Central bank balance sheet and systemic risk

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Abstract

Central banks' balance sheet policies, while intended to address financial market dislocations and stimulate the economy, may have unintended persistent effects on systemic risk. Using a structural bayesian vector autoregressive model, this paper estimates the impacts of exogenous innovations to the central banks' balance sheet on the aggregate systemic risk in the euro area, the United States and Japan. Our results suggest that these policies have positive effects on financial stability in the short and medium term and seems to have no effects in the long term. Moreover, we study the effects of central balance sheet policies shocks on financial institutions' systemic risk through a panel VAR and highlight the role of leverage in the transmission of unconventional monetary policy to financial firms' systemic risk.

Keywords: balance sheet policies, srisk, structural BVAR, zero and sign restrictions, leverage

JEL : C32, C33, E44, E52, E58

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\By becoming the \only game in town" and using their discretionary powers, central banks revealed the immense power of their balance sheet" (Orphanides, 2016)

1 Introduction

The global financial crisis led central banks to expand their balance sheet on an unprecedented scale, as a result of implementing various unconventional monetary policy operations. In 2008-09, in order to address the risk that the transmission of monetary policy was impaired by the financial shocks, central banks started by short-term lending and purchasing short-term assets. However, the unconventional policies progressively moved toward longer-term operations. Moreover, as policy rates has reached their effective lower bound, balance-sheet policies have become the primary monetary policy instruments to stimulate the economy and prevent renewed financial tensions.

More than ten years later, central banks are still using their balance sheet as an active tool of monetary policy and the recent turmoil implied by the Covid-19 crisis has led to a further expansion in asset purchasing and lending programs in order to address market strains and providing policy stimulus.

As underlined by Curdia & Woodford (2010), the global financial crisis has confronted central banks with a number of questions beyond the scope of standard accounts of the theory of monetary policy. One is the question of the appropriate size of the central bank's balance sheet. Another, less exploited, is its appropriate composition.

The literature on central bank balance sheet policies has surged following the financial crisis, most papers focusing on how effective the unconventional monetary policies were in supporting financial stability and economic activity (Altavilla et al., 2015). However, there is still uncertainty about the magnitude of these effects and, more importantly, about the mechanisms through which these policies operate. From an empirical perspective, the estimation of these effects on the real economy as well as on the financial sphere is complex. Identifying a causal effect of balance sheet policies is challenging, as they are usually implemented in response to economic events, thereby creating an endogeneity problem.

More recently, the debate on unconventional monetary policy has concentrated on the risks and side effects potentially associated with these measures in place for a prolonged period of time. Questions are raised as to the "quasi fiscal" implications of central banks' balance sheets due to large-scale purchases of government bonds, distortion to resource allocations leading to lower productivity, international policy spillovers (Potter & Smets, 2019).

There is also a growing literature investigating the possible side effects of monetary policy on financial stability (Chodow-Reich, 2014). While the aim of central banks' unconventional monetary policy is initially to cope with short-term risks to financial stability at times when conventional measures are ineffective, there are also possible medium and long-term concerns arising from such a significant shift in the size and composition of central bank balance sheets. While the nature of the different risks can be demonstrated, they are extremely hard to quantify and to find within what time horizon they might materialize. Balance sheet policies can adversely affect financial stability via different transmission channels. First, a persistent flattening of the yield curve can put pressure on bank profits and on pension funds and life insurance companies' financial health, and also slows down their recapitalization. Second, a protracted period of low interest rates and abundant liquidity may over time induce excessive risk-taking in financial intermediaries. This behavior can

be reinforced by the increase of moral hazard due to the fact that financial investors systematically expect the central bank to intervene whenever asset valuations collapse. Finally, balance sheet policies, especially large-scale asset purchases may lead to the emergence of asset price bubbles. There does not yet seem to be any empirical or theoretical evidence regarding the occurrence of asset price bubbles due to the use of balance sheet policies. For example, Huston & Spencer (2018) or Blot, Hubert & Labondance (2017) did not found indication of asset price bubbles in the United States.
On the other hand, there are serious arguments for maintaining permanently central bank balance sheet as a monetary policy tool, in particular to meet a financial stability objective. The most compelling and mentioned argument in favor of this has been made by Greenwood & al. (2016) who emphasize that there is a strong demand from the private sector for safe, liquid, short-term securities, and that central banks are in a unique position to offer such assets.

Decisions to engage in unconventional monetary policy are weighty, and require the central bank to balance the positive effects of such policy on financial stability and economic activity against the possible side effects, many of which can occur over the longer term. From a regulatory and supervisory point of view, it is useful to assess the total impact of balance sheet policies on the aggregate systemic risk and it is equally important to identify which financial institutions are most exposed to these measures.
Thus, in this paper, we evaluate balance sheet policies' effects on one of the most reliable systemic risk measure, the SRISK indicator (Acharya & al., 2012; Brownlees & Engle, 2016). According to Colletaz & al. (2018), this measure presents various advantages such as its theoretical foundations, the facts that it can be computed using publicly available data and that the SRISK can predict which institutions are going to be confronted with losses during a financial crisis. Moreover, this indicator is particularly suitable for our study as in addition to being calculated for each financial institution, there is an aggregated version constructed by summing the SRISK of individual firms. At the individual level, SRISK can be defined as "the expected capital shortfall of a given financial institution, conditional on a crisis affecting the whole financial system" (Benoit & al., 2017). In its aggregated version, this indicator corresponds to the total amount of capital that would be needed to bail out the financial system if a financial crisis were to occur (Colletaz & al., 2018).
As a proxy for balance sheet policies, which included lending programmes and asset purchase programmes, we use the central bank total assets' growth which is one of the most used proxy in this literature (Gambacorta & al, 2014); Boeckx & al, 2017 ; Kremer, 2015 ; Burriel & Galesi, 2016 ; Haldane & al, 2016 ; Gambetti & Musso, 2017). Moreover, to identify exogenous innovations to the central bank balance sheet, we use a mixture of zero and sign restrictions.

We contribute to the literature investigating the effects of unconventional monetary policy on financial stability by analyzing the effects of balance sheet shocks on the aggregate systemic risk and on financial institutions' systemic risk. Macroeconomic studies relative to the risk-taking channel are scarce. In line with the paper of Colletaz & al. (2018) which study the causality between conventional monetary policy and the SRISK indicator in euro area, we decide to fill this gap by analyzing the effects of unconventional monetary policy on the SRISK indicator in the euro area, the United States and Japan.
Another original aspect of our study is to complete this macroeconomic analysis by a microeconomic approach. The aggregate approach does not take into account the possible heterogeneity of the

effects of monetary policy shocks. On the other hand, evidence of risk-taking at the microeconomic level does not necessarily imply significant macroeconomic effects (Colletaz & al., 2018 ; Bonfim and Soares, 2014). We furthermore confirm the importance of the financial institutions business model in the transmission of monetary policy to systemic risk (Brissimis and Delis (2010) ; Delis and Kouretas (2011) ; and Ricci (2015) ; Lamers & al. 2019) by focusing our study on the role of leverage.
In the first part of our paper, we use a structural BVAR model over the period January 2008 to December 2018 for the euro area and the United States and January 2000 to March 2018 for Japan. In the second part, we are take a more granular approach and look at the financial institutions' systemic risk. Therefore, we use a panel dataset of financial institutions for each area. We no longer use the aggregated SRISK but the SRISK of the financial institutions. Moreover, we control for the size and the risk of the financial institutions by adding three variables to our model : leverage, market capitalisation and LRMES (Long-Run Marginal Expected Shortfall).

The main empirical challenge for our study, as in any empirical analysis of the effects of unconventional monetary policy, is the endogeneity issue. Central bank balance sheet fluctuations are a combination of changes in monetary policy that could be interpreted as exogenous, and an endogenous response to developments in the economy and to financial turbulence. To isolate central bank balance sheet shocks, we use a similar identification scheme of the one used by Boeckx & al. (2017), Burriel & Galesi (2018) and Gambacorta & al. (2014).

Our results suggest that balance sheet policies have beneficial effects on the aggregate systemic risk at the short and medium term. In the long term (five years in our study), we find no significant effects, which means that increasing the size of central banks' balance sheet does not appear to have an adverse effect on financial stability.
Conversely, conventional monetary policy shocks lead in the short term to an increase in systemic risk in the euro area and have no effect on the United States and Japan.
At a disaggregated level, we find similar results : unconventional monetary policy shocks lead to an improvement in financial stability. Moreover, we highlight the role of leverage in the transmission of unconventional monetary policy to financial firms' systemic risk as these policies have a greater impact on financial institutions with the highest leverage.

The remainder of this paper is organized as follows. Section II describes central bank balance sheet policies and the literature relative to the effects of such policies on financial stability. Section III presents empirical results of our structural BVAR model on the impact of balance sheet policies on systemic risk . Section IV provides additional results on the links between central bank balance sheet and financial stability at a disaggregated level. Section V concludes.

2 Balance sheet policies and financial stability

Central banks' balance sheet has significantly expanded since the global financial crisis. This phenomenon has been driven by balance sheet policies which allow central banks to influence financial conditions beyond the short-term policy rate by adjusting their balance sheet (size and/or composition). Balance sheet policies include large-scale asset purchases programmes and the supply of central bank funding at non-standard terms and conditions. While the immediate financial stability effects of these measures have been positive while providing new liquidity, resolving dysfunctional financial markets and reducing uncertainty, several observers have raised concerns with regard to the build-up of new financial stability risks stemming from such policies. There is no consensus about possible unintended side effects of those unconventional measures particularly within financial markets. One of the most concern is the fact that unconventional monetary policy encouraged excessive risk-taking by financial intermediaries. Frame and Steiner (2018) find evidence on US quantitative easing policies lead to crowding out effects on private investment and reaching for yield behaviour by financial institutions. Some evidence of an "incubation period" for the risk-taking kind of side effects of ECB's unconventional monetary policy is provided by Colletaz et al (2018). Other authors do not find little reason for concern over additional risk-taking (Foley-Fischer, Ramcharan, and Yu 2016 ; Kurtzman, Luck, and Zimmerman 2017). More recent concerns amplified by the Covid-19 crisis are the financial markets dependence to central bank's policies ; the risks of bubbles accumulated in financial assets (Lacalle 2018).

2.1 Central bank balance sheet policies

The size and composition of central banks' balance sheets have been profoundly altered following the adoption of unconventional monetary policy.

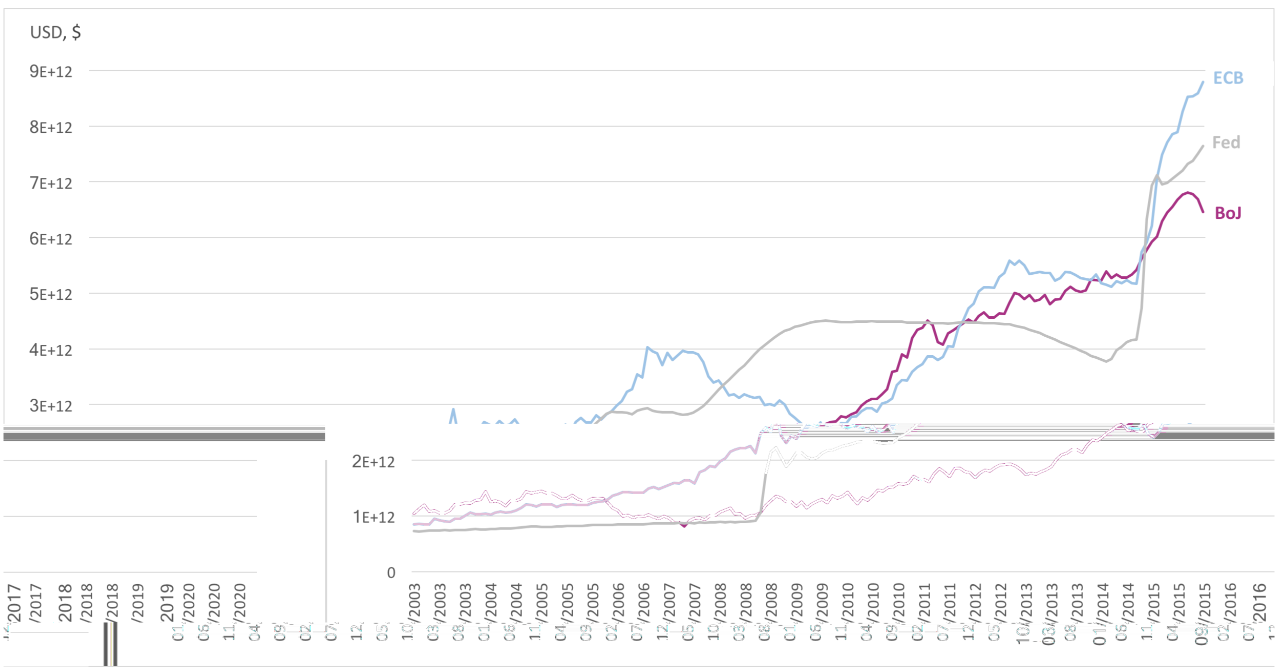


Figure 1: Central bank assets (Refinitiv Eikon)

Our paper focuses on the European Central Bank (ECB), the Federal Reserve of United States (Fed) and the Bank of Japan (BoJ). Besides the BoJ, which had already used the size of its balance sheet as a monetary policy instrument (in response to the banking crisis of the 1990s), the balance sheets of the Fed and the ECB recorded a sizeable expansion in the second half of 2008 (figure 1). This change has been driven by lending to banks and asset purchase programmes (table 1 and 2)

aimed at stabilising financial markets as well as promoting growth and employment.
Lending programmes were designed to alleviate severe tensions in the interbank money market and to affect credit conditions by providing ample liquidity to banks and other financial institutions. The break with the conventional use of central bank lending in the global financial crisis' aftermath is related to the characteristics of these operations. Central banks created new, or extended existing lending facilities to provide ample liquidity to financial institutions, under considerably looser conditions (mostly by allowing lower-quality collateral), for longer horizons (from weeks to years), and possibly at a lower cost.
The second category of balance sheet policies, asset purchase programmes, allows to lowering borrowing costs for the real economy mostly by reducing the returns and associated risk premia of the assets purchased. Central banks began quantitative easing by purchasing government bonds. To a lesser extent, their programmes included other securities, such as mortgage-backed securities (MBS) in the United States or investment grade corporate bonds in the euro area or equities in Japan.
The Covid-19 epidemic also recently prompted renewed lender-of-last resort interventions and asset purchases by central banks in order to ensuring a smooth functioning of the financial system and facilitating the flow of credit to households and firms.
Although these two policies may have different effects on financial stability, we choose to focus on the overall effect of the increase in central bank balance sheet size.

Table 1 : overview of ECB, Fed and BoJ asset purchases programmes

ECB	Covered bond purchase programme 1 (05/2009) Securities Market programme (05/2010) Covered bond purchase programme 2 (10/2011) Asset-backed securities purchase programme (09/2014) Covered bond purchase programme 2 (10/2014) Public Sector Purchase Programme (03/2015) Corporate Sector Purchase Programme (03/2016) Pandemic Emergency Purchase Programme (03/2020)
Fed	Large-scale asset purchases 1 - agency debt (11/2008) Large-scale asset purchases 1 - MBS (11/2008) Large-scale asset purchases 1 - Treasuries (03/2009) Large-scale asset purchases 2 - Treasuries (11/2010) Maturity Extension programme (09/2011) Large-scale asset purchases 3 - Agency MBS (09/2012) Large-scale asset purchases 3 - Treasuries (12/2012)
BoJ	CP purchase (01/2009) Corporate bond purchase (02/2009) Comprehensive Monetary Easing (10/2010) Quantitative and Qualitative Easing (04/2013) Quantitative and Qualitative Easing with yield curve Control (09/2016)

Table 2 : overview of ECB, Fed and BoJ lending programmes

ECB	Fixed rate full allotment (08/2007), LTRO / VLTRO (12/2011), TLTRO (09/2014), TLTRO II (06/2016), TLTRO III (09/2019), PELTRO (04/2020)
Fed	Term Auction Facility (12/2007), Primary dealer credit facility (03/2008), Term Securities Lending Facility (03/2008), Asset-Backed Commercial Paper Money Market Fund Liquidity Facility (09/2008), Commercial Paper Funding Facility (10/2008)
BoJ	CP repo (10/2008), Fixed rate funds (10/2008), Special funds corporate financing (12/2009), Fund-provisioning measure to facilitate strengthening of the foundations for economic growth (12/2008), Loan support programme (12/2012)

2.2 Literature review

Economists have not yet fully analysed the potential effect of balance sheet policies on macroeconomic and financial variables. Empirical and theorical uncertainty remains on their precise effectiveness and, more importantly, about the mechanisms through which these policies operate. The dynamic responses of variables that are reported in the literature are often controversial and, under close scrutiny, lack robustness (Ramey, 2016). Not just the magnitude and the significance, but even the sign of the responses of crucial variables such as output and prices depend on the identification strategy, the sample period, the information set considered, and the details of the model specification (Miranda Agripino & Ricco, 2017). In this section, we will focus on the competing views regarding the effects of central bank's balance sheet policies on financial stability in the short, medium and long term.

Greenwood, Hanson & Stein (2016) argue for retaining a large central bank balance sheet to control financial stability risks. More precisely, they argue for the Fed to use its balance sheet by supplying safe assets to lean against private sector maturity transformation. Reducing the scarcity of safe assets also reduces the incentives for financial intermediaries to fund on a short-term basis (Adrian, Laxton & Obstfeld, 2018). The literature about the supply of safe assets to enhance financial stability has been surveyed by Golec and Perotti (2017). This argument is for now less relevant in the case of the euro area and Japan because of their predominantly bank-based nature financial system. Nevertheless, the structural changes (the increased role of secured money market transactions, the importance of a broad set of market rates beyond the overnight rate, the growing relevance of non-bank institutions in market-based finance, the scarcity of safe assets that affects the functioning of markets) are also growing in the euro area and in Japan and it is important to reflect on the possible limitations of monetary policy transmission by only influencing the very short end of money-market rates (Vítor Constâncio, 2016). Deev & Hodula (2016) demonstrate the risk for financial stability of maintaining central banks' balance sheet at their current levels. This paper investigates the effects of monetary policy on systemic risk in the euro area. The authors use a TVP-SVAR model to account for variations in the size of monetary policy shocks, and their study includes the pre-crisis period as well as the post-crisis period. Their analysis suggests that unconventional monetary policy, approximated by the aggregate M2, leads to undesired outcomes and aggravates financial instability in euro area countries (approximated by the aggregate SRISK).

To correctly investigate the financial stability effects of balance sheet measures, some authors prefer to consider the two types of policies separately, since they can have contradictory effects on systemic risk. For instance, Pill & Reichlin (2016) make a distinction between balance sheet policies that compensate for the dysfunction of the traditional monetary policy transmission channels (passive policies) and those that exploit new monetary policy transmission channels (active policies). The expansion of central bank intermediation as a substitute for the dysfunctioning of private markets should greatly promote financial stability. In contrast, with unconventional active policies, encouraging shifts in private portfolios to riskier assets may pose some risks to financial stability. Thus, depending on the nature of the type of unconventional instrument used, the effects on financial stability can be either negative or positive.

Other authors, like Peersman (2011) does not distinguish between balance sheet expansions induced by increased demand for liquidity and asset purchase programs. According to him, even if balance sheet expansion is demand-driven, the decision to provide the banking sector with as much liquidity as necessary is taken by the central bank and is therefore a political decision. Another justification is given by Boeckx & al. (2017) who argue that this variation in demand might be stimulated by changes in monetary policy, so can be labeled as a monetary policy shock.

Some authors have focused only on the impact of assets purchase programmes on financial stability. For instance, Woodford (2016) finds a positive impact of asset purchase programmes on financial stability. To capture this link, the author develops a monetary equilibrium model that simultaneously examines the effects of the central bank's balance sheet on financial conditions and how the financing decisions of private banks can increase risks to financial stability. He demonstrates that this unconventional monetary policy instrument allows for greater financial stability through a reduction in the equilibrium risk premium. Indeed, this reduction in the spread between the expected return on risky assets and the risk-free rate leads to a reduction in the purchase of risky assets, which de facto reduces overall systemic risk. He find that quantitative easing increases the supply of reserves/Tbills, reduce the net supply of long-term assets, reduce safety premium, reduce desire of private sector to do maturity transformation.

Lewis & Roth (2019) use a VAR model to estimate the dynamic effects of asset purchase programs on the macroeconomy and their possible side effects on financial stability. They show that ECB's asset purchase programs increase market volatility, liquidity risk and contagion risk putting therefore financial stability in danger.

It is difficult to draw conclusions about the link between unconventional monetary policy and financial stability. First, there are several unconventional tools that have no reason to have the same effect on financial stability. Moreover, there are different transmission channels of these measures to the real sphere but also to the financial sphere, so there may be contradictory effects for the same tool. This is compounded by the complexity of estimating the effects and identifying monetary policy shocks.

3 The empirical approach

3.1 Structural BVAR model

In this section, we assess the impact of balance sheet policies on the SRISK indicator in the euro area, the United States and Japan by adopting a macroeconomic approach. The idea is that while

these instruments seem to have served their purpose in the short term, perhaps unanticipated adverse effects on financial stability may emerge in the medium/long term.
The empirical model adopted to undertake this analysis is represented by a structural BVAR model.
We consider a time series dataset at a monthly frequency which ranges from January 2008 to December 2018 for the euro area and the United States and from January 2000 to March 2018 for Japan. The short time period makes it necessary to choose monthly observations in order to have sufficient information available to estimate the structural BVAR model.
Our analysis is related to the VAR studies of Gambacorta & al. (2014), Boeckx & al. (2017), Weale & Wieladek (2016), Gambetti & Musso (2017) and Lewis & Roth (2019) who investigate the macroeconomic effects of the balance sheet policies.
The VAR allows us to model the effects of shocks dynamically, while imposing only a minimum set of assumptions about the structure of the economy. We use a Bayesian approach as it accounts for estimation uncertainty due to our partial identification with the methodology of sign and zero restrictions (Jarocinski & Karadi, 2018). In a Bayesian procedure, the parameters are treated as random variables and their posterior distribution is estimated via the imposition of prior beliefs on their distribution. The prior and posterior distributions of the reduced-form VAR belong to the Normal-Wishart family. It allows, compared to the Minnesota prior, to relax the assumption that the residual covariance matrix β is known. We specify the prior using standard values for the hyper-parameters following Dieppe & al. (2016), i.e. we set the AR coefficient of the prior to 0.8, overall tightness $\lambda 1 = 0.1$, cross-variable weighting $\lambda 2 = 0.5$, lag decay $\lambda 3 = 1$ and exogenous variable tightness $\lambda 4 = 100$. All variables of the model deviate from their stationary state, which removes any cointegration problems.
The structural BVAR model that we consider has the following representation:

$$A_0 Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + ... + A_p Y_{t-p} + C + B\epsilon_t \quad (1)$$

Where Y_t is the vector of endogenous variables , A_0 is the matrix of contemporaneous influences, A_p is the matrix of influences at lag p and ϵ_t is a vector of (uncorrelated) structural shocks', normally distributed with mean 0 and variance $I_k(0,1)$.
The starting point for estimating the structural model is to assume that A0 is invertible and express the model in its reduced form:

$$\theta_0 Y_t = \theta_1 Y_{t-1} + \theta_2 Y_{t-2} + ... + \theta_p Y_{t-p} + C + Bu_t \quad (2)$$

Where :

$$\theta_p = A_0^{-1} A_p \quad (3)$$

$$u_t = A_0^{-1} \epsilon_t \quad (4)$$

$$E(u_t u_t') = \Omega = E(A_0^{-1} \epsilon_t \epsilon_t' A_0'^{-1}) = A_0^{-1} I_k A_0'^{-1} \quad (5)$$

The vector of endogenous variables Yt contains three variables included in all standard monetary policy VARs of the literature: the log of the consumer price index, the log of the industrial production index and a short-term interest rate measuring the stance of conventional monetary policy (EONIA for euro area, Tibor for Japan and the effective federal funds rate for the United States). These core model variables are complemented by two additional endogenous variables: the log differences of central bank total assets as in order to control for potential additive seasonality in the

data and remove the upward drift in the log levels of these serie (Kremer, 2016), and the aggregate SRISK measure as a proxy for financial instability (Colletaz & al. 2018). We obtain historical data on macroeconomic variables essentially from Datastream. Aggregated SRISK indicator was provided us by the Volatility Institute (V-Lab) for Japan and the United States (in million of dollars) and by the Center for Risk Management Lausanne (CRML) for the euro area (in billion of euro).
The SRISK indicator is mostly used to identify systemically important financial institutions (SIFIs) at micro-level (Banulescu & Dumitrescu 2015 ; Benoit & al. 2015), but there already exist a growing number of studies using this indicator as a proxy for aggregate systemic risk at macro-level in the financial system (Engle & al. 2015 ; Grinderslev & Kristiansen 2016 ; Langfield & Pagano 2015 ; Colletaz, Levieuge & Popescu 2018). At the individual level, SRISK corresponds to "the expected capital shortfall of a given financial institution, conditional on a crisis affecting the whole financial system" (Benoit & al., 2017). This measure combines an economic analysis of Acharya & al.(2010) and an econometric model developed by Brownlees & Engle (2012). The main features of the SRISK indicator are presented in Tavolaro & Visnovsky (2014). This measure is based exclusively on publicly available information (market and accounting data) : the market capitalization of firms, their financial leverage and data related to the sensitivity of the equity return to market shocks. Therefore, it accounts not only for the size of the institution and its individual risk, but also for the correlations between the market and the firm's return. It hence takes into account the two main components of systemic risk, size and interconnectedness (Colletaz & al. 2018).
The idea behind the aggregate measure of systemic risk, which is common to use in the literature of systemic risk, is that the total amount of capital that would be needed to bail out the financial system if a financial crisis were to occur is the sum of all the capital needed by each institution. Aggregate SRISK can be thought of as a stress test on the financial system, where the adverse case scenario is defined as a 40% decrease of the global equity market over a 6-month time horizon (Engle & Zazzara, 2018). This aggregate SRISK is based on four types of financial firms: banking institutions, insurance companies, financial services and real estate firms. According to Deev & Hodula (2016), who evaluate the performance of three systemic risk measures for the euro area (SRISK, CISS and term-spread) using combination of Markov-switching models and dynamic conditional correlation models, the SRISK indicator seems to identify successfully the accumulation phases that might eventually lead to financial instability. To check the robustness of our results we also consider an indicator of financial stress : the composite Indicator of Systemic Stress of Hollo & al. (2012) for the euro area and the Financial Stress Index for Japan (Park & Mercado, 2013) and the United States (Hakkio & Keeton, 2009).
Second, proxies for unconventional monetary policy are the subject of debate in the economic literature. Here, we use the central bank total assets' growth as a proxy for balance sheet policies, following Gambacorta & al (2014); Boeckx & al (2017); Kremer (2015); Burriel & Galesi (2016); Gambetti & Musso (2017). The use of balance sheet size is criticised by some authors (Elbourne & al.,2018 ; Kanga & Levieuge, 2018) who argue that balance sheet policies are generally announced in advance for a given period and therefore that balance sheet changes are largely anticipated by economic agents. However, this indicator allows to capture the overall stance of the various forms of balance sheet policies, these are mainly manifested by the increase in the size of the balance sheet. And the objective of this study is indeed to capture the total effect of balance sheet policies.

3.2 Identification of balance sheet shocks

Economic research faces new econometric challenges with the identification and the estimation of monetary policy shocks since the development of unconventional monetary policy tools. Assessing the effects of monetary policy on real and financial variables requires the identification of monetary policy shocks. These shocks should be exogenous with respect to the other current and lagged endogenous variables in the model, uncorrelated with other exogenous shocks and represent either unanticipated movements in exogenous variables or news about future movements in exogenous variables (Ramey, 2016).

Before the global financial crisis, monetary policy was usually examined in the context of one instrument, typically the policy rate. At the effective lower bound, unconventional measures describe almost all the stance of monetary policy. However, no particular observables directly represent these new instruments. Furthermore, the unconventional monetary policy period is relatively short, starting broadly defined from the aftermath of the crisis. This small number of observations can lead estimation uncertainty and to a lack of identification (Rossi, 2019). In Elbourne (2019), are also listed important econometric issues for successfully isolate exogeneous variation : the foresight problem, fixed rate tenders with full allotment, structural breaks. Regarding the foresight problem, when estimating unconventional monetary policy effects, private agents' information set contains not only current and past observables but also information about future monetary policy changes because of foresight induced by the forward guidance instrument. Therefore, balance sheet shocks, that are economically meaningful, cannot be easily extracted from statistical innovations. Thus, new identification schemes that are suitable at the effective lower bound have been developed following the 2007-08 crisis, but there is still no consensus on the most appropriate method for measuring monetary policy shocks.

Among these methods, Krippner (2013) and Wu & Xia (2016) have proposed shadow rate measures of interest rates to quantify the stance of monetary policy in unconventional times. The shadow rate measure can be defined as the shortest maturity rate, extracted from a term structure model, that would generate the observed yield curve had the effective lower bound not been binding. An embedded and somewhat hidden assumption of shadow rates is that every unconventional monetary policy action only matters to the extent that it affects the term structure of government bond yields, especially its long end (Lombardi & Zhu, 2018).

Much of the recent empirical working on the effects of unconventional monetary policy has taken the event-study approach (Kuttner, 2001 ; Bernanke & Kuttner, 2005 ; Altavilla & Giannone 2014; Rogers, Scotti & Wright 2014 ; Altavilla & al. 2020). This strategy consists of identifying monetary policy shocks as the asset price changes on a short window of time around monetary policy announcements.

Another approach, built on the literature on the effects of monetary policy announcements using high-frequency identification, is via a "VAR with functional shocks" (Inoue & Rossi, 2018), where the shock is the exogenous shift in the yield curve due to monetary policy. It allows to capture several dimensions of monetary policy such as forward guidance and asset purchases programs and captures only monetary policy changes that are fully unexpected by financial markets. This approach differs from event-study approach, which focus only on the effects of monetary policy on yields at specific maturities, by focusing on the change in both the shape and the magnitude of the whole yield curve, not only .

A potential issue faced by these types of identification is that the identified shocks may not be pure monetary policy shocks, since they might be contaminated by other shocks or information that the central bank is releasing about the future state of the economy in their announcements (Rossi, 2018). New methods have been developed that allow researchers to clean the shocks from informational effects by regressing them on Central bank's own forecasts (Miranda-Agrippino & Ricco, 2018; Jarocinski & Karadi, 2018). More precisely, they combine the high-frequency identification of Gertler & Karadi (2015) and Romer & Romer (2004)'s narrative approach and propose a novel instrument for monetary policy shocks that takes into account both the slow absorption of information in the economy, and the signalling channel of monetary policy that arises from the asymmetry of information between the central bank and market participants.

In line with Boeckx, Dossche & Peersman (2017), we identify the monetary policy shocks by imposing a combination of zero and sign restrictions. This identification strategy is also typically used in the monetary policy literature (Gambacorta, Hofman & Peersman, 2014 ; Weale & Wieladeck, 2016 ; Haldane & al., 2016 ; Boeckx, Dossche & Peersman, 2017 ; Burriel & Galesi, 2018 ; Lewis & Roth, 2019).

The aim of our analysis is to assess quantitatively the effects of the balance sheet policies of the ECB, the Fed and the BoJ on the aggregate systemic risk. Thus, we must identify exogenous central bank balance sheet shock.
For this purpose, we use a mixture of zero and sign restrictions on the contemporaneous matrix β in equation (1). Our identifying restrictions are summarized in Table 3 and 4. The unconventional monetary policy and the conventional monetary policy shocks are respectively annotated "ump" and "cmp".

Table 3 : Sign and zero restrictions values

Variables/Shocks	srisk	ump	supply	demand	cmp
srisk		-			
total assets		+			0
cpi		+	-	+	+
production index		+	+	+	+
short-term interbank rate		0			-

Table 4 : Sign and zero restrictions periods

Variables/Shocks	srisk	ump	supply	demand	cmp
srisk		0 1			
total assets		0 1			0 1
cpi		1 2	0 1	0 1	0 1
production index		1 2	0 1	0 1	0 1
short-term interbank rate		0 1			0 1

Our identification scheme is drawn from the results of the economic literature. The first two aggregate shocks are aggregate demand and supply shocks. They are intended to capture important factors driving fluctuations in the real economy and are included in the model to ensure that the central bank balance sheet shocks are exogenous rather than endogenous responses to macroeconomic conditions.

The restrictions used to identify aggregate shocks are well established in the literature on the basis of standard theoretical models : after an aggregate supply shock, inflation and output move in opposite directions, while they move in the same direction after an aggregate demand shock (Peersman & Straub 2009 ; Elbourne & al. 2018).

To identify unconventional monetary policy shocks, we first follow most of the literature on monetary policy by assuming that output and prices respond positively to unconventional monetary policy shocks (Gambacorta & al 2014 ; Ryuzo & Tatsuyoshi, 2017 ; van den End & Pattipeilohy 2015). Moreover, these two variables respond with a lag to monetary disturbances (Elbourne & al. 2018).

Third, since we are interested in the response of systemic risk to central bank balance sheet policies, we only assume that our SRISK indicator responds in the very short-term period negatively to an increase in the size of the balance sheet. We can constrain this relationship in the very short term as we are interested in the systemic risk impulse response function in the short, medium and long term. Furthermore, as indicated by Gambacorta & al. (2014) or Boeckxx & al. (2017), this restriction is required to disentangle such innovations from the endogenous very short-term response of the balance sheet to financial stress.

Finally, given that we want to estimate the dynamic effects of shocks to central bank balance sheet that are orthogonal to shifts in the monetary policy rate (conventional monetary policy), the identified shocks have a zero contemporaneous impact on the short term interest rate.

3.3 Results

3.3.1 Impulse response analysis

Figures 2, 3 and 4 presents the monthly impulse response functions of the SRISK indicator to a one-standard-deviation balance sheet innovation (UMP shock) and to a one-standard-deviation of the central bank interest rate (CMP shock). Red dots depict the median, the dark blue-shaded band the associated 95-percent confidence intervals and the light blue-shaded band the associated 68-percent confidence intervals.

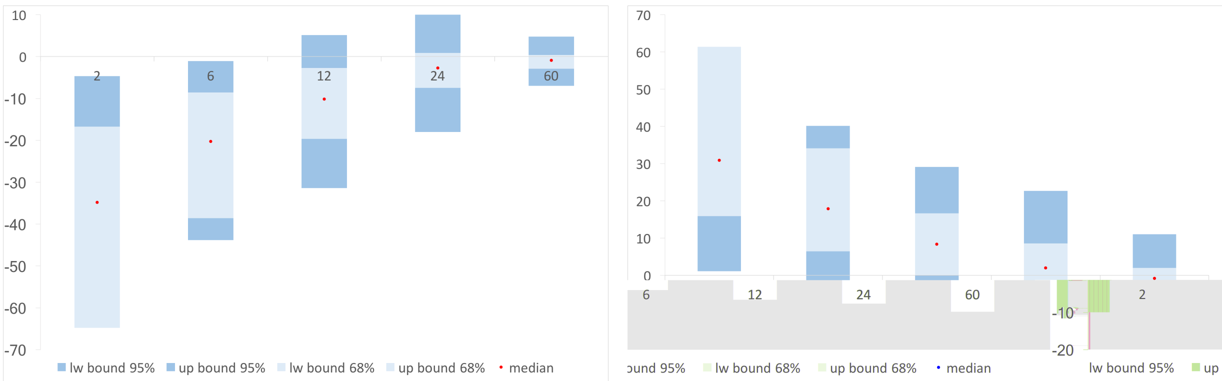
While being (weakly) imposed by the sign restriction on impact and the first month after the shock, an expansionary balance sheet shock leads to a significant decline of the SRISK indicator. More precisely, the response of the systemic risk is statistically different from zero at the 68 percent confidence intervals during twelve months after the shock for the euro area and the United States, and during five years after the shock for Japan (six months for the euro area and the United States and twenty-four months for Japan at the 90 percent confidence intervals).

The effect fades out gradually and returns progressively to the baseline.

During our sample period, central banks was often concerned with ensuring the stability and the functioning of the financial system. This result is evidence that unconventional monetary policy has been successful at reducing financial market failures.

Moreover, it would seem that even in the medium term (or even long term for Japan), these instruments continue to have a positive effect on financial stability.

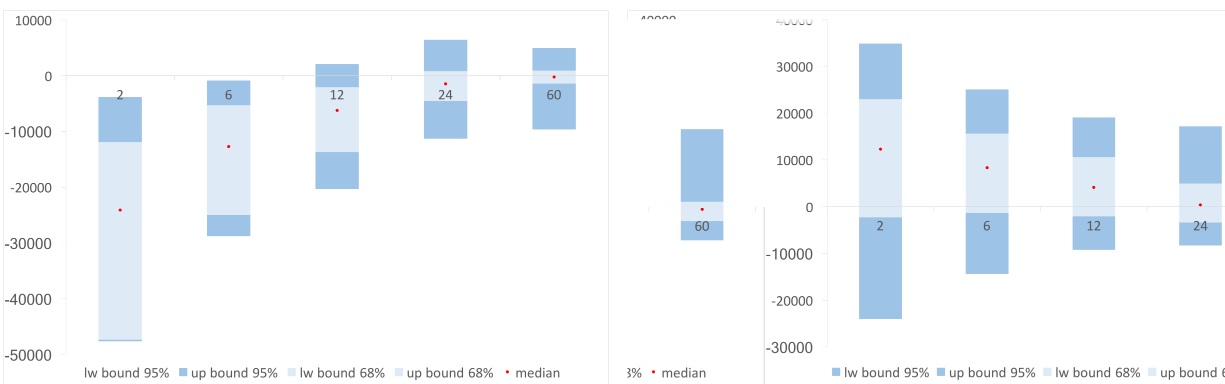
Conversely, conventional monetary policy shocks lead in the very short term to an increase of the systemic risk in the euro area, and have no significant effect in the United States and Japan. This is in line with the fact that before the financial crisis central banks were not acting on financial stability .
The dynamics of real GDP and consumer prices reveal that balance sheet policies conducted in the aftermath of the financial crisis were effective in supporting the macroeconomy. Both variables display a significant increase after an expansion in the central bank balance sheet. The response pattern of output turns out to be qualitatively very similar to a conventional monetary policy shock.



(a) UMP shock

(b) CMP shock

Figure 2: Impact of monetary policy shocks on the SRISK in the euro area

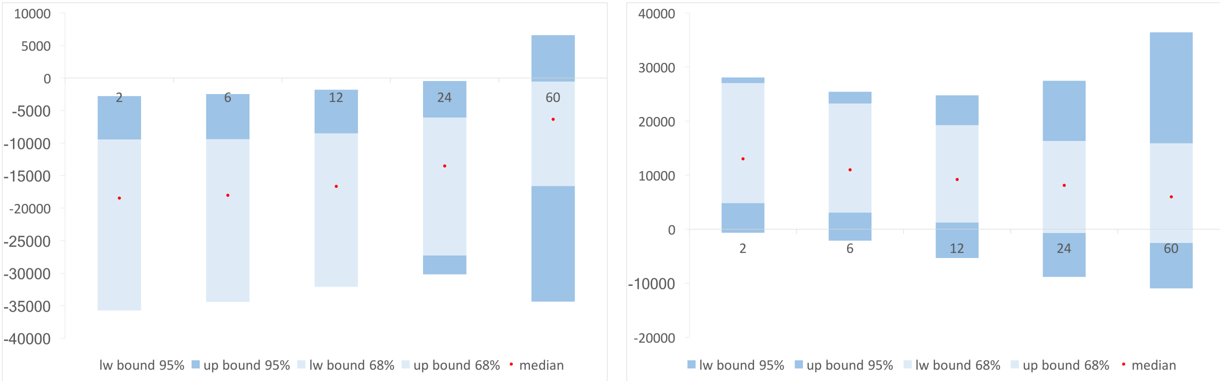


(a) UMP shock

(b) CMP shock

Figure 3: Impact of monetary policy shocks on the SRISK in the United States

In our paper, we focus on the effect of central bank balance sheet policies on the SRISK measure in order to draw conclusions about the link between balance sheet policies and financial stability.
The SRISK indicator relates to financial stability for financial institutions, but financial stability also includes risk related to asset price bubbles, i.e. valuations that deviate from their fundamental value. Bursting asset price bubbles can have detrimental effects on the financial system and give



(a) UMP shock (b) CMP shock

Figure 4: Impact of monetary policy shocks on the SRISK in Japan

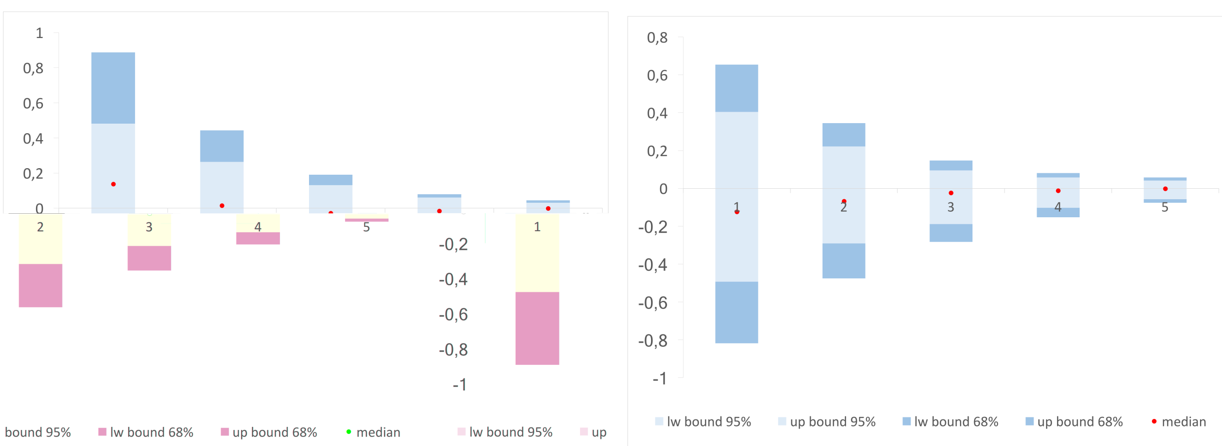
rise to systemic financial crises (example of the one preceding the global financial crisis).
Therefore, it is interesting to reestimate our BVAR model by replacing the SRISK indicator with an asset price bubble indicator. Indeed, if balance sheet policies reduce the systemic risk contribution of financial firms (SRISK indicator), they can negatively affect financial stability through the formation of asset price bubbles.
In particular, one of the intended effects of asset purchase programs, artificially lowering risk premia, introduces the risk of inflating asset pricing bubbles. Furthermore, the search for yield caused by this measure which reduce long term interest rates could steer prices of risky assets to a level that lies above their fundamental value (Hudepohl, van Lamoen & de Vette, 2019). Rising asset prices are one of the transmission channels of monetary policy, but the key question is whether these rising prices are disconnected from fundamentals and reflect the emergence of a bubble.
To build our bubble indicator, we follow the methodology of Blot & al. (2020). First, we calculate the bubble component of stock prices for the United-States, the euro area and Japan with three alternative methods : the "structural", the "data-driven", and the "statistical" approaches. The first consists of capturing the bubble component as the deviation from the fundamental value derived from the estimation of the discounted cash-flow model. Under the second approach, we estimate a model where the stock price index is explained by macroeconomic and financial variables. The asset price bubble indicator corresponds to the residuals of the equation. The third method consists simply of identify deviations from a statistical trend. Appendix A shows the different indicators for each zone.
Then, we summarize the information in a composite indicator by using a principal-component analysis (PCA). The first principal component corresponds to the common denominator of the three approaches.

Regarding the impulse responses of the asset price bubble indicator to conventional monetary policy shock, we find no significant results. Otherwise, our findings suggest that central bank balance sheet shocks have no significant effects on asset price bubbles, over all horizons and for the three areas (figures 5, 6, 7). The 68 percent confidence interval includes the zero-response.
Therefore, during our study period, the positive effects of balance sheet policies on the aggregate systemic risk do not seem to be counterbalanced by the emergence of asset price bubbles. In other

words, our results reject the idea that asset purchase programmes lead to disproportionate increases in stock prices.

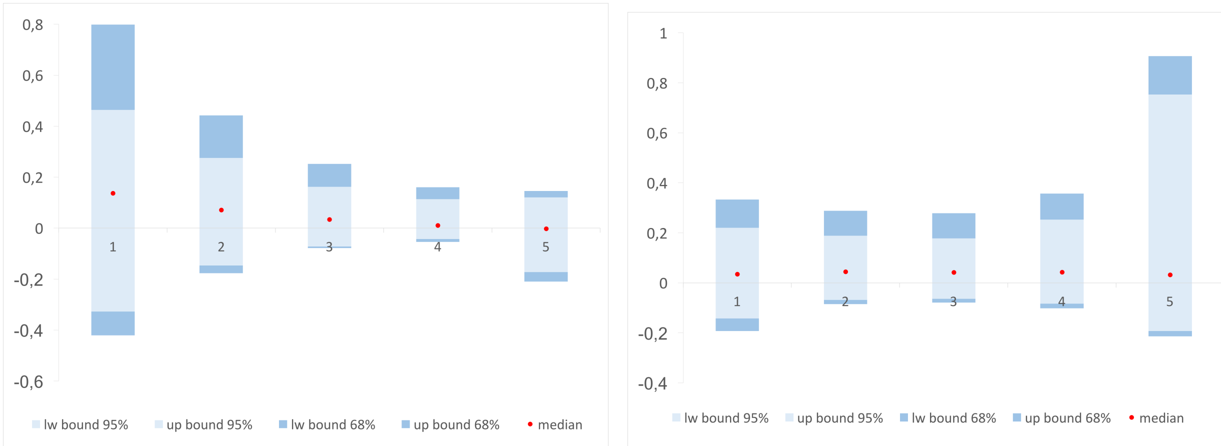
Our results are in line with Blot & al. (2018) who focus on the bubble component of asset prices and find that the risk that quantitative easing would inflate asset price bubbles does not materialize in the data over the period January 1999 to June 2016 in the euro area. Their results even indicate that positive balance sheet shocks tend to lessen the bubble component of stock prices. In a more recent paper, Blot & al. (2020), they find that ECB monetary policy has affected stock prices imbalances since 2008 but this effect is driven by ECB information shocks and not by pure policy shocks. Hudepohl, van Lamoen & de Vette (2019) who use the GSADF-test, a recent advances in bubble detection techniques, also find that the announcement and the start of asset purchases programmes in the euro area led to an exuberant increase in the stock prices in several countries, even after controlling for improving fundamentals.

This issue is not the subject of a consent within the monetary policy literature and there are still very few studies that establish whether balance sheet policies coincides with the formation of asset bubbles. Yet this is a key issue for central banks. They need to know if monetary policy have negative side-effects on financial stability through its effects on asset prices or if these asset price movements are desirable. This need has been all the more reinforced with the Covid-19 crisis as central banks have increased their purchases of assets and broadened the nature of securities accepted.



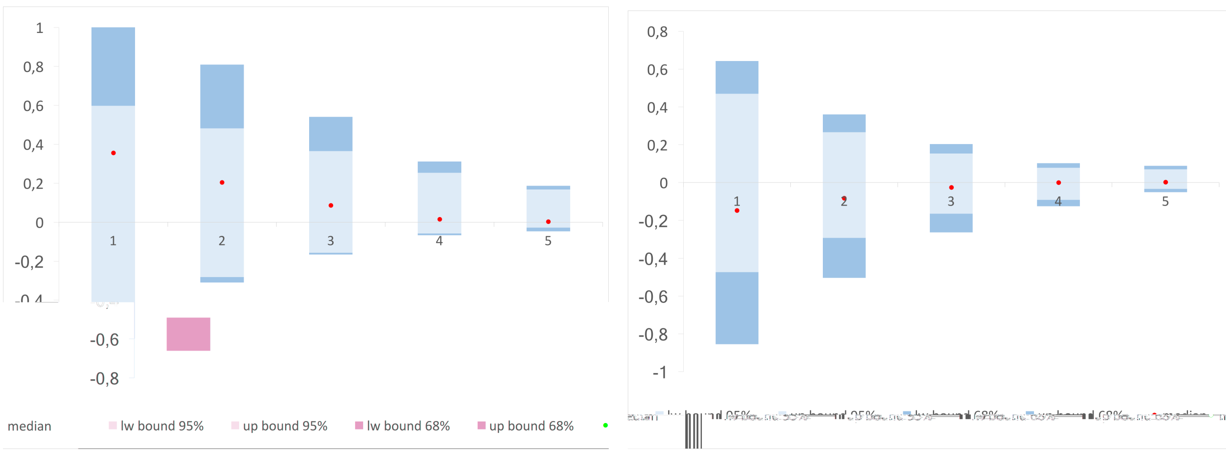
(a) UMP shock (b) CMP shock

Figure 5: Impact of monetary policy shocks on the asset price bubble indicator in the euro area



(a) UMP shock (b) CMP shock

Figure 6: Impact of monetary policy shocks on the asset price bubble indicator in the United States



(a) UMP shock (b) CMP shock

Figure 7: Impact of monetary policy shocks on the asset price bubble indicator in Japan

3.3.2 Historical decomposition analysis

Historical decomposition simulates the dynamics of the system under study for all the dates of the period under consideration and for each of the observed series, indicating the share of the historical value observed on each of the dates, which is due to each of the structural shocks. Figures 14, 15 and 16 present the historical decomposition of the SRISK indicator over the sample period, showing the contribution of a particular shock to SRISK in the euro area, the United States and Japan. We focus on the contribution of UMP shocks and CMP shocks. For the three areas, CMP shocks make a much smaller contribution than UMP shocks to SRISK fluctuations. This finding is consistent with the view that since the global financial crisis and also the use of unconventional monetary policy tools, central banks respond more or less implicitly to financial stability objectives.

In the US, the SRISK increases from 2011 to 2012 but UMP shocks contribute negatively to the evolution of this variable. During the same period, two asset purchase programmes were set up, LSAP2 (12.11.2010) and MEP (03.10.2011). Moreover, the sharp decline in the SRISK indicator over the period 2013 - end 2014 was almost entirely driven by innovations to UMP, which may be related to the launch of the LSAP3 treasuries (03.01.2013). However, UMP shocks contribute to the rise of the SRISK since the end of 2015. It coincides with the normalisation of the Fed's monetary policy which began at the end of 2014.

In Japan, UMP shocks are the main contributors to the increase in the SRISK over the 2010 - 2013 period but play an important role in the decrease in the SRISK between 2013 and 2016. The direction of the relationship appears to coincide with the degree of monetary policy accommodation. After a number of years of unconventional monetary policies including subsequent rounds of asset purchases as part of its "Comprehensive Monetary Easing" (CME) policies in 2010-2013, the BOJ, in April 2013, took monetary easing one step further by introducing Quantitative and Qualitative Monetary Easing (QQE). QQE aimed at doubling the monetary base and changing the composition of asset purchases, with greater emphasis on longer-dated government securities and expanding purchases of risk assets such as commercial paper, corporate bonds, exchange-traded funds and Japanese REITs. With the introduction of this program, the degree of accommodation of Japanese monetary policy has greatly increased. Figure 16 indicates that Japan's monetary policy from 2013 onwards has been sufficiently accommodative to reduce systemic risk.

In euro area, the decomposition suggests that decreases of the SRISK over the period 2009 - 2010 and in 2015 has been mainly attributable to UMP shocks, but UMP contributes also to increases of the SRISK between 2012 and 2013 and between 2016 and 2017. Between 2009 and 2010, the ECB launched the Covered Bond Purchase Programme (CBPP1) in July 2009 and the Securities Market Programme (SMP) in May 2010. The aim of the first programme has been to "support a specific financial market segment that is important for the funding of banks and that had been particularly affected by the financial crisis" (ECB press release, 30 June 2010). The SMP was intended to ensure depth and liquidity in malfunctioning segments of the debt securities markets. In 2015, the ECB launched its Public Sector Purchase Programme (PSPP) in order to maintain bond and repo market liquidity by supporting market making for the securities. Henceforth, these three programmes, which were intended to enhance financial stability, did contribute to the decline of the SRISK.

Regarding the periods during which UMP shocks contributed to the rise in SRISK, the ECB launched the Long Term Financial Operations II in February 2012, the Targeted Long Term Financial Operations II and the Corporate Sector Purchase Programme (CSPP) in June 2016. It may seem counter-intuitive that these programs have contributed to the increase in systemic risk (effect contrary to its intention). It could be hypothesised that the markets were expecting a more overreaction from the central bank.

These graphs show the complexity of concluding on the link between balance sheet policies and systemic risk and the need to study this link in more details.

4 Balance sheet policies and systemic risk at a disaggregated level

The aim of this section is to further study the link between central bank balance sheet and financial stability at a granular level, i.e. to study the effects of balance sheet policies on the financial institutions' systemic risk.

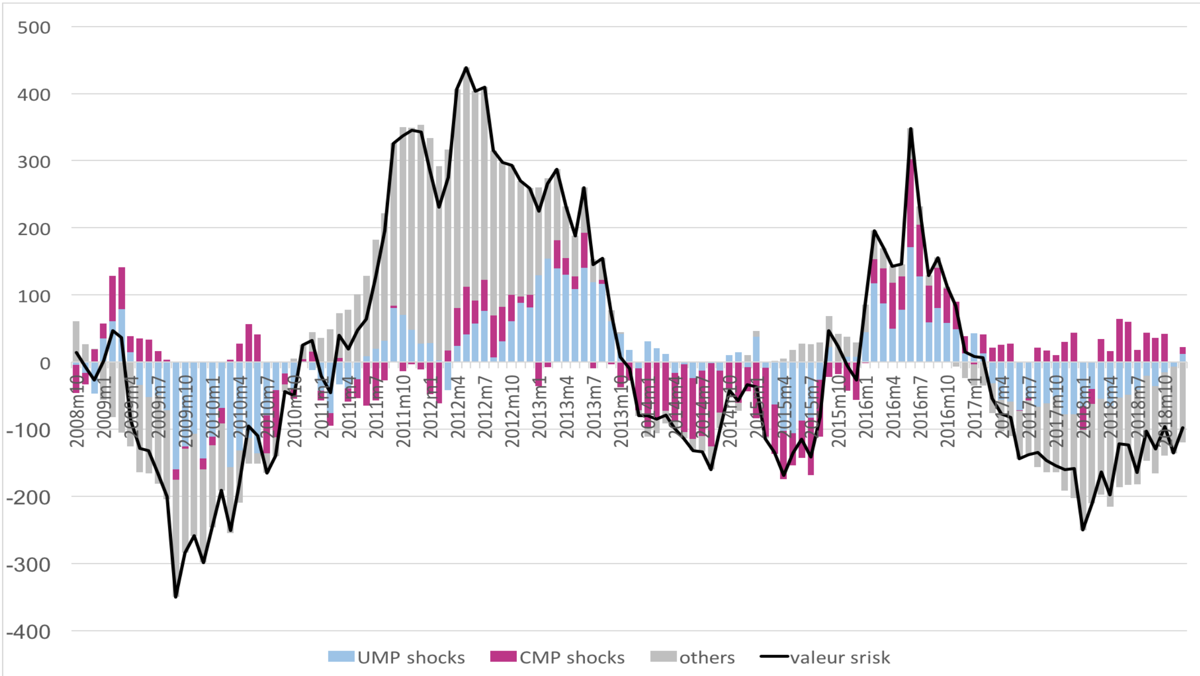


Figure 8: Euro area - Contribution of UMP and CMP shocks in SRISK fluctuations

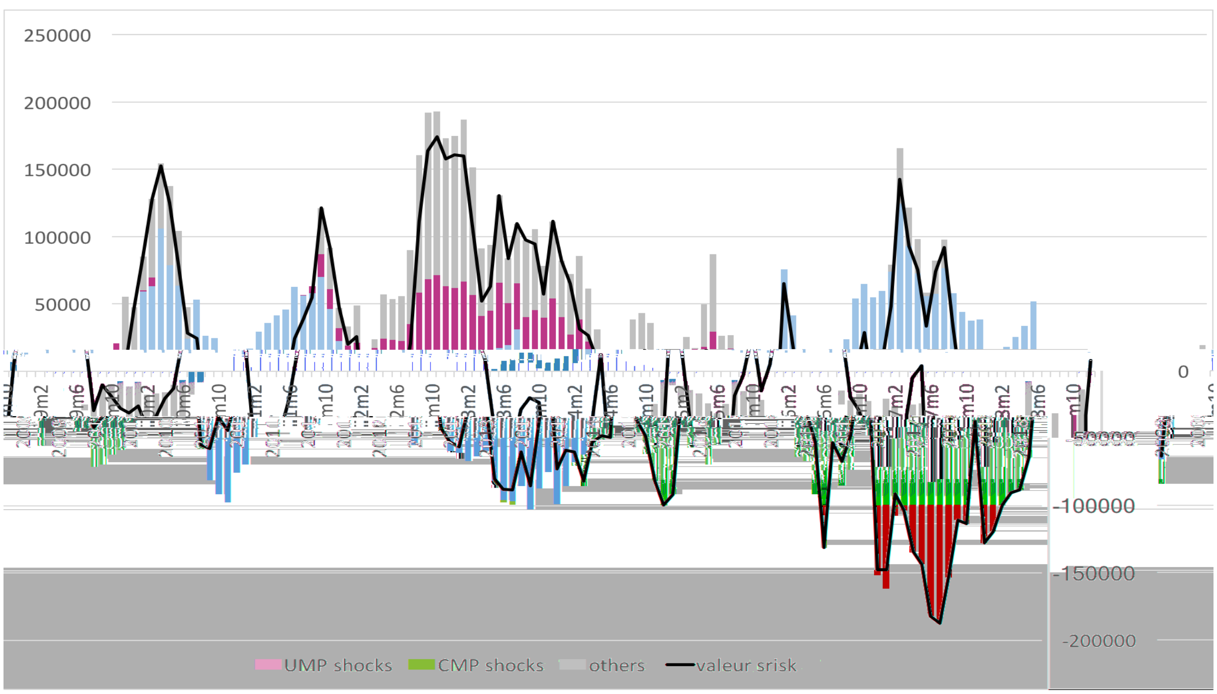


Figure 9: US - Contribution of UMP and CMP shocks in SRISK fluctuations

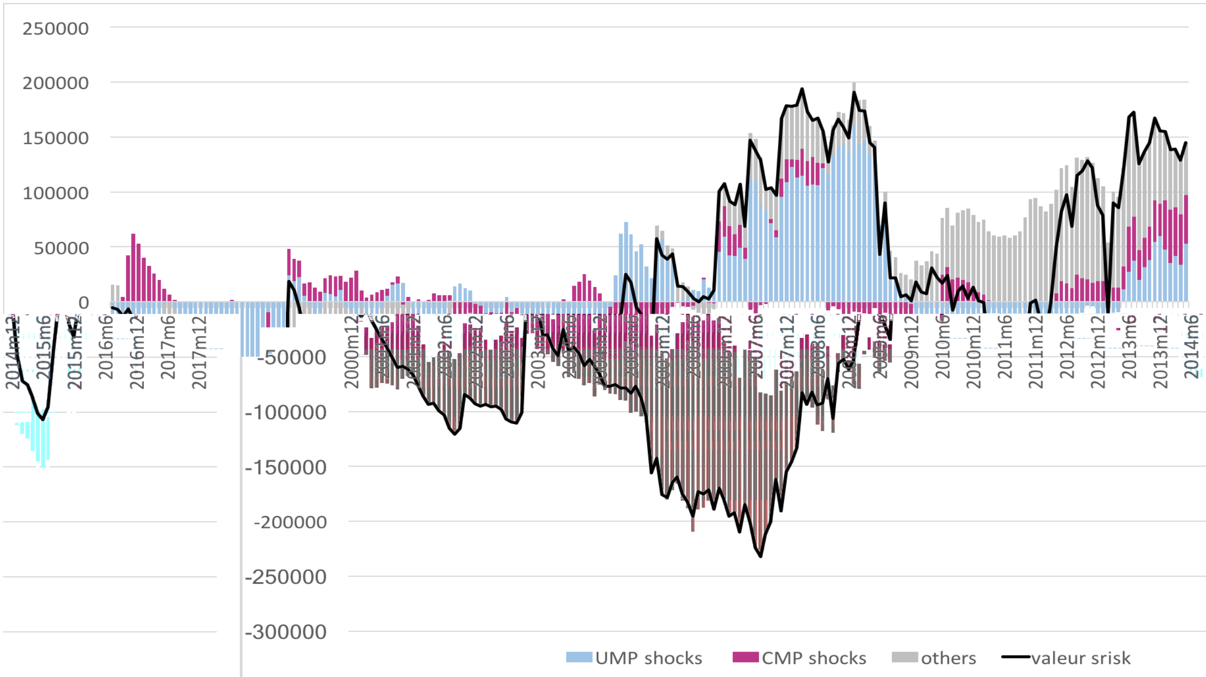


Figure 10: Japan - Contribution of UMP and CMP shocks in SRISK fluctuations

Is the positive effect of balance sheet policies on financial stability at the aggregate level to be found at a more disaggregated level ? Is it the same according to the characteristics of the financial institutions ? Is there any heterogeneous response of banks towards monetary policy changes ? What are key bank-specific variables that can affect banks' systemic risk if central banks implement the expansionary monetary policies ? Lamers (2019), for example, highlights the importance of the characteristics of banks' business models (asset/capital/financing/income structure) in the transmission of monetary policy to financial firms' systemic risk.

4.1 Literature review

The previous section highlighted the total impact of balance sheet policies on the overall systemic risk in our three research areas. This macroeconomic perspective does not allow us to perceive a possible heterogeneous effect of these policies. For example, since there are still asymmetries in the euro area countries in terms of differences in the transmission mechanisms (Berben et al., 2004), the level of unemployment and prices (Barigozzi et al., 2014) or sovereign debt, the effect of the common monetary policy could have an asymmetrical impact on financial stability. The possible heterogeneity of these effects can also be seen through financial institutions and it is equally important to identify which of them characteristics are most exposed to unconventional monetary policy measures.

Thus, in this section, we revisit the relationship between central bank balance sheet policies and systemic risk by adopting a microeconomic approach in order to focus on the possible heterogeneous response of financial institutions to these unconventional measures. This relates to two different segments of the economic literature: (1) the study of the risk-taking channel in the context of the

use of unconventional monetary policy tools, (2) the literature relative to monetary policy transmission and financial institutions' heterogeneity.
When looking at the effect of monetary policy on the systemic risk of financial institutions, most studies focus on the risk-taking channel (Borio & Zhu 2008 ; Adrian & Shin 2008; Jimenez & al. 2014 ; Dell'Ariccia & al. 2017). The risk-taking channel operates in two ways : low returns on investments may increase incentives for banks, asset managers and insurance companies to take on more risk for contractual or institutional reasons. Excessive risk-taking is especially relevant to institutions, such as insurance companies, with commitments to streams of fixed future payments (Rajan 2005). Moreover, low interest rates affect valuations, incomes and cash flows, which in turn can modify how banks measure risk (Gambacorta, 2009).
The effects of unconventional monetary policy on bank risk are more ambiguous, there are different transmission channels that can have contradictory effects. Furthermore, encouraging more risk-taking, and thereby more lending, was a key aim of asset purchases programmes, and therefore more risk taking should be regarded as a success of monetary policy (Claeys & Darvas, 2015). It is excessive risk-taking that can lead to financial instability.
Financial firms may take on additional risk and leverage because of the flattening yield curve and the cut in the term premium. At the same time, balance sheet policies may have positive valuation and liquidity effects (Brana, Campmas & Lapteacru, 2018 ; Delis & al., 2017). More precisely, Lamers, Mergaerts, Meuleman & Vander Vennet (2019) identify four channels through which unconventional monetary policy can affect bank stability. First, asset purchases flatten the yield curve and reduce banks' returns on maturity transformation and credit risk and consequently decrease banks' net interest margins which may affect bank profitability negatively. Second, loosening of monetary policy tend to boost asset prices and can be considered as a stealth recapitalization channel (Brunnermeier & Sannikov 2014). Third, lending programs of central banks lead to an alleviation of funding risk for banks and hence higher bank profitability. The fourth channel is the forbearance channel : improving profitability and funding stability may allow banks to postpone cleaning up their balance sheets by writing off non-performing loans.
According to Chodorow-reich (2014), unconventional monetary policy affects the risk held by financial institutions in three ways : by changing the hurdle rate for risky projects, through general equilibrium effects on asset values and product demand, and by possibly causing some institutions to reach for yield or expand leverage. He found that for insurance companies and bank holding companies, stock prices rose and spreads on credit default swaps fell immediately following the announcements of large-scale asset purchases. He attributed this to an improvement in the value of the assets already on the institutions' books, which lessened solvency concerns (Kuttner, 2018). Focusing on banks, Kurzman, Luck, and Zimmerman (2017) attributed the increased lending to the improvement in the banks' capital positions and not to the QE1 and QE3. Other transmission channels are listed. For example, according to Sueppel (2020), protracted suppression of volatility due to unconventional measures typically fosters undue leverage through endogenous market dynamics, such as "collateral amplification", creates a false sense of the robustness of conventional statistical risk metrics and may even impair investment professionals' personal resilience in the face market distress.
Among this area of research on risk-taking, some authors have studied the effects of monetary policy, especially conventional monetary policy, on metrics of systemic risk. Faia & Karau (2019) use a fixed effects panel VAR model and find that exogenous increase in the interest rate leads to a significant drop of CoVar (Adrian & Brunnermeier, 2016) and LRMES (Brownlees & Engle, 2012).

Lamers & al. (2019) assess the impact of monetary shocks on bank systemic risk, approximated by LRMES, using a panel regression framework. They find that accommodative policy generally has a positive effect on bank stability in the euro area due to a stealth recapitalization channel but a negative effect in the United States due to risk-shifting.
Regarding the literature relative to monetary policy transmission and financial institutions' heterogeneity, Gambacorta & Shin (2016) or Acharya et al. (2016) highlight the importance of financial institutions' characteristics in the transmission of monetary policy to the real economy, especially through the lending channel. They use an empirical specification, based on Ehrmann & al. (2003) and Gambacorta & Mistrulli (2004), designed to test whether banks with different leverage ratios react differently to a monetary policy shock. They find that higher bank capital is associated with greater lending, and that the mechanism involved in this channel is the lower funding costs associated with better capitalised banks.
Gräb & Zochowski (2017), who assess spillovers of unconventional monetary policy on bank lending, find that banks with liquidity constraints have been most positively affected by quantitative easing measures. Argimon & al. (2019), who are also interested in international spillovers of monetary policy, find that these depend on financial institutions' business models. They find marked heterogeneity in the transmission of monetary policy across the three types of institutions, across the three banking systems, and across banks within each banking system. For example, U.S. banks, which follow a more centralized business model, are more sensitive to domestic monetary policy changes than Dutch and Spanish banks.
Other authors as Lamers & al. (2019) emphasizes the role of bank business model characteristics, including asset, funding, capital, income structure, in the transmission of monetary policy to bank's systemic risk. This general result had previously been demonstrated by Delis and Kouretas (2011) and Ricci (2015) who respectively find that the increase bank risk-taking due to low interest rates is more pronounced for euro area banks with low level of risk asset and that stock prices of European banks with weaker balance sheets and operating with high-risk were more sensitive to monetary policy interventions. Lamers & al. (2019) identify monetary policy shock through heteroscedasticity approach (Rigobon and Sack, 2003, 2004) and use it to explore how bank systemic risk is affected across different bank business models in the euro area and the United States. They find that an expansionary monetary policy shock reduces systemic risk more for banks with higher asset risk in the two areas. This indicates the presence of a recapitalization effect, i.e. the accommodative monetary policy shock increases security prices and de facto causes a positive revaluation of the banks'securities portfolios. Moreover, improved collateral values may furthermore decrease the probability of default within the banks' loan portfolios. Another bank characteristic seems to play a role in the transmission of monetary policy shock to systemic risk : in the United States, banks that rely on deposit funding experience a larger increase in bank systemic risk. They explain this result by the fact that higher proportion of insured deposits can decrease monitoring incentives and increase agency problems.

4.2 Empirical approach

4.2.1 Data

In the first part of our study, we have shown that balance sheet policies tend to reduce the aggregate systemic risk in the euro area, the United States and Japan in the short and medium term.
The objective of this second part is to examine whether these effects act heterogeneously according

to the characteristics of financial institutions.
For that purpose, we use a panel VAR model with pooled estimator, consisting of monthly data for different financial firms. Our sample contains the financial institutions whose SRISK is calculated by the V-lab institute, including depositories, broker-Dealers, insurance, non depository institutions and real estate. We exclude financial firms with significant missing data during our study period.
The benchmark panel VAR model for unit i (with i = 1, 2, ..., N) has the following representation :

$$Y_{i,t} = \sum_{j=1}^{N} \sum_{k=1}^{p} A_{ij,t}^{k} Y_{j,t-k} + C_{i,t} x_t + \beta \epsilon_{i,t} \tag{6}$$

Y_{it} denotes a $n \times 1$ vector comprising the n endogenous variables of unit i at time t, while $Y_{ij,t}$ is the j^{th} endogenous variables of unit i. $\alpha_{ij,t}^{k}$ is a $n \times$n matrix of coefficients providing the response of unit i to the k^{th} lag of unit j at period t. For matrix $A_{ij,t}^{k}$, the coefficient $a_{ij,lm,t}^{k}$ gives the response of variable l of unit i to the k^{th} lag of variable m of unit j. x_t is the $m \times 1$ vector of exogenous variables, and $C_{i,t}$ is the $n \times$m matrix relating the endogenous variables to these exogenous variables. For $C_{i,t}$, the coefficient $c_{ij,l,t}^{k}$ gives the response of endogenous variable j of unit i to the l^{th} exogenous variable.
Finally, $\epsilon_{i,t}$ denotes a $n \times 1$ vector of residuals for the variables of unit i, with the following properties:

$$\epsilon_{i,t} \sim N(0, \epsilon_{ii,t}) \tag{7}$$

With :

$$\sum_{ii,t} = E(\epsilon_{i,t}\epsilon_{i,t}') = E \begin{pmatrix} \epsilon_{i,1,t} \\ \epsilon_{i,2,t} \\ \vdots \\ \epsilon_{i,n,t} \end{pmatrix} \begin{pmatrix} \epsilon_{i,1,t}' & \epsilon_{i,2,t}' & \cdots & \epsilon_{i,n,t}' \end{pmatrix} = \underbrace{\begin{pmatrix} \sigma_{ii,11,t} & \sigma_{ii,12,t} & \cdots & \sigma_{ii,1n,t} \\ \sigma_{ii,21,t} & \sigma_{ii,22,t} & \cdots & \sigma_{ii,2n,t} \\ \cdots & \cdots & \ddots & \cdots \\ \sigma_{ii,n1,t} & \sigma_{ii,n2,t} & \cdots & \sigma_{ii,nn,t} \end{pmatrix}}_{n \times n} \tag{8}$$

$\epsilon_{i,t}$ is assumed to be non-autocorrelated, so that E$(\epsilon_{i,t}\epsilon_{i,t}') = \sum_{ii,t}$, while E$(\epsilon_{i,t}\epsilon_{i,s}') = 0$ when t $\neq$ s. In this general setting the variance-covariance matrix for the VAR residuals is allowed to be period-specific, which implies a general form of heteroskedasticity.
Our dataset contains the same variables as our precedent BVAR model (consumer price index, industrial production index, central bank total assets, short-term interest rate) plus financial institutions' systemic risk and control variables for financial institutions (leverage, LRMES and market capitalisation). This allows us to control for the size, the risk and the leverage effects. Data specific to financial firms (SRISK, LRMES, leverage) comes from V-Lab website and the market capitalisation from Bloomberg. LRMES (Long-Run Marginal Expected Shortfall) is defined as the expected fractional loss of the firm equity when the MSCI World Index declines significantly in a six-month period. Regarding the leverage measure used by the V-Lab institute, it is the quasi leverage of a company which is 1 plus its book value of liabilities divided by its market value of equity. As a first step, we obtain the impulse responses functions of the financial institutions' SRISK including all financial institutions in our sample for each zone. The results are fully consistent with those

obtained in the first part. Central bank balance sheet policies seems to lower the financial institutions' systemic risk in the short and medium term.
In a second stage, for each area, we split the sample of financial firms into two groups (table 4), according to their leverage, in order to study its role in the transmission of central bank balance sheet shocks to financial institutions' systemic risk.
The importance of leverage in the transmission of conventional monetary policy to systemic risk has already been highlighted by Faia & Karau (2019). We could have replaced the leverage with capital or liquidity ratios, but we had a consistent measure of leverage across all financial institutions in our sample, with the same method of calculation, provides by the V-lab website. We select the 12 firms with the lowest leverage (Model 1 in blue) and the 12 firms with the highest leverage (Model 2 in red).

Table 4 : Sample financial institutions

	The 12 with the lowest leverage	**The 12 with the highest leverage**
euro area	Banco di Sadergna SpA, Luxempart SA, Brederode SA, Sofina SA, Corp Financiera Alba SA, Gimv NV, Grivalia Properties REIC AE, Union Financiere de France BQE SA, Wereldhave Belgium NV, OVB Holding AG, Financiere de Tubize SA, Hellenic Exchanges - Athens Stock Exchange SA, DeA Capital SpA	Societe Generale SA, Wuestenrot & Wuerttembergische AG, Aareal Bank AG, Natixis SA*, Bank of Ireland Group PLC, Deutsche Bank AG, Piraeus Bank SA, Credit Agricole SA*, Eurobank Ergasias SA, Commerzbank AG, Dexia SA
United States	T Rowe Price Group Inc, Cohen & Steers Inc, SEI Investments Co, MasterCard Inc, Franklin Resources Inc, Federated Hermes Inc, Waddell & Reed Financial Inc, Eaton Vance Corp, Moody's Corp, Equifax Inc, Brown & Brown Inc, Marsh & McLennan Cos Inc	MetLife Inc, American International Group Inc, E*TRADE Financial Corp, Bank of America Corp, Prudential Financial Inc, Lincoln National Corp, Morgan Stanley, Hartford Financial Services Group Inc/The, CNO Financial Group Inc, SLM Corp, Citigroup Inc, Genworth Financial Inc
Japan	Aeon Mall Co Ltd, Mitsubishi Estate Co Ltd, Mitsui Fudosan Co Ltd, Matsui Securities Co Ltd, NTT Urban Development Corp, Acom Co Ltd, Sumitomo Realty & Development Co Ltd, Nomura Real Estate Holdings Inc, Tokyo Tatemono Co Ltd, AEON Financial Service Co Ltd, Tokio Marine Holdings Inc, ORIX Corp	Gunma Bank Ltd/The, Shinsei Bank Ltd, Hiroshima Bank Ltd/The, Sumitomo Mitsui Trust Holdings Inc, Mitsubishi UFJ Financial Group Inc, Sumitomo Mitsui Financial Group Inc, Shiga Bank Ltd/The, Shinkin Central Bank, Resona Holdings Inc, 77 Bank Ltd/The, Mizuho Financial Group Inc, Hokuhoku Financial Group Inc

4.2.2 Results

Impulse responses from the institutions with the lowest leverage are not significant at any horizon for the euro area and the United States. They are significant only for Japan up to the 12th month but the effects are very small. These results seem consistent given that financial institutions with

low leverage do a priori not pose a financial stability problem. Thus, central banks have little leeway to reduce their vulnerability.
Regarding the other group, the balance sheet shocks substantially affect their SRISK indicator, i.e. balance sheet policies reduce their expected capital shortfall. Impulse responses are significant up to the 6th month for the United States, 12th month for the euro area and up to the 24th month for Japan. We can put forward several hypotheses that could explain this result.
First, the institutions with the highest leverage being the most indebtedness are also the most vulnerable ones as during downturns, leverage amplifies the losses incurred by investors. As these financial firms take the most risk in terms of purchasing financial assets, they will benefit more from the raise of the value of legacy assets generated by central bank asset purchase programmes with the strengthening of their balance sheet.
Also, balance sheet policies will be geared more towards the riskiest banks. For example, when central banks buy back risky securities from banks' balance sheets, these actions will further reduce the systemic risk of the riskiest financial institutions. These idea may also explain the longer duration of the effects of balance sheet policies in the case of Japan ; the BoJ buys ETFs (the riskiest assets) since 2010. An other effect of balance sheet policies, is to reduce delinquency and default rates and to raise profits, by promoting recovery in the real economy. This effect is stronger for banks with the highest leverage as they are the ones who grant the most loans.
Our results suggest that the effects of balance sheet policies on stock market and on the economic activity which are reflected in the reduction of the srisk, more than offset the negative impact of low interest rate on the risk-taking behavior.
Our findings are close to those of Ricci (2015) or Lamers & al. (2019), i.e. central bank balance sheet shocks reduces systemic risk more for the financial institutions with the highest leverage.
This second part confirms the role of balance sheet policies to reduce the systemic risk and point to a strong role for financial institutions' characteristics in shaping the transmission mechanism of balance sheet policies to financial institutions' systemic risk.

5 Conclusion

In this paper, we have analysed the effects of balance sheet policies on systemic risk in the euro area, the United States and Japan, using a monthly structural BVAR model in the first part of our study and a panel VAR model in the second part. Our identification strategy of balance sheet shocks is based on sign and zero restrictions.
Our empirical analysis points that asset purchases programs and lending programs of central banks have significantly decrease the aggregate systemic risk in the short and medium term. In the long-term, these shocks do not appear to pose a threat to financial stability, as the results of the impulse response functions are not significant. We also find that unconventional monetary policy has a heterogeneous effect on financial institutions : the effect is stronger for those with the highest leverage. Overall, our findings contribute to the recent literature on the link between unconventional monetary policy and financial stability by showing that central banks' balance sheet policies lower the SRISK several months after the shocks. These results are robust to the use of two different approaches : a macroeconomic approach and a microeconomic approach.
As a follow-up to this work, it would be interesting to study the effects of balance sheet policies on financial stability in a more granular way focusing on a particular monetary policy tool and its effect on a particular market segment.

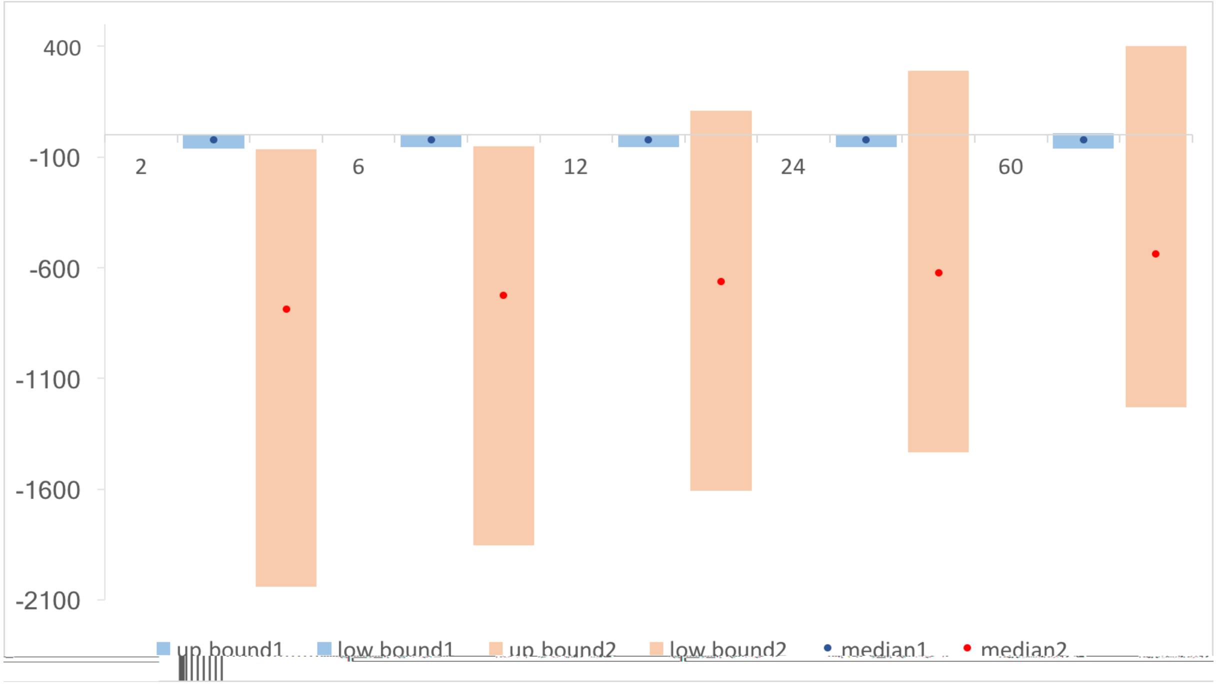


Figure 11: Euro area - IRF of SRISK to UMP shock

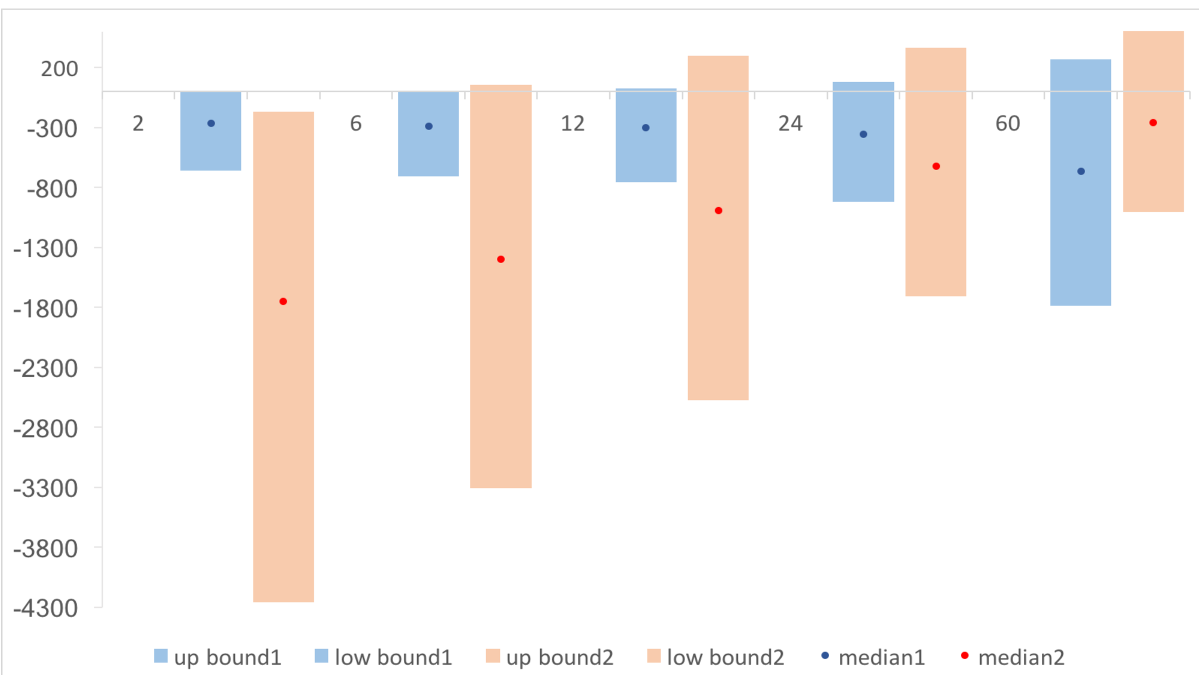


Figure 12: US - IRF of SRISK to UMP shock

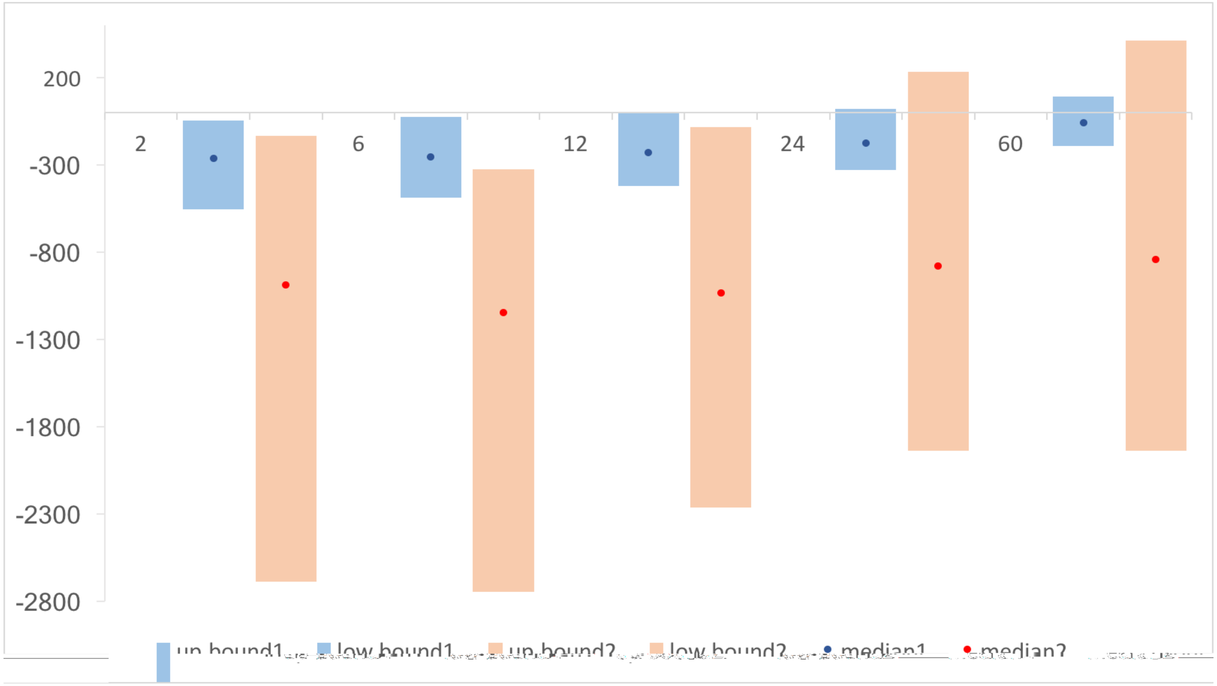


Figure 13: Japan - IRF of SRISK to UMP shock

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APPENDIX A

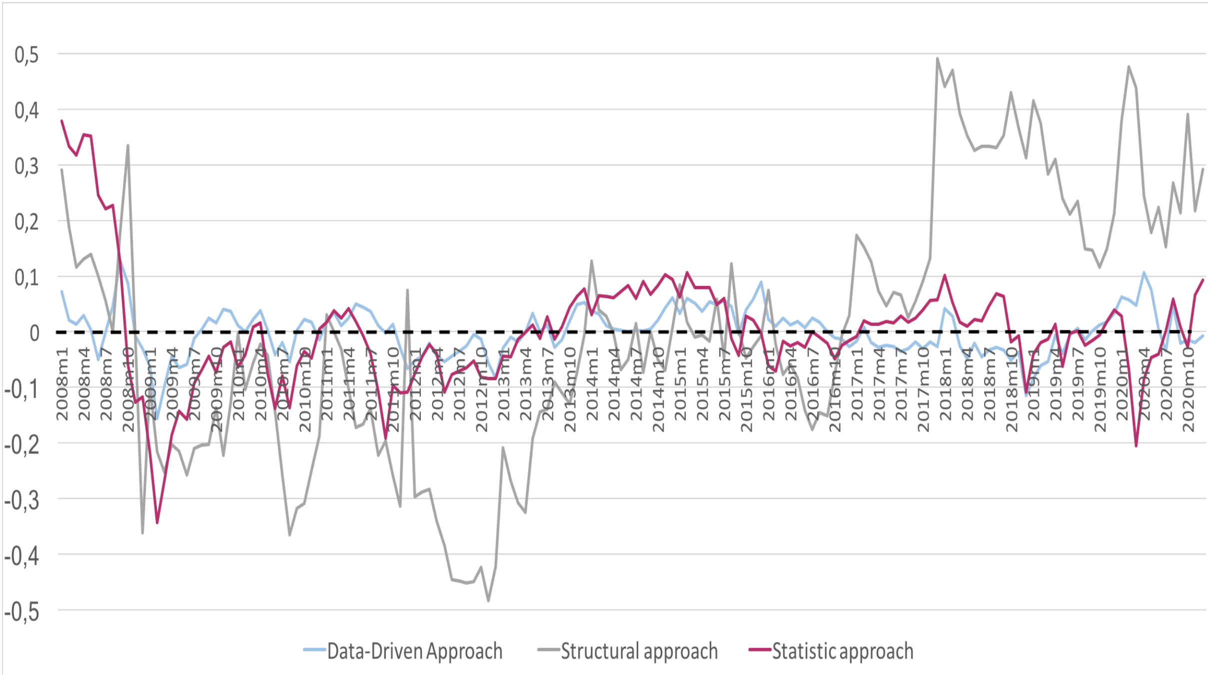

Figure 14: US - Deviations of S&P 500 from various benchmarks

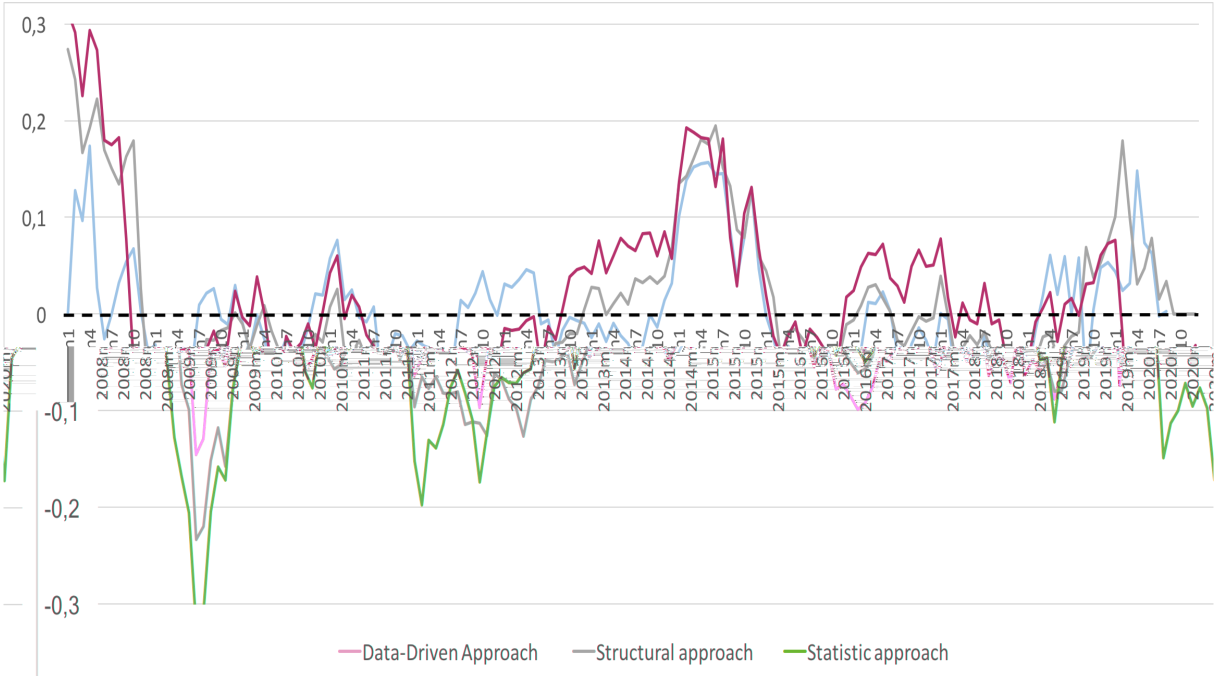

Figure 15: Euro area - Deviations of Euro Stoxx 50 from various benchmarks

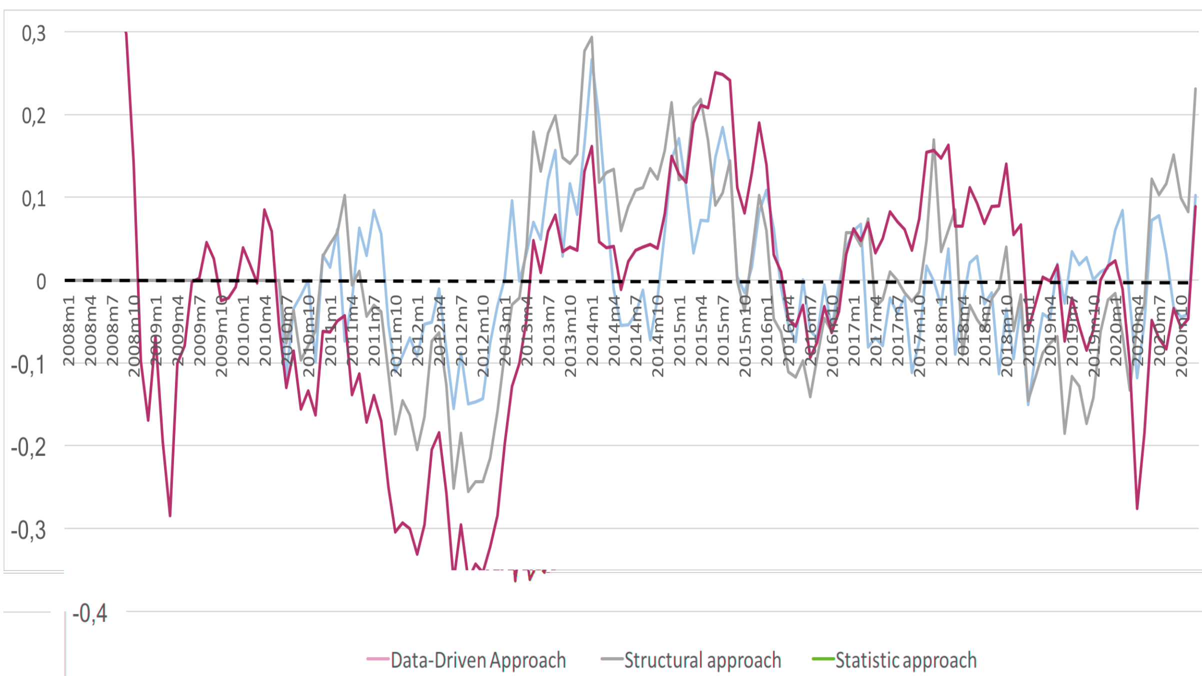

Figure 16: Japan - Deviations of Nikkei 225 from various benchmarks

APPENDIX B

Table 5 : Descriptive statistics (sample with the lowest leverage)

		euro area	**United States**	**Japan**
Leverage	mean	1.19	1.22	4.21
	sd	0.24	0.17	2.36
	min.	1	1.01	1.30
	med.	1.12	1.19	3.54
	max.	5.03	2.02	38.32
SRISK	mean	-832.85	-8676.58	-3343.30
	sd	742.20	14872.43	4202.62
	min.	-4600.30	-131156.20	-22341.40
	med.	-574.65	-3263.20	-1595.35
	max.	-28.70	-174.70	4870
LRMES	mean	30.37	41.10	37.68
	sd	10.81	7.63	6.48
	min.	-4.98	22.44	18.54
	med.	29.80	42.39	37.49
	max.	83.63	63.67	63.64
Market cap.	mean	1309.31	16055.26	10610.73
	sd	1169.95	26520.60	9872.09
	min.	170.53	373.82	714.30
	med.	812.24	6265.16	4828.70
	max.	6890.44	231169.90	45120.55
Observations	*3168*	*3168*	*3168*	*3168*

Table 6 : Descriptive statistics (sample with the highest leverage)

		euro area	**United States**	**Japan**
Leverage	mean	417.38	18.28	33.49
	sd	1945.61	16.16	10.80
	min.	1.80	3.30	11.57
	med.	45.64	14.31	32
	max.	22740.52	219.45	82.03
SRISK	mean	32132.53	21639.86	35529.38
	sd	38692.46	29692.10	47425.16
	min.	-4551	-48228.90	1411
	med.	12202.10	9708.05	8424.80
	max.	170166.90	154312.50	184029.50
LRMES	mean	50.30	47.64	29.52
	sd	15.33	10.58	13.28
	min.	11.52	11.74	-23.11
	med.	52.36	47.05	32.62
	max.	94.93	98.03	59.91
Market cap.	mean	12687.42	43379.44	18423.51
	sd	14534.84	55493.58	24687.65
	min.	8.38	169.97	1083.62
	med.	6786.11	18661.15	5929.64
	max.	68261.16	329193.68	119054.52
Observations	*3168*	*3168*	*3168*	*3168*