SMP	Securities Market Programme
CBPP	Covered-Bond Purchase Programme
WIT	"Whatever it takes" speech of ECB president Mario Draghi
OMT	Outright Monetary Transactions
ABSPP	Asset-Backed Securities Purchase Programme
EAPP	Expanded Asset Purchase Programme
APP	Asset Purchase Programme
SLS	Special Liquidity Scheme
APF	Asset Purchase Facility
FLS	Funding Lending Scheme
SFSO	Special Funds Supplying Operations
GSFF	Growth-Supporting Funding Facility
CME	Comprehensive Monetary Easing
QQE	Quantitative and Qualitative monetary Easing
QQEnir	QQE with negative interest rates
QQEYCC	QQE with Yield Curve Control scheme

Appendix C. List of UMP announcements

This paper covers an extensive number of announcements of unconventional monetary policies. More than 160 events are identified from 2007 to 2016, mostly including new announcements on press conferences, press releases and statements of the FOMC, the Government Council of the ECB, the Monetary Policy Committee of the BoE and the Policy Board of Bank of Japan. This dataset also includes some announcements from a few speeches such as the "Whatever it takes" speech of the former ECB President Draghi. All this information have been tracked from the websites of the four central banks, which constitute our major sources of information. We have also checked the information provided in relevant papers cited in this document, such as Falagiarda, McQuade and Tirpák (2015) and Altavilla et al. (2015).

In order to capture the "relevant announcements", we only include those announcements that reveal new information. The number of total announcements per central banks is relatively even. The Bank of Japan made over the period analyzed the major number of announcements (52), while the Bank of England announced 34 measures. The Fed made 37 announcements and the ECB 41 over the period analyzed. A more difficult task is the aggregation of these announcements by type of measure: liquidity, asset purchases and forward guidance. This is due to the fact that different types of measures have been announced on the same day. In this case, only the most unexpected and novel measure is considered. Some robustness checks have also been carried out without big impact on the results. For further information, see tables C.9,C.10, C.11 and C.12 that provide all the announcements covered in this paper.

Table C.9: Dates of UMP measures for Federal Reserve

Date	Announcement	Measure
17/08/2007	Term Discount Window Program's announcement	Liquidity
12/12/2007	Term Auction Facility 's announcement and Reciprocal Currency Agreements	Liquidity
11/03/2008	Term Securities Lending Facility and Single-Tranche OMO programme	Liquidity
19/09/2008	ABCP Money Market Fund Liquidity Facility (CPFF)	Liquidity
25/11/2008	Purchase $100 billion of agency debt and $500 billion agency mortgage-backed securities	LSAP1

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Table C.9 – *Continued from previous page*

Date	Announcement	Measure
16/12/2008	"The Committee anticipates that weak economic conditions are likely to warrant low levels of federal funds rate for some time" 0-25 bp Fed funds rate target; possibility of long-term Treasury purchases.	FG
28/01/2009	Expansion of QE to include long-term Treasuries	LSAP1
18/03/2009	Expansion of QE: $300 billion in Treasuries, $750 billion of agency MBS, increase holdings of agency debt to $200 billion; low federal funds rate for an extended period	LSAP1
12/08/2009	Slow pace of purchases. All purchases will be finished by the end of October, not mid-September	LSAP1 EXIT
23/09/2009	Gradually slow pace of purchases. Agency debt and MBS purchases will finish at the end of 2010Q1	LSAP1EXIT
04/11/2009	Limit agency debt purchases below previously announced $200 billion. Agency debt purchases will finish at $175 billion	LSAP1/EXIT
10/08/2010	BS will be maintained.Reinvest MBS principal into Treasuries; low rates for an extended period.	LSAP1
27/08/2010	Bernanke speech at Jackson Hole, mentioning potential additional purchases of long-term securities.	LSAP2
15/10/2010	Bernanke speech at Boston Fed: prepared for more policy accommodation if needed.	LSAP2
03/11/2010	Purchase of a further $600 billion of longer term Treasuries.	LSAP2
22/06/2011	QE2 finishes: treasury purchases will wrap up at the end of the month, as scheduled; principal payments will continue to be reinvested.	LSAP2/ EXIT
09/08/2011	Growth slower than expected; low fed funds rate at least until mid-2013.	FG
26/08/2011	Bernanke speech at Jackson Hole	FG
21/09/2011	MEP using $400 billion Treasury securities announced.	MEP
25/01/2012	FOMC meeting: Low federal funds rate at least until late 2014.	FG
20/06/2012	FOMC meeting: MEP extended until end-2012; low federal funds rate through late 2014.	MEP
31/08/2012	Bernanke speech, Jackson Hole, Wyoming.	LSAP3

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Table C.9 – *Continued from previous page*

Date	Announcement	Measure
13/09/2012	FOMC meeting: Fixed monthly MBS and Treasury purchases; mid-2015 rate guidance.	LSAP3
12/12/2012	FOMC meeting: 6,5% unemployment threshold introduced in the rate guidance.	LSAP3
22/05/2013	Bernanke alludes to "drawbacks of persistently low rates..."	TAPER
19/06/2013	FOMC statement offers no clarification to the Chairman's May speech.	TAPER
18/12/2013	Cut monthly purchases of MBS and Treasuries to $35 billion and $40 billion. Unemployment rate threshold of 6,5% for lift-off abandoned.	EXIT
29/01/2014	Cut monthly purchases of MBS and Treasuries to $30 billion and $35 billion.	EXIT
19/03/2014	Cut monthly purchases of MBS and Treasuries to $25 billion and $30 billion.	EXIT
30/04/2014	Cut monthly purchases of MBS and Treasuries to $20 billion and $25 billion.	EXIT
18/06/2014	FOMC statement: Cut monthly MBS and Treasuries purchases to $15 and $20 billion	EXIT
30/07/2014	FOMC statement: Cut monthly MBS and Treasuries purchases to $10 and $15 billion	EXIT
17/09/2014	FOMC statement: Cut monthly MBS and Treasuries purchases to $5 and $10 billion	EXIT
29/10/2014	FOMC statement: "The Committee decided to conclude its asset purchase program this month"	EXIT
18/03/2015	"an increase in the target range for the federal funds rate remains unlikely at the April FOMC meeting"	FG
28/10/2015	FOMC statement. It mentions probability of raising interest rates in the next meeting.	FG
16/12/2015	FOMC statement: "only gradual increases in the federal funds rate. The federal funds rate is likely to remain, for some time, below levels that are expected to prevail in the longer run."	FG

Table C.10: Dates of UMP measures for European Central Bank

Date	**Announcement**	**Measure**
22/08/2007	Announcement of Supplementary LTROs with a maturity of months	LTRO
12/12/2007	Reciprocal currency agreements	RCA
28/03/2008	Supplementary 6-month LTROs	LTRO
07/10/2008	Enhance LTROs and expand US dollar liquidity providing operations	LTRO
08/10/2008	Announcement of a fixed rate tender procedure with full allotment on MROs	FRTPFA
15/10/2008	Expansion of the list of assets eligible as collateral, enhance the provision of LTROs and provide US dollar liquidity through foreign swaps.	LTRO
18/12/2008	MROs will continue to be carried out through FRTFA for as long as needed.	FRTPFA
07/05/2009	Announcement of CBPP with an initial amount of 60 mm E and LTROs with a maturity of one year.	CBPP/LTRO
04/06/2009	Details of technical modalities of CBPP1	CBPP
03/12/2009	Enhancement of the provision of LTROs and continue conducting MROs as FRTFA for as long as needed	FRTPFA/LTRO
04/03/2010	Enhancement of the provision of LTROs and continue conducting MROs as FRTFA for as long as needed	FRTPFA/LTRO
10/05/2010	Announcement of Securities Market Programme (SMP)	SMP
04/08/2011	Further LTROs with a maturity of and months	LTRO
08/08/2011	The GovC decided to actively implement its SMP for Italy and Spain	SMP
06/10/2011	New Covered Bond Purchase Programme (CBPP2) for an intended amount of 40billion.	CBPP
03/11/2011	Technical modalities of CBPP2	CBPP
08/12/2011	The GovC decided to conduct 2 LTROs with a maturity of 3 years and to increase collateral availability.	LTRO
06/06/2012	FRTPFA for as long as necessary, and to conduct 3-month LTROs and FRTPFA, at least until January 2013	FRTPFA/LTRO
26/07/2012	Draghi’s London speech "whatever it takes..."	FG/OMT

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Table C.10 – *Continued from previous page*

Date	Announcement	Measure
02/08/2012	Announcement of outright open market operations (OMT) of a size adequate to reach its objective.	OMT
06/09/2012	Technical details of OMTs	OMT
06/12/2012	FRTPFA for as long as necessary, and to conduct 3-month LTROs as FRTPFA, at least until July 2013	FRTPFA/LTRO
02/05/2013	FRTPFA for as long as necessary, and at least until July 2014	FRTPFA/LTRO
04/07/2013	The GovC expects the key ECB interest rates to remain at present or lower levels for an extended period of time	FG
07/11/2013	FRTPFA for as long as necessary, and at least until July 2015.	FRTPFA/LTRO
05/06/2014	Targeted long-term refinancing operations (T-LTROs)	TLTRO
03/07/2014	Technical details for the series of TLTROs	TLTRO
29/07/2014	ECB publishes legal act relating to T-LTROs	TLTRO
04/09/2014	Announcement of purchases of ABS (ABSPP) and a broad portfolio of euro-denominated covered bonds issued by MFIs (CBPP3)	ABSPP/CBPP
02/10/2014	Operational details of ABSPP and CBPP3. it will last two yeas	ABSPP/CBPP
17/11/2014	"The GovC is unanimous in its commitment to using additional unconventional instruments [â] Unconventional measures might entail the purchase of a variety of assets, one of which is sovereign bonds" (M. Draghi's speech at the EP)	APP
26/11/2014	"we will have to consider buying other assets, including sovereign bonds in the secondary market [â]" (V. Constancio, London)	APP
04/12/2014	"Evidently, we are convinced that a QE programme which could include sovereign bonds falls within our mandate" (Draghi's press conference)	APP
22/01/2015	Announcement of the expanded asset purchase programme (EAPP).	APP
03/12/2015	Extension of EAPP until the end of March 2017, or beyond, if necessary.	APP
10/03/2016	Increase of monthly purchases to 80 billion euros (EAPP) (from 60bn) and inclusion of a new Corporate Sector Purchase Programme (CSPP)	APP

Continued on next page

Table C.10 – *Continued from previous page*

Date	Announcement	Measure
21/04/2016	Technical details of the corporate sector purchase programme (CSPP).	APP
02/06/2016	The Eurosystem will start making purchases under its corporate sector purchase programme (CSPP).	APP
21/07/2016	"The Governing Council confirms that the monthly asset purchases of 80 billion euros are intended to run until the end of March 2017, or beyond, if necessary, and in any case until it sees a sustained adjustment in the path of inflation consistent with its inflation aim."	FG
20/10/2016	"The Governing Council continues to expect the key ECB interest rates to remain at present or lower levels for an extended period of time, and well past the horizon of the net asset purchases.Â´Â´	FG
08/12/2016	"The GC decided to continue its purchases under the asset purchase programme (APP) at the current monthly pace of 80 billion euros until the end of March 2017. From April 2017, the net asset purchases are intended to continue at a monthly pace of 60 billion euros until the end of December 2017, or beyond, if necessary"	APP

Table C.11: Dates of UMP measures for Bank of England

Date	Announcement	Measure
12/12/2007	Reciprocal currency agreements, announced by five central banks	Liquidity
21/04/2008	Special liquidity Scheme	Liquidity
17/09/2008	Extension of the Special liquidity Scheme	Liquidity
03/10/2008	Extended collateral long term repo operations	Liquidity
13/10/2008	Further us dollar liquidity operations	Liquidity
19/12/2008	US dollar operations	Liquidity
19/01/2009	The Chancellor of the Exchequer announces the BoE will set up an APF.	APF/QE1
03/02/2009	Extension of swap facility and info about SLS	Liquidity
06/02/2009	Details about app	APF/QE1
05/03/2009	APF announcement: £75 billion of gilts	APF/QE1
07/05/2009	APF extended to £125 billion.	APF/QE1
06/08/2009	APF extended to £175 billion	APF/QE1
05/11/2009	APF extended to £200 billion.	APF/QE1
10/05/2010	Reactivation of US dollar swap facility	Liquidity
17/12/2010	ECB swap line agreement	Liquidity
21/12/2010	Extension of US dollar swap facility	Liquidity
15/09/2011	Additional US dollar liquidity providing operation over year on year	Liquidity
06/10/2011	APF extended to £275 billion.	APF/QE2
09/02/2012	APF extended to £325 billion.	APF/QE2
05/07/2012	APF extended to £375 billion.	APF/QE2
13/07/2012	The Bank and Treasury launch the Funding for Lending Scheme (FLS).	FLS
12/09/2012	Extension of swap facility agreement with ECB	Liquidity
24/04/2013	Extension of the FLS until January 2015	FLS
07/08/2013	The BoE "expects not to raise Bank Rate from 0,5% at least until unemployment falls below 7%"	FG
16/09/2013	Extension of the swap facility agreement with the BOE/ECB	Liquidity
28/11/2013	The Bank and Treasury re-focus the FLS to support business lending in 2014	FLS

Continued on next page

Table C.11 – *Continued from previous page*

Date	Announcement	Measure
09/01/2014	"Members therefore saw no immediate need to raise Bank Rate even if the 7% unemployment threshold were to be reached in the near future"	FG
16/01/2014	The BOE launched a new regular market-wide Indexed Long-Term Repo (ILTR) operation	Liquidity
12/02/2014	"Despite the sharp fall in unemployment there remains scope to absorb spare capacity further before raising Bank Rate" and the "path of Bank Rate over the next few years will, however, depend on economic developments".	FG
12/06/2014	Widening access to the Sterling Monetary Framework broker-dealers and central counterparties	Liquidity
05/11/2014	Widening access to the Sterling Monetary Framework broker-dealers and central counterparties	Liquidity
02/12/2014	BOE and Treasury announce extension to the FLS	FLS
30/11/2015	BOE and Treasury announce a two-year extension to the FLS	FLS
23/06/2016	Brexit vote.	Brexit
04/08/2016	Introduction of a Term Funding Scheme, the purchase of non-financial investment-grade corporate bonds of up to £10 billion (CBPS) and increase the stock of purchased UK government bonds by £60 billion to a total of £435 billion. (APF 3)	APF/QE3

Table C.12: Dates of UMP measures for Bank of Japan

Date	Announcement	Measure
12/12/2007	Reciprocal currency agreements, announced by five central banks	Liquidity
14/10/2018	Measures to improve liquidity in the JGB repo market and expansion of US dollar funds supplying operations	Liquidity
31/10/2008	Complementary deposit facility	Liquidity
02/12/2008	Special Fund Supplying Operation	SFSO
19/12/2008	Increase JGB purchases	JGB/CFI purchases
22/01/2009	Purchase up to 3 trillion yen in commercial paper and ABCP. Outright purchases (CPs, corp bonds)	JGB/CFI purchases
19/02/2009	Expansion of Special Funds-Supplying Operations and details on corporate bonds	JGB/CFI purchases
18/03/2009	Increase of outright purchases of Japanese government bonds (from 16.8 trillion yen per year to 21.6 trillion yen per year	JGB/CFI purchases
26/06/2009	Extension of temporary reciprocal currency arrangements	Liquidity
15/07/2009	Extension of commercial paper.	JGB/CFI purchases
14/10/2009	Amendment to "Guidelines on Eligible Collateral"	Liquidity
30/10/2009	Extension of the programme.	SFSO
01/12/2009	New funds-supplying operation (offer 10 trillion yen in 3month loans)	FRO
18/12/2009	Clarification of the "Understanding of Medium- to Long-Term Price Stability"	FG
17/03/2010	Expansion of the size of fixed-rate funds supplying operations to 20 trillion yen	FRO
21/05/2010	Preliminary framework for the fund provisioning measure to facilitate strengthening of the foundations for economic growth Fund-Provisioning. GSFF (offer 3 trillion yen in 1-year loans	GSFF
15/06/2010	Information about GSFF	GSFF
30/08/2010	Introduction of a six-month term in the fixed-rate funds-supplying operation (10 additional trillion)	FRO
05/10/2010	Announcement of Comprehensive monetary easing	CME
05/11/2010	Details of purchases of ETFs and J-REITs	CME
21/12/2010	Extension of temporary US dollar liquidity swap arrangements	Liquidity
14/03/2011	APP extended by about 5 trillion yen to 40tr	CME

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Table C.12 – *Continued from previous page*

Date	Announcement	Measure
28/04/2011	Outline for the Funds-Supplying Operation to Support Financial Institutions in Disaster Areas	Liquidity
14/06/2011	GSFF. Expand another 0.5 trillion loans	GSFF
04/08/2011	APP extended by about 10 trillion yen to 50tr	CME
27/10/2011	APP extended by about 5 trillion yen to 55tr. JGB	CME
14/02/2012	APP extended by about 10 trillion yen to 65tr	CME
13/03/2012	GSFF- increase by 2 trillion yen from 3.5 tr yen to 5.5	GSFF
10/04/2012	A New U.S. Dollar Lending Arrangement Established as part of the "Fund-Provisioning Measure to Support Strengthening the Foundations for Economic Growth"	Liquidity
27/04/2012	APP extended by about 5 trillion yen to 70tr	CME
19/09/2012	APP extended by about 10 trillion yen to 80tr	CME
05/10/2012	Amendment on collateral	Liquidity
30/10/2012	APP extended y about 11 trillion yen to 91tr	CME
20/12/2012	APP extended by about 10 trillion yen to 101tr	CME
22/01/2013	Introduction of the price stability target and the open-ended asset purchasing method. APP extended to 13tr monthly	CME
04/04/2013	Introduction of the QQE. Purchase of different kinds of assets, targeting a doubling of the monetary base by 2014.	QQE
18/02/2014	Double GSFF and SBLF and extend their applications one year	GSFF/ SBLF
11/03/2014	Changes for the loan support programme	Liquidity
21/05/2014	(QQE) has been exerting its intended effects, and the Bank will continue with it, aiming to achieve the price stability target of 2 percent, as long as it is necessary for maintaining that target in a stable manner"	FG
31/10/2014	QQE expansion: accelerating JGB's purchase, extending its average remaining maturity and triple ETF and JREIT purchase	QQE
19/11/2014	QQE: the monetary base will increase at an annual pace of about 80 trillion yen.	QQE
21/01/2015	Extension of GSFF and SBLF and FRO for disaster for 1 year and increase of the amount to GSFF	GSFF/ SBLF
20/03/2015	Changes to securities lending facility	Liquidity

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Table C.12 – *Continued from previous page*

Date	Announcement	Measure
19/06/2015	New Framework for Monetary Policy Meetings: release and transparency	FG
07/10/2015	Amendment on eligible collateral	Liquidity
18/12/2015	QQE: extend the average maturity of JGB purchases and broaden the type of assets eligible to serve as collateral for central bank loans	QQE
29/01/2016	QQEnir: Apply a negative interest rate of minus 0,1 percent to part of the accounts that institutions hold at the Bank	QQEwnir
15/03/2016	Details on QQE with Negative Interest Rates operations	QQEwnir
11/04/2016	QQEnir:increase the ration applied to the portion of deposits exempt from negative rates to 2,5 percent from the initial zero	QQEwnir
28/04/2016	ETF increase in purchases up to 3.3tr/years	QQEwnir
29/07/2016	Increase ETF purchases up to 6tr/year and extend liquidity measures	QQEwnir
21/09/2016	QQE with Yield Curve Control scheme introduction.	QQEwYCC

Appendix D. Macroeconomic data releases

Table D.13: Macroeconomic data releases used in event-study. *Notes*: Sample period from January 2007 to December 2016. These are the indicators included in the event-study to control for relevant macroeconomic releases that can affect market players' perceptions. In the case of the US, UK and Japan, we only include the variables affecting this country, while for the Eurozone, we have chosen the most relevant indicators of the region (Euro area, France, Germany, Italy and Spain.

Area	Variable
US	Nonfarm payroll
US	Housing starts
US	New home sales
US	Existing home sales
US	Retail sales
US	Iinitial jobless claims
US	Unemployment rate
US	Business inventories
US	Factory orders
US	Construction spending
US	Consumer Price Index (CPI)
US	Gross Domestic Product
US	Industrial Production
Euro area	Consumer confidence. Euro Area
Euro area	CPI MoM. Euro Area
Euro area	Economic confidence. Euro Area
Euro area	GDP SA QoQ. Euro Area
Euro area	Industrial Production SA MoM. Euro Area
Euro area	Consumer confidence. France
Euro area	CPI YoY. France
Euro area	GDP QoQ. France
Euro area	Industrial Production MoM. France
Euro area	CPI MoM. Germany
Euro area	GDP SA QoQ. Germany
Euro area	IFO Business Climate. Germany
Euro area	Industrial Production SA MoM. Germany
Euro area	Unemployment rate. Germany

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Table D.13 – *Continued from previous page*

Area	**Variable**
Euro area	ZEW Survey Expectations. Germany
Euro area	CPI EU Harmonised YoY. Italy
Euro area	GDP WDA QoQ. Italy
Euro area	Industrial Production MoM. Italy
Euro area	GDP QoQ. Spain
Euro area	Unemployment rate. Spain
Euro area	CPI EU Harmonised YoY. Spain
UK	Consumer confidence
UK	Consumer Price Index (CPI)
UK	Gross Domestic Product
UK	Purchasing Manager's Index (PMI)
UK	Industrial Production
UK	Unemployment rate
UK	Retail sales
UK	House prices
Japan	Consumer Confidence Index
Japan	Consumer Price Index
Japan	Business Surveys
Japan	Industrial Production
Japan	Unemployment Rate
Japan	Gross Domestic Product
Japan	Retail Trade
Japan	Housing Starts

Appendix E. Event study. Additional checks.

Appendix E.1. Two-day window

Table E.14: UMP announcements and option-implied tail risks in the short run. Two-day window

Area	**Fed**		**ECB**		**BOE**		**BOJ**	
Variables	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$
UMP	-0.02	-0.08*	-0.04***	-0.13***	-0.04**	-0.09	0	-0.03
	[0.017]	[0.044]	[0.017]	[0.041]	[0.019]	[0.071]	[0.018]	[0.055]
News	0	-0.02**	0	0	-0.01**	-0.03**	-0.01	-0.02
	[0.003]	[0.010]	[0.003]	[0.008]	[0.005]	[0.016]	[0.008]	[0.028]
Observations	2,517	2,517	2,540	2,540	2,552	2,552	2,446	2,446

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the change in a two-day window in the option-implied probability of a τ = -5;-10 percent decrease in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period of 1 month. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in each area; see D.13 for more information. UMP in the rest of the areas are also controlled for. Newey West standard errors in brackets and *** p<0.01, ** p<0.05, * p<0.1

Table E.15: UMP and option-implied tail risks across different horizons. Two-day window

Area	**Fed**		**ECB**		**BOE**		**BOJ**	
Variables	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$
1-month	-0.02	-0.08*	-0.04***	-0.13***	-0.04**	-0.11*	0	-0.03
	[0.017]	[0.044]	[0.017]	[0.041]	[0.019]	[0.067]	[0.018]	[0.055]
2-month	-0.01	-0.03	-0.01	-0.04*	-0.03**	-0.04*	0	-0.01
	[0.009]	[0.019]	[0.013]	[0.022]	[0.010]	[0.023]	[0.014]	[0.026]
3-month	-0.01	-0.02	-0.01	-0.02	-0.02**	-0.03**	0.01	0.01
	[0.007]	[0.012]	[0.014]	[0.019]	[0.008]	[0.015]	[0.015]	[0.021]
Observations	2,517	2,517	2,540	2,540	2,552	2,552	2,446	2,4476

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the change in a two-day window in the option-implied probability of a τ = -5;-10 percent decline in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1 , 2 or 3 months. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details are provided in Appendix C. In all the regressions, other relevant macroeconomic releases ("News") and other UMP announcements in other areas have been controlled for, even if not reported in this table. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Appendix E.2. Details of disaggregated Event-Study Analysis

Table E.16: Fed. Event-study by type of UMP program

Variables	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,2}^{5\%}$	$\Delta F_{t,2}^{10\%}$	$\Delta F_{t,3}^{5\%}$	$\Delta F_{t,3}^{10\%}$
Liquidity	-0.04	-0.09**	-0.03*	-0.05***	-0.02	-0.04**
	[0.024]	[0.037]	[0.020]	[0.020]	[0.015]	[0.018]
LSAP1	-0.03	-0.04	-0.01	-0.02	-0.01	-0.02
	[0.029]	[0.034]	[0.015]	[0.018]	[0.015]	[0.016]
LSAP2	-0.05***	-0.15***	-0.03***	-0.05***	-0.02***	-0.04***
	[0.006]	[0.020]	[0.002]	[0.015]	[0.004]	[0.007]
LSAP3	-0.01	-0.09	0	-0.02	0	-0.01
	[0.010]	[0.072]	[0.007]	[0.025]	[0.005]	[0.010]
MEP	0.02	-0.03	0.02***	0.03	0.02***	0.02*
	[0.017]	[0.107]	[0.002]	[0.024]	[0.001]	[0.013]
FG	-0.09***	-0.27***	-0.05***	-0.11***	-0.03***	-0.07***
	[0.013]	[0.051]	[0.006]	[0.015]	[0.004]	[0.009]
News	0	-0.01*	0	0	0	0
	[0.002]	[0.007]	[0.001]	[0.003]	[0.001]	[0.002]
Observations	2,517	2,517	2,517	2,517	2,517	2,517

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a τ = -5;-10 percent decline in the S&P500 for a period of n = 1 , 2 or 3 months. LSAP1, LSAP2, LSAP3, MEP and FG represent the announcements dates related to these programs. More details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in the US; see D.13 for more information. UMP in the rest of the areas are also controlled for. Newey-West standard errors in brackets and *** p<0.01, ** p<0.05, * p<0.1

Table E.17: ECB. Event-study by type of UMP program

Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,2}$	$\Delta F^{10\%}_{t,2}$	$\Delta F^{5\%}_{t,3}$	$\Delta F^{10\%}_{t,3}$
Liquidity	-0.04**	-0.09**	-0.02**	-0.04**	-0.02	-0.03*
	[0.014]	[0.037]	[0.010]	[0.018]	[0.010]	[0.015]
CBBP/ABSPP	0	-0.01	-0.01	-0.01	-0.02	-0.02
	[0.027]	[0.070]	[0.017]	[0.034]	[0.016]	[0.026]
SMP	0.01	0.02	0	0	0.01	0
	[0.045]	[0.100]	[0.032]	[0.064]	[0.024]	[0.049]
OMT	0.02	-0.03	0.06***	0.05***	0.08***	0.08***
	[0.015]	[0.048]	[0.007]	[0.017]	[0.007]	[0.011]
APP	-0.06**	-0.13***	-0.03*	-0.05*	-0.03	-0.03
	[0.023]	[0.052]	[0.017]	[0.027]	[0.018]	[0.024]
FG	-0.03**	-0.11***	-0.01	-0.03	0	-0.01
	[0.013]	[0.036]	[0.015]	[0.021]	[0.015]	[0.020]
News	0	0	0	0	0	0
	[0.002]	[0.005]	[0.002]	[0.003]	[0.002]	[0.002]
Observations	2541	2541	2541	2541	2541	2541

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a τ = -5;-10 percent decline in the EuroStoxx 50 for a period of n = 1 , 2 or 3 months. Liquidity captures the announcement dates of LTRO, TLTRO, COLL, FOR and FRTFA measures, and the rest of variables includes the related releases. More details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in the euro area; see D.13 for more information. UMP in the rest of the areas are also controlled for. Newey-West standard errors in brackets and *** p<0.01, ** p<0.05, * p<0.1

Table E.18: BOE. Event-study by type of UMP program

Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,2}$	$\Delta F^{10\%}_{t,2}$	$\Delta F^{5\%}_{t,3}$	$\Delta F^{10\%}_{t,3}$
FLS	-0.02	-0.11	0	-0.01	0.01	0
	[0.027]	[0.109]	[0.015]	[0.034]	[0.013]	[0.019]
APF1	-0.01	-0.02	-0.01	-0.02	-0.01	-0.02
	[0.023]	[0.059]	[0.021]	[0.035]	[0.020]	[0.028]
APF2	-0.03***	-0.06***	-0.02***	-0.03***	-0.02***	-0.03***
	[0.008]	[0.023]	[0.004]	[0.007]	[0.007]	[0.005]
APF3	-0.15	-0.56***	-0.05	-0.17	-0.03	-0.07
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
FG	-0.05***	-0.10***	-0.05**	-0.06*	-0.05**	-0.06**
	[0.017]	[0.024]	[0.021]	[0.030]	[0.019]	[0.028]
Liquidity	-0.04***	-0.09**	-0.02***	-0.04***	-0.02***	-0.03***
	[0.011]	[0.034]	[0.006]	[0.013]	[0.007]	[0.009]
Brexit	-0.05	-0.18	0.05	0	0.01	0
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
News	-0.01**	-0.03***	0	-0.01	0	0
	[0.003]	[0.011]	[0.002]	[0.004]	[0.002]	[0.003]
Observations	2,552	2,552	2,552	2,552	2,552	2,552

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a τ = -5;-10 percent decrease in the FTSE 100 for a period of n = 1 , 2 or 3 months. More details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in the UK; see D.13 for more information. UMP in the rest of the areas are also controlled for. Newey-West standard errors in brackets and *** p<0.01, ** p<0.05, * p<0.1

Table E.19: BOJ. Event-study by type of UMP program

Variables	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,2}^{5\%}$	$\Delta F_{t,2}^{10\%}$	$\Delta F_{t,3}^{5\%}$	$\Delta F_{t,3}^{10\%}$
Liquidity	-0.04***	-0.06**	-0.01	-0.03**	0.01	0
	[0.014]	[0.027]	[0.020]	[0.015]	[0.021]	[0.018]
QQE	-0.03	0	-0.01	0	-0.01	-0.02
	[0.052]	[0.102]	[0.034]	[0.063]	[0.020]	[0.027]
QQEwNIR	-0.02	-0.09**	0	-0.01	-0.01	-0.02
	[0.020]	[0.035]	[0.014]	[0.020]	[0.013]	[0.012]
QQEwYCC	-0.11	-0.7	-0.06	-0.14	-0.07	-0.09
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
CME	0	0.05	0.01	0.01	0.01	0.01
	[0.034]	[0.140]	[0.018]	[0.049]	[0.019]	[0.029]
JGB/CFIpurchases	0.02	-0.01	-0.04	-0.04	-0.04	-0.04
	[0.044]	[0.040]	[0.051]	[0.048]	[0.038]	[0.041]
FG	-0.10***	-0.27***	-0.03	-0.09**	-0.02	-0.05
	[0.018]	[0.040]	[0.020]	[0.040]	[0.024]	[0.033]
News	0	-0.02	0	0	0.01	0.01
	[0.007]	[0.022]	[0.006]	[0.007]	[0.006]	[0.006]
Observations	2,447	2,447	2,447	2,447	2,447	2,447

Notes: The sample period is from January 2007 to December 2016. The dependent variable refers to the daily change in the option-implied probability of a τ = -5;-10 percent decline in the Nikkei 225 for a period of n = 1 , 2 or 3 months. Further details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in Japan; see D.13 for more information. UMP in the rest of the areas are also controlled for. Newey West standard errors in brackets and *** p<0.01, ** p<0.05, * p<0.1

Appendix E.3. Controlling for liquidity risks

Liquidity issues might be a source of concern in option markets. That is why, we use the most liquid index options, such as SP500, Eurostoxx 50, FTSE 100 and Nikkei225. In order to control for potential liquidity risks, we run an additional robustness check to our baseline specification. We calculate the relative bid-ask spread for each region and use it as a control variable in the event-study analysis. Therefore the event-study in this alternative specification will be as follows:

$$\Delta F_{t,i,n}^{\alpha\%} = \beta_i A_{i,t}^{UMP} + \sum_{j=1}^{J} \gamma_{i,j} News_{i,j,t} + \rho_i Spread_{i,t} + \varepsilon_{i,t} \tag{E.1}$$

with $\alpha = 5\%, 10\%$ and $n = 1,2,3$ months and where $\Delta F_{t,i,n}^{\alpha\%}$ stands for the change in the expected probability (in logs) of an $\alpha\%$ decline in the stock market for a period of n months for each area i; $A_{i,t}^{UMP}$ is a dummy variable equal to one on the day of the UMP announcement, zero otherwise; *Spread* controls for the liquidity risk. The rest of the specification follows 1.

Table E.20, E.21 and E.22 confirm the results of our baseline specification. [22]

Table E.20: UMP announcements and option-implied tail risks in the short run. Liquidity control

Area	**Fed**		**ECB**		**BOE**		**BOJ**	
Variables	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$	$\Delta F_{t,1}^{5\%}$	$\Delta F_{t,1}^{10\%}$
UMP	-0.05***	-0.15***	-0.04***	-0.10***	-0.04***	-0.10***	-0.03***	-0.07*
	[0.012]	[0.034]	[0.011]	[0.028]	[0.009]	[0.030]	[0.012]	[0.042]
News	-0.00	-0.02**	-0.00*	-0.01	-0.01***	-0.04***	-0.01	-0.02
	[0.003]	[0.010]	[0.003]	[0.006]	[0.004]	[0.012]	[0.007]	[0.017]
Spread	0.01	0.10	0.09**	0.22**	0.09**	0.32**	0.02	0.05
	[0.029]	[0.085]	[0.041]	[0.104]	[0.043]	[0.132]	[0.039]	[0.137]
Obs.	2,517	2,517	2,541	2,541	2,552	2,552	1,885	1,885

Notes: The sample period is from January 2007 to December 2016, except for the case of Japan that it starts from mid-2009. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decrease in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1 month. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in each area and "spread" for liquidity risk. UMP announcements in the rest of the areas are also controlled for. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

[22] The spillovers effects are also robust to this new specification. Results can be provided upon request.

Table E.21: UMP and option-implied tail risks across different horizons: Liquidity control

Area	**Fed**		**ECB**		**BOE**		**BOJ**	
Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$
1-month	-0.05***	-0.15***	-0.04***	-0.10***	-0.04***	-0.10***	-0.03***	-0.07*
	[0.012]	[0.034]	[0.011]	[0.028]	[0.009]	[0.030]	[0.012]	[0.042]
2-month	-0.03***	-0.06***	-0.02**	-0.04**	-0.02***	-0.04***	-0.01	-0.03**
	[0.007]	[0.013]	[0.008]	[0.014]	[0.006]	[0.011]	[0.008]	[0.015]
3-month	-0.02***	-0.04***	-0.01	-0.02*	-0.02***	-0.03***	0.00	-0.02
	[0.005]	[0.009]	[0.009]	[0.012]	[0.006]	[0.008]	[0.012]	[0.010]
Obs.	2,517	2,517	2,541	2,541	2,552	2,552	1,885	1,885

Notes: The sample period is from January 2007 to December 2016, except for the case of Japan thaat it starts from mid-2009. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decline in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1, 2 or 3 months. UMP is a dummy variable that captures the announcement dates of major unconventional monetary policies in each area, including liquidity measures. Further details about the list of events included are provided in Appendix C. In all the regressions, other relevant macroeconomic releases ("News"), liquidity controls ("Spread") and other UMP announcements in other areas have been controlled for, even if not reported in this table. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Table E.22: Heterogeneous UMP and option-implied tail risks in the short run. Liquidity control

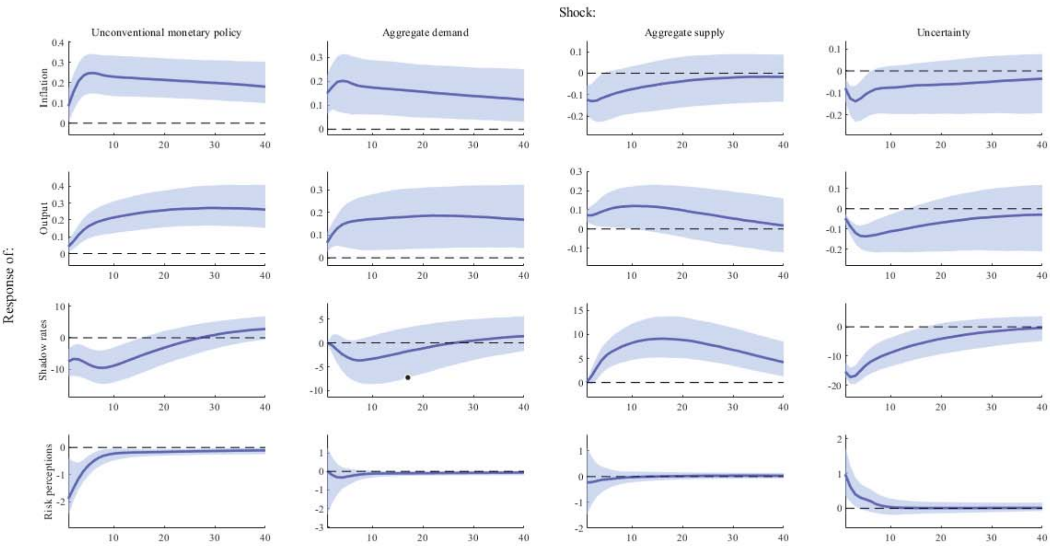
Area	**Fed**		**ECB**		**BOE**		**BOJ**	
Variables	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$	$\Delta F^{5\%}_{t,1}$	$\Delta F^{10\%}_{t,1}$
Liquidity	-0.04	-0.09***	-0.04**	-0.09**	-0.04***	-0.11***	-0.03***	-0.05
	[0.024]	[0.036]	[0.014]	[0.038]	[0.011]	[0.036]	[0.011]	[0.034]
Sterilized AP	0.02	-0.03	0.02	-0.01	-0.00	0.01		
	[0.017]	[0.110]	[0.020]	[0.050]	[0.015]	[0.021]		
Unsterilized AP	-0.03**	-0.09***	-0.04**	-0.09*	-0.04	-0.11	-0.02	-0.04
	[0.014]	[0.029]	[0.020]	[0.048]	[0.024]	[0.079]	[0.021]	[0.081]
FG	-0.09***	-0.27***	-0.04***	-0.14***	-0.06***	-0.11***	-0.10***	-0.27***
	[0.012]	[0.051]	[0.014]	[0.030]	[0.017]	[0.024]	[0.018]	[0.040]
News	-0.00	-0.02**	-0.00*	-0.01	-0.01***	-0.04***	-0.01	-0.02
	[0.003]	[0.010]	[0.003]	[0.006]	[0.004]	[0.012]	[0.007]	[0.017]
Spread	0.00	0.09	0.09**	0.22**	0.09**	0.32**	0.02	0.05
	[0.029]	[0.085]	[0.041]	[0.105]	[0.043]	[0.133]	[0.039]	[0.137]
Observations	2517	2517	2541	2541	2552	2552	1,885	1,885

Notes: The sample period is from January 2007 to December 2016, except for the case of Japan that it starts from mid-2009. The dependent variable refers to the daily change in the option-implied probability of a 5% and 10% decline in the S&P500, the EuroStoxx 50, the FTSE 100 and the Nikkei 225 for a period t = 1, 2 or 3 months. UMP announcements are disaggregated into liquidity, sterilized asset purchases, unsterilized asset purchases and forward guidance. Further details about the list of events included are provided in Appendix C. "News" controls for relevant macro releases in each area and "Spread" for liquidity risk. UMP announcements in the rest of the areas are also controlled for. Newey-West standard errors in brackets, and *** p<0.01, ** p<0.05, * p<0.1

Appendix F. Additional results of SVAR & Robustness checks.

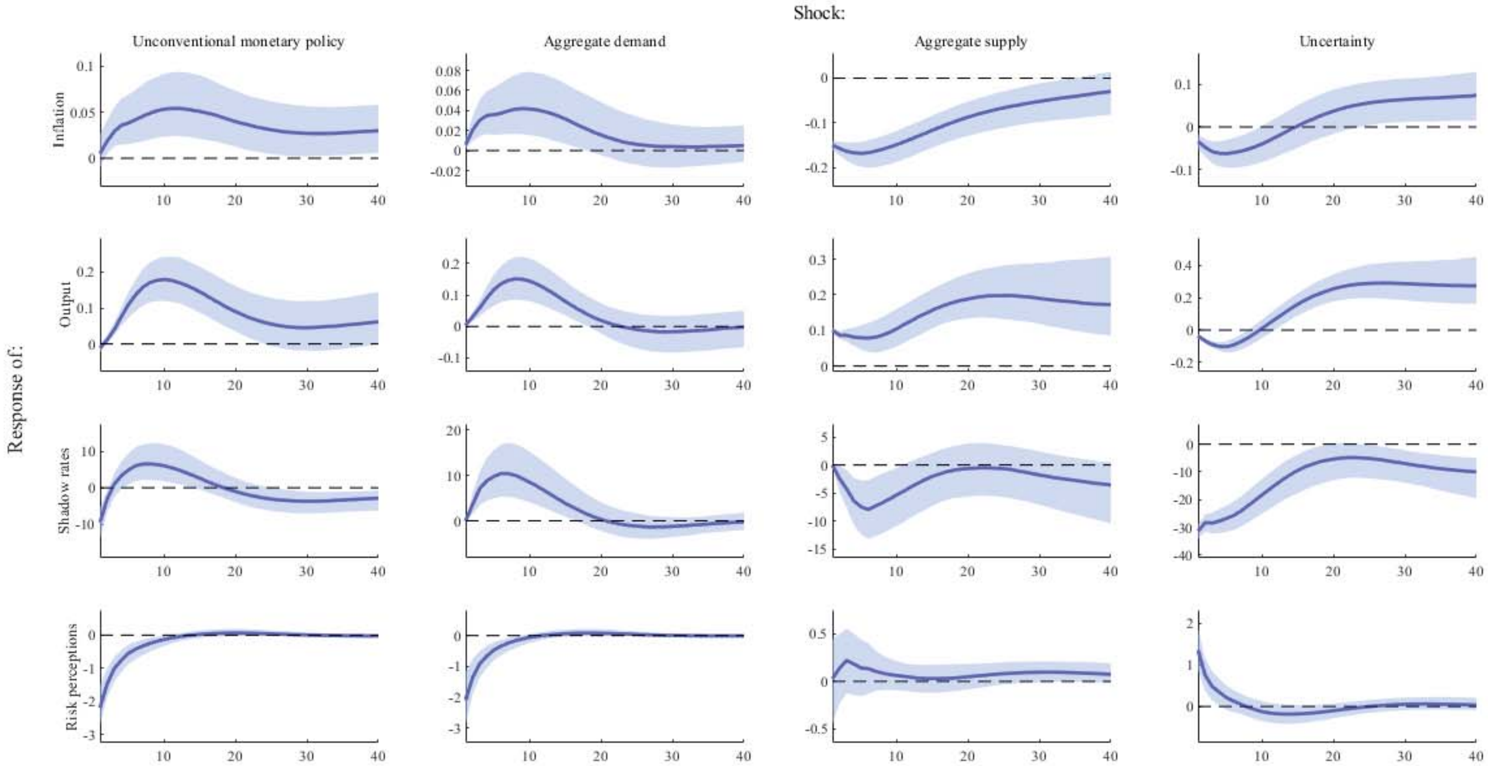
Appendix F.1. Baseline results for each area

Figure F.9: Fed baseline results



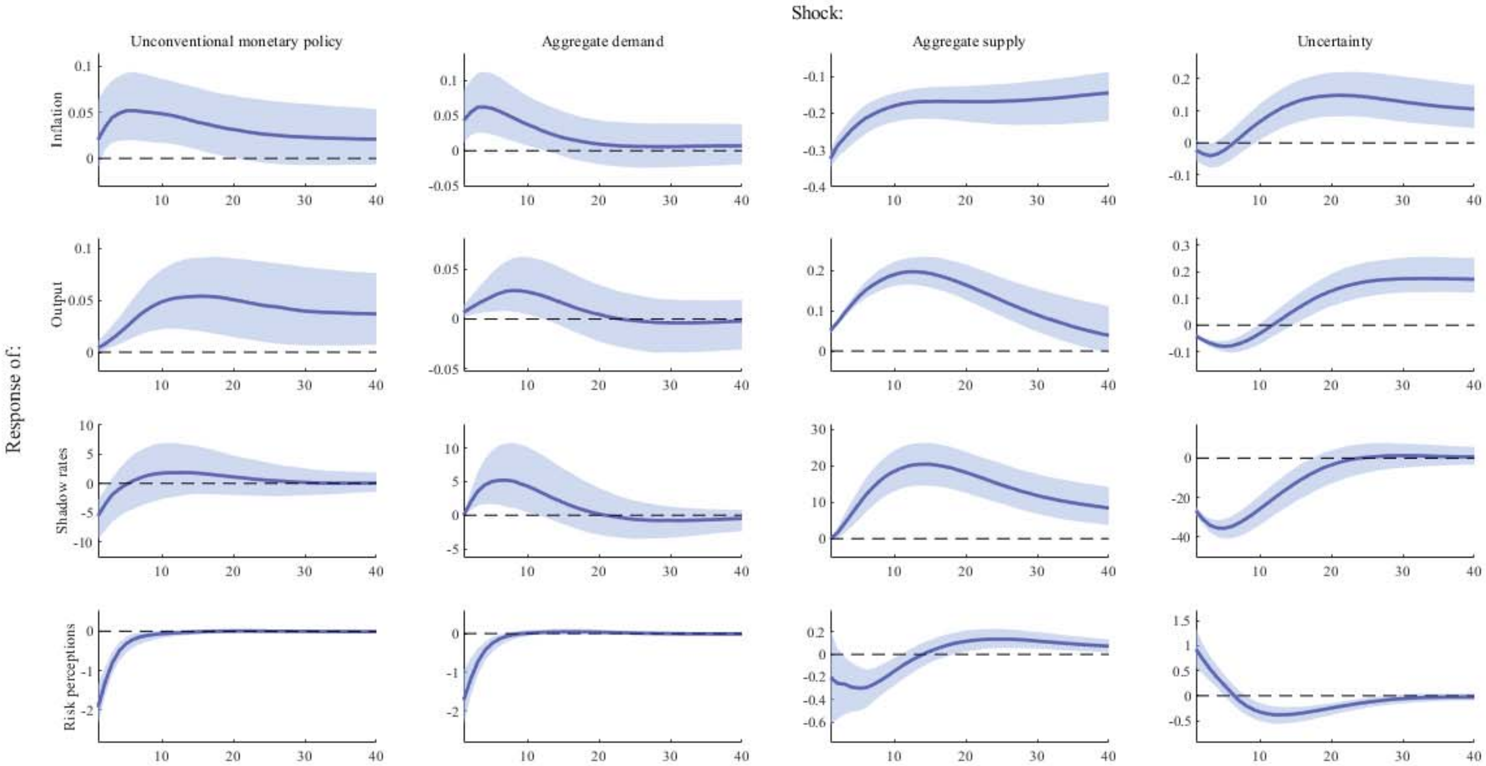
Impulse-responses functions (IRFs) from SVAR models to UMP, demand, supply and uncertainty shocks, identified by sign and zero restrictions summarized in 5. The figure F.9 depicts the response of the economic variables under study to a one-standard-deviation shock. Each row corresponds to an economic variable, and the different shocks identified (UMP, demand, supply and uncertainty) are organized in columns. Each chart displays the median of the posterior distribution (solid line), and the 68 percent credibility interval (shaded area).

Figure F.10: ECB baseline results



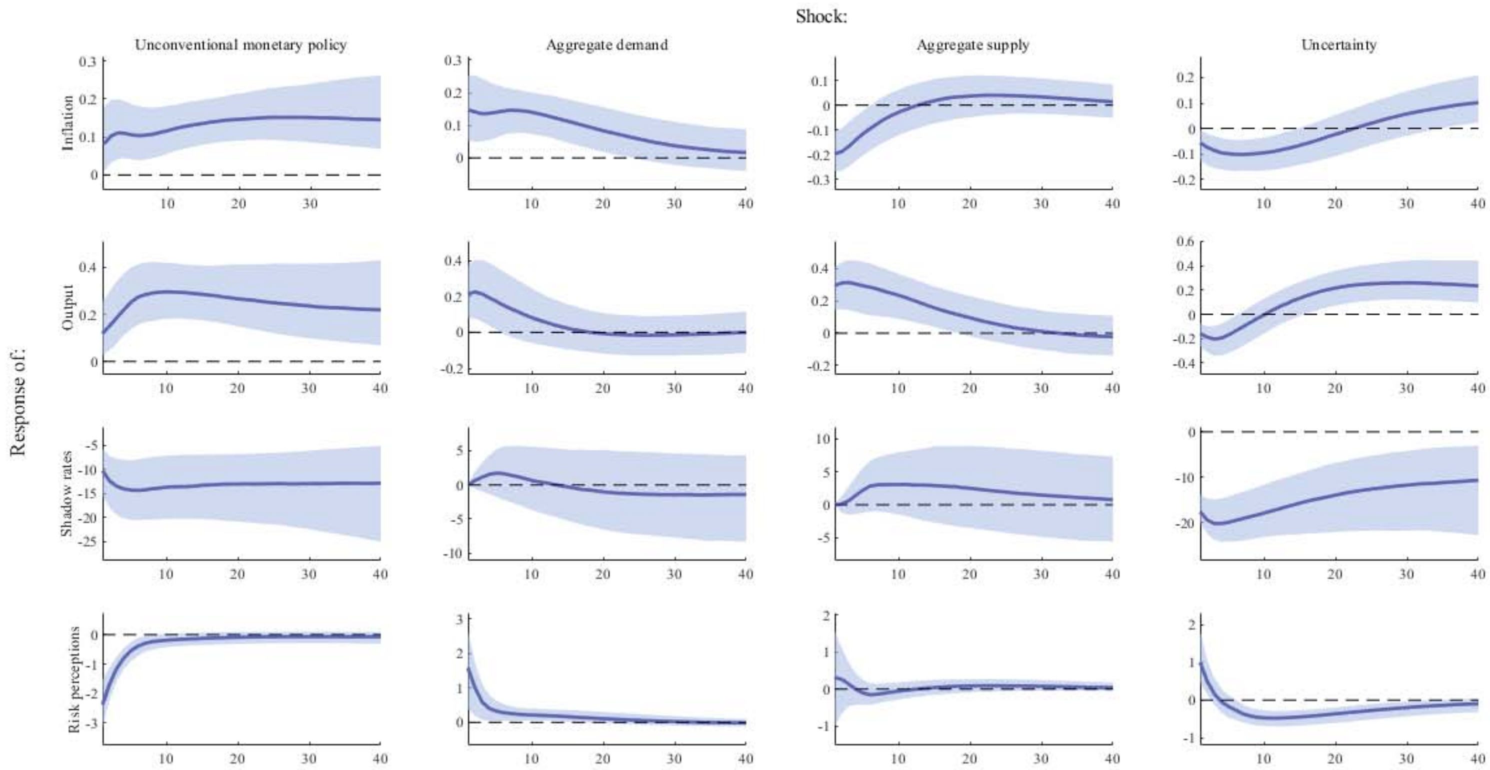
Impulse-responses functions (IRFs) from SVAR models to an UMP, a demand, a supply and an uncertainty shock, identified by sign and zero restrictions summarized in 5. The figure F.10 depicts the response of the economic variables under study to a one standard deviation shock. Each row corresponds to an economic variable, and the different shocks identified (UMP, demand, supply and uncertainty) are organized in columns. Each chart displays the median of the posterior distribution (solid line), and the 68 percent credibility interval (shaded area).

Figure F.11: BOE baseline results



Impulse-responses functions (IRFs) from SVAR models to UMP, demand, supply and uncertainty shocks, identified by sign and zero restrictions summarized in 5. Figure F.11 depicts the response of the economic variables under study to a one-standard-deviation shock. Each row corresponds to an economic variable, and the different shocks identified (UMP, demand, supply and uncertainty) are organized in columns. Each chart displays the median of the posterior distribution (solid line), and the 68 percent credibility interval (shaded area).

Figure F.12: BOJ baseline results



Impulse-responses functions (IRFs) from SVAR models to UMP, demand, supply and uncertainty shocks, identified by sign and zero restrictions summarized in 5. The figure F.12 depicts the response of the economic variables under study to a-one-standard deviation shock. Each row corresponds to an economic variable, and the different shocks identified (UMP, demand, supply and uncertainty) are organized in columns. Each chart displays the median of the posterior distribution (solid line), and the 68 percent credibility interval (shaded area).

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