University of Naples "Federico II"

Ph.D. in Economics

XXXIII ciclo

Essays in Empirical Macroeconomics: Frequentist and Bayesian Analysis

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Academic Year 2021-2022

To My Mum

Acknowledgements

I would like to thank Dimitris Korobilis for all his support and guidance in my MRes studies. Without him nothing of what I am discussing (and even analysing) would have been possible. This thesis is the result of the author's original and individual research activity, which has been financially supported for two years and half by the university of Naples Federico II, which I gratefully acknowledge.
Many thanks to Hamid Nejadghorban, Simin Nie, Aubrey Poon, Aristeidis Raftapostolos and all PhD candidates of the University of Glasgow, University of Strathclyde and University of Essex for their useful comments and stimulating discussions.
I would also want to thank Giorgio Di Giorgio, Guido Traficante and Salvatore Nisticò, met in my MSc studies, for many helpful discussions.
Finally, I would want to mention the great motivational support of my family and my friends, which allowed me to write this work with passion and motivation. Thank you all.

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Abstract

This work presents two empirical studies aimed to evaluate the financial and macroeconomic effects following monetary policy and political decisions. Both studies rely on the application of an event-study methodology, which has long been considered an accurate statistical procedure to quantify the impact effects following a broad range of events, such as political decisions, implementation of new business strategies, exogenous geopolitical events, and many others. The outline of this thesis is structured as follows.

Chapter 1 expands the empirical work of Altavilla *et al.* [2014] by considering the impact of alternative non-conventional monetary policies (Securities Markets Programme, Longer-Term Refinancing Operations and Outright Monetary Transactions) on multiple financial assets: (i) benchmark stock market prices, (ii) bank index prices, (iii) 10-year government yields. After assessing the economic impact of the aforementioned policies, we perform a multi-country vector autoregression in order to analyse the dynamic effects that a positive monetary shock generates on the gross domestic product and the harmonised index consumer price of 4 European countries (Germany, France, Italy and Spain). In contrast with Altavilla *et al.* [2014], and according with our empirical evidence, we conclude by inferring that not all non-conventional policies behave as exogenous positive monetary shocks, as Longer-Term Refinancing Operations has generated negligible financial effects on the economies considered.

Chapter 2 investigates the economic impact effect on benchmark stock market prices and 10-year government yields of the main trading partners of the UK, after nine important Brexit events listed in Table 2.1. We cover a sample period running from the referendum result of June 24, 2016 through the general elections of December 12, 2019. The surprising Brexit outcome

is considered as an exogenous uncertainty shock, and thus we investigate the effects that a UK uncertainty shock generates on the real economy of 15 alternative countries. Then, in the spirit of Brodersen *et al.* [2015], we also investigate the average macroeconomic effect of this political decision, by comparing two different scenarios: the case of *Brexit* and *no-Brexit*. The latter is represented by estimating a stochastic system from 1996Q1 through 2019Q1, and then forecasting the gross domestic product and the inflation rate for the next 3 years.

In both studies when the number of predictors is objectively low, we use a frequentist econometric approach. Whereas, when the equations become richly parameterized, we apply econometric strategies based on Bayesian theory (Minnesota prior, Gibbs sampling, Metropolis-Hastings) in order to deal with the curse of dimensionality.

Chapter 1

The Financial and Macroeconomic Effects of SMP, LTRO and OMT Announcements

This study evaluates the financial and macroeconomic effects following the announcements of three non-conventional monetary policies: (i) Securities Markets Programme (SMP), (ii) Longer-Term Refinancing Operations (LTRO) and (iii) Outright Monetary Transactions (OMT). The analysis focuses on four European countries: Germany, France, Italy and Spain. Empirical results show that 10-year government bonds, benchmark stock market and bank index prices have been significantly responsive only after SMP and OMT announcements, while LTRO impact effects have been mostly negligible. Impulse response functions display that a positive monetary shock yields beneficial and persistent results for the gross domestic product of Italy and France. In contrast, Germany and Spain real economy smoothly decreases after 2 years. More homogeneous cross-country results have been found in the country-specific inflation response.

keywords: Securities markets programme · outright monetary transactions · longer-term refinancing operations · event-study · multi-country vector autoregression · Gibbs sampling.

1.1 Introduction

The term *non-conventional monetary policies* refers to a specific kind of maneuver, in which a central bank may adopt some forms of interventions, that are considered of extraordinary nature (i.e. negative interest rates, asset purchases, extended liquidity operations). The global financial crisis and COVID pandemic are good examples to explain the use of unconventional approaches by central institutions, as long as the standard measures are temporarily of no help[1].

There are several situations in which the rate and credit channels lose importance, bringing a conventional policy to lose its effectiveness. For example, when interest rates approach to zero, investors are more likely to hold cash and not to buy medium\long-term securities for the sake of speculation. If this happens, the maneuver of the rates, through the lowering of the benchmark rates, and therefore more generally the short-term rates, does not produce any effect. In particular, investors are prone to believe that interest rates will grow rapidly enough, causing a capital loss greater than the interest income resulting from holding securities. Hence, the aggregate money demand becomes infinitely elastic at interest rate levels close to zero. In this scenario, no matter how much money a central institution is willing to distribute all over the market, money holders will simply accumulate this wealth, letting the monetary policy being ineffective. This is what Keynes [1937] commonly named as "liquidity trap". Second, the credit channel is also ineffective when banks face a financial crisis, in which, since they have suffered capital losses, they can not grant any new credit again; the interbank market is blocked and the liquidity situation remains critical.

These unusual economic difficulties developed violently during the global financial crisis 2007-2009. In this scenario a central bank can move towards the use of unconventional policies, which can be summarized as follows. First, massive creation of liquidity (quantitative easing), through the purchase of assets in the market, with the hope that traders are committed to buy the excess cash stocks. Second, shift-down the interest rates curve (influencing economic prices is the main goal, giving a framework of low and

[1] See Mishkin [1995] for an overview on standard mechanisms of monetary transmission

stable rates). Third, outlet of the credit market, which purpose concerns the credit reactivation in the economy and this can be done through the refinancing operations of the central bank, which accepts as guarantee the securities issued by private individuals.

A number of studies have investigated the economic effects related to unconventional monetary policies. Some examples are Christensen and Rudebusch [2012] and Fratzscher *et al.* [2018] for the US economy, Kapetanios *et al.* [2012] and Breedon *et al.* [2012] for the UK market, Peersman [2011] and Altavilla *et al.* [2014] for the euro area. The latter paper has been influential in my thinking. In particular, Altavilla *et al.* [2014] estimates the financial and macroeconomic effects that outright monetary transactions (OMT)[2] announcements generated on bond yields of Germany, France, Italy and Spain. However, even though the European sovereign bonds are the main object of the unconventional policy, Altavilla *et al.* [2014] have left uncovered some research questions that we aim to answer in this paper. First, it might be of interest to understand whether the announcements have generated any other effect on alternative assets (e.g. benchmark stock market indexes and bank' indexes), and consequently evaluate the transmission mechanism at a macro level (i.e. impact on the gross domestic product and the level of inflation). Generally, when a monetary policy engages in accommodative decisions, several asset prices have a positive reaction in the short run[3], which may influence the level of real economy as well. Moreover, other than OMT, the European Central Bank (ECB) engaged in two additional unconventional monetary policies before the quantitative easing: securities market programme (SMP) and long term refinancing operations (LTRO). Hence, this paper expands the empirical evidence found in Altavilla *et al.* [2014], by evaluating the financial and macroeconomic effects of SMP, LTRO and OMT on several assets.

The empirical analysis is conducted in a two step procedure. First, we

[2]This is an unconventional monetary policy announced by the former president of the European Central Bank Mario Draghi in July 2012, which states that the central institution would have purchased bonds issued by EU member states, in secondary-sovereign bond market in order to preserve the ongoing of euro currency.

[3]See Bernanke and Gertler [2000], Clarida [2012], Coenen *et al.* [2012], Bauer and Neely [2014], Bowman *et al.* [2015] and Wu and Xia [2016] among many others

perform an event-study analysis to evaluate the impact effect on (i) benchmark stock market indexes, (ii) bank financial indexes (we select 2 banks per country that have the highest level of liquidity assets), and (iii) 10-year government bonds, following SMP, LTRO and OMT announcements. The procedure follows Altavilla *et al.* [2014]. Namely, we regress the financial asset on dummy variables that take value 1 on the day of the announcement, while the remaining observations are set equivalent to zero. For each index we evaluate the reaction in a 2 and 5-day window respectively. In this way, we can assess whether the policy generates temporary or even persistent effects. Moreover, the standard regression is augmented by including an additional variable that collects - and even controls - the financial and macroeconomic surprise effect. We refer to this factor throughout the paper as *News*. When the analysis is meant to evaluate the impact effect on benchmark stock market and bank indexes, *News* incorporates the prediction error of S&P Global Equity Index (the hierarchical motivation behind the choice of S&P can be found in Burdekin *et al.* [2018]). Whereas, when the dependent variable is the 10-year government bond, *News* is the prediction error of 105 different macroeconomic variables listed in Table 7 at the end of the paper.

In a second analysis, we consider the unconventional policies as positive monetary shocks occurring in financial markets, and therefore we quantify the macroeconomic impact that these structural variations generate on the gross domestic product (GDP) and the level of inflation of each country analysed in the first exercise. In particular, for each country we consider the GDP, the harmonised index consumer price (HICP), and in turn 10-year sovereign bonds, benchmark stock market indexes and 2 private bank' indexes, plus 2 common factors (STOXX50 assessing the volatility in European markets, and the euro area overnight money market rate as a measure of monetary policy decisions). Therefore, we construct 4 different large multi-country vector autoregression (VAR) of 14 dependent variables. The stochastic systems are estimated in a Bayesian fashion, by using a Gibbs-sampling methodology thoroughly discussed in appendix .3.

Empirical evidence shows that overall unconventional monetary policies have generated trivial effects on 10-year government yields of France and Germany, while for Italy and Spain the impact has always been statistically significant. Namely, 1% of significance for Italy and Spain following SMP and OMT announcements in both classical and controlled experiment. 10% of significance for Germany after SMP, LTRO and OMT, and a general 10% of significance for Italy and Spain following LTRO. French 10-year government bonds have been mostly unaffected. More homogeneous effects can be seen for benchmark stock market indexes and private bank' indexes, since they all positively reacted after SMP and OMT, while the effects generated by LTRO can be considered negligible.

Turning to a macro level, after a positive monetary shock the GDP of Italy and France show positive and persistent effects, while in Spain and Germany, the positive reaction of real economy on average decreases after two years. Consumer price effects are less heterogeneous, since for any financial variable included in the multi-country VAR, there is a positive reaction at the impact, and a smooth decrease after one year.

This paper links to many other works in the academic literature. First, it is related to empirical studies assessing the economic consequences following a government or a market strategy decision with the prominent contributions of Dimson and Marsh [1986], Austin [1993], Agrawal and Kamakura [1995], Binder [1998] and Swanson *et al.* [2011]). According to these well-cited papers the event-study is a well suited methodology when the researcher aims to investigate asset price reaction following specific announcements or events. In our case, we want to evaluate the financial and macroeconomic effects following 3 different monetary policies and the event-study is used as a starting point to select the right variables to include in the large VAR. Second, this work is also related to the academic literature discussing the economic effects following unconventional policy announcements (Gertler and Karadi [2011], Joyce *et al.* [2012], Gambacorta *et al.* [2014], Neely [2015] and Acharya *et al.* [2019]). Therefore, empirical results found in this paper might be a sort of guide for central institutions, in order to understand how financial assets react after a positive monetary shock.

The remainder of this paper is structured as follows. Section 1.2 presents a brief overview of non standard policies in general, and the European ones investigated in this study. Section 1.3 introduces the event-study methodology used to estimate the impact of SMP, OMT and LTRO. Section 1.4

illustrates the structural shocks by using a multi-country VAR, and section 1.5 concludes.

1.2 The New Monetary Policies of the European Central Bank

The central banks of the major developed countries, in response to the global financial crisis, have adopted non-conventional monetary policies. Previously, the monetary policies of many countries seemed to follow the Taylor rule, according to which the central bank varies the nominal interest rate in response to changes in inflation and GDP, with an inflation target as a benchmark. The financial crisis of 2007 has led the monetary authorities of the major countries to no longer consider the conventional criteria on which they had always based their interventions, pushing them to adopt exceptional measures called non-conventional policies. The Federal Reserve (FED) has been forced to go through unconventional measures, not only because of the severity of the crisis, but also because the traditional instruments could no be of help anymore, as the Fed Funds Rate was already at minimum levels (close to zero). Therefore, the FED has developed innovative monetary policy instruments to alleviate the tensions on the money market and reduce the repercussions on the real one. These instruments were introduced at an early stage of the crisis and subsequently upgraded following the bankruptcy of Lehman Bank. The FED adopted the quantitative easing measures to facilitate the access to credit loans and stimulate the economic growth. An operation where the bank acts as an investor of its economy. Hence, FED ordered the purchase of securities for a total of $ 40 billion per month by introducing the Term Auction Facility (TAF), which provides liquidity after one month through an auction mechanism and against a broader category of guarantees. Moreover, since 2009, in accordance with the Treasury, the central bank started buying (i) medium and long-term treasuries, (ii) debt securities of federal agencies and (iii) mortgage-backed securities issued by federal agencies.

The European Central Bank (ECB), in line with FED, also adopted unconventional policies to fight the financial crisis. In particular, from 2008 through 2011, the total assets in the ECB's balance sheet have doubled to around € 3,000 billion. However, the two banks faced the crisis by using different instruments in accordance to the different structure of their financial markets and the different role of banks in financing the economy. Namely, while the FED developed a program aimed to ensure the direct disbursement of credit to households and businesses, the ECB has favored the bank's liquidity offer to counter the credit contraction, implementing the so-called *Credit-Easing* (CE).

Thus, FED and ECB have faced the crisis by using different instruments. The former has undertaken direct actions aimed to ensure the direct disbursement of credit and has launched plans to purchase public and private securities, the latter has favoured the supply of liquidity to banks in order to contain the contraction of the credit supply and has always sterilized the unconventional measures of monetary policy, giving rise to the so-called *Credit-Easing*. In the next sections we briefly describe the nature of 3 unconventional policies that we use in the empirical exercises in section 1.3 and 1.4.

1.2.1 Securities Markets Programme

Since October 2008, the ECB has conducted any refinancing operation through fixed rate auctions with full awarding of the amounts, ensuring in this way an unlimited liquidity offer. Unlike the usual practice, the financial institutions were awarded the full amount of liquidity required. This measure was designed to meet the short-term needs of banks in order to facilitate the provision of credit. The central bank has extended the types of assets eligible for collateral in open market operations, and it has also increased the number and the frequency of longer-term refinancing operations, thereby increasing the size of assets. The refinancing operations that, before 2008, were mostly constituted by "short-term" refinancing operations, at the beginning of 2012 were almost exclusively made up by "longer-term" refinancing operations. Since 2009 the ECB has intervened directly in some securities markets:

i. The first intervention has concerned the covered bonds. In fact, between 2009 and 2012 the ECB bought € 68 millions of them through two purchase programs: The Covered Bond Purchasing Program (CBPP and CBPP2), to look after the financing conditions of banks and firms. The aim of both programs was to support a specific segment of the financial market that is important for bank's financing operations, which had been particularly affected by the financial crisis.

ii. The second intervention has concerned the Securities Markets Programme (SMP) related to the sector of government bonds. This strategy provided the purchase, on the secondary markets, of government bonds accepted by the ECB as collateral in the refinancing operations. The program initially concerned Greece, Ireland and Portugal; subsequently, in August 2011, it was extended to Spain and Italy as well.

The core of SMP was to purchase country-specific securities on the secondary market for a value of € 219 millions until the end of 2012, with the aim of fixing the serious malfunctions of debt security markets of several European countries and to safeguard the effectiveness of monetary policy transmission. The impact of the program on government bond spreads has been immediate, in fact the spread between Greek and German government bonds recorded a fall of 400 basis points; for Italy and Spain, the fall touched 100 basis points. The long-term effect on sovereign bond was significant as well, in fact it has been estimated a reduction between 0.1 and 7 basis points for 10-year bonds for every € 100 millions of securities purchased. Similar results were found for 5-year Italian bonds. According to some studies (see for example Ghysels *et al.* [2017] and Schwaab *et al.* [2013]), SMP financial effects could even be around 200 basis points on Italian 2 and 10-year bonds. Furthermore, ECB purchases significantly reduced the volatility of government bonds.

1.2.2 Longer-Term Refinancing Operations

In October 2011 and December 2012, two bank refinancing operations were activated: the 3-year Longer-Term Refinancing Operations (LTRO) that allowed liquidity to the Eurozone for more of € 1,000 billions avoiding the risk of a looming crisis. Through the LTROs the European banks obtained liquidity at a rate of 1%, of which one quarter of the funds was given to Italian banks. The two 3-year auctions have added additional liquidity of about € 523 million to the system. In the first few months of 2014, funds amounting to € 60 million were returned. At the end of 2013, Italian banks held € 232 billions of LTRO funds, with a 15% restitution rate compared to 39% of the Euro-area. It has been estimated that LTRO liquidity injections have reduced interest rates on the interbank market by 70-100 basis points. Most of the funds that the Italian banks obtained in the LTROs were used to buy domestic debt securities. Between 2011 and 2013 purchases were about € 150 billions, and the share of assets held by credit institutions in government bonds went from 6% to 10% of these purchases; bonds with a fixed term of up to 5 years were more than 80%.

1.2.3 Outright Monetary Transactions

In September 2012 ECB Board of Directors announced that the bank might have engage in outright monetary transactions (OMT), through which the ECB undertakes to buy government bonds on the secondary market without restrictions. This was a plan with the aim to reduce the pressures arising from the spread and allaying fears on the international markets. Main points of OMT are summarized as follows:

i. The ECB does not set ex ante quantitative limits on the security purchases;

ii. Transactions take place on the secondary market; the market for outstanding securities;

iii. The liquidity created by the OMT plan will be sterilized, to avoid that the plan becomes a way to introduce liquidity with consequent inflationary tensions;

iv. In order to receive aid from the OMT maneuver, a cross-compliance program must be signed.

Therefore, the subscription by the State to a program of the European stability mechanism fund (EMS) describes a necessary condition in order to engage in OMT program. The cross-compliance program concerns the supervision of budgets and the application of structural reforms. The OMT plan is a security measure to protect investors, as the ECB is meant to be the guarantor of the Euro system. On the 4^{th} of September 2014, the Governing Council of the ECB decided to launch a new program to purchase covered bonds (CBPP 3) which, together with the program to purchase securities issued for securitization transactions and the LTRO program, had the purpose to facilitate the orientation of ECB's monetary policy, and the provision of credit in the Euro area. The covered bonds are considered suitable if they meet some conditions (such as a credit rating of at least grade 3, equal to a BBB rating, and the 70% limit of the issue in regard to the total share held by the central bank) in addition to what was required in the previous programs.

1.3 Event-Study

To assess the effects of unconventional policies on financial markets, an event-study methodology has been performed. This "mature" strategy still represent a well-suited methodology in order to quantify the immediate impact of corporate events on an economic variable of interest. It has been largely used in the academic literature with the prominent contributions of Fama *et al.* [1969], Dimson and Marsh [1986], Boehmer *et al.* [1991], Austin [1993], Agrawal and Kamakura [1995], Binder [1998], Kane [2000], Kothari and Warner [2007], and Kolari and Pynnönen [2010]. The methodology of event-studies is in continuous growth, and despite its easy implementation, the literature has concluded that this strategy provides reliable inference either on serving empirical results following government announcements, and on assessing market efficiency. Event-study methods have been used to study the impact effect on different statistical measures[4], however in this work we discuss the financial and macroeconomic effects of unconventional policies on the mean values of alternative asset prices: (i) benchmark stock market indexes, (ii) private bank stock indexes, and (iii) 10-year government bond

[4] On trading volume like Beaver [1968] and Campbell and Wasley [1996], on operating performance (Barber and Lyon [1996]), or on return variances (Patell [1976]) and so on.

yields, of 4 European markets: Germany, France, Spain and Italy. Daily data run from 2002M1 through 2012M12 for a total of 2,807 observation, and as common practice we regress each financial measure on a dummy variable that takes value 1 on the day of the announcement, and 0 in the $T-1$ remaining days. We report for each index a study of 2- and 5-day window. Impact values are measured by performing an F-test on the total variation of the index, in line with Altavilla *et al.* [2014].

SMP. The unconventional policy was announced by the Governing Council on 10 May 2010. Therefore, in this case we regress each financial index on one dummy variable and the linear regressions that we use to assess the financial effects are

$$\Delta y_t = c + \beta_1 D_{1,t} + \epsilon_t \tag{1.1}$$

$$\Delta y_t = c + \beta_1 D_{1,t} + \beta_2 News_t + \epsilon_t \tag{1.2}$$

where y is a $T \times 1$ vector of observed values, describing in turn the benchmark stock market index, the private bank stock index, and the 10-year government bond yield of each country; c is a $T \times 1$ vector of constant terms; D is a $T \times 1$ vector of dummy variables; $News$ of equation (1.2) is a $T \times 1$ vector reporting the financial and macroeconomic surprise effect, that serves as a measure to control the impact effect; βs and ϵ are respectively the coefficients and the error terms. Δ refers to the daily variation of the financial variable of interest. The model is estimated through ordinary least squares, and each dummy variable may assume a value of 1 on the day of the announcement, and for the next 4 days as well. The daily change is first analysed in a 2-day window (see Table 1.1), and then reported in a 5-day window (see Table 1.2) fore each index. It is evident that SMP has been statistically significant for all benchmark stock market indexes analysed for both classical and controlled experiment. Moreover, according to Table 1.2, we can also infer that the effects have not only been immediate, but the closed prices continued to turn positive even after day 4. The same can be inferred in regard to the stock index of the main two banks of each country. In fact, from Table 1.3 we can see that SMP impact effect has been 1% statistically significant for the banking sector in the classical and controlled experiment, and this positive impact has been persistent as well (see Table 1.4). After this announcement, in Piazza Affari, FTSE-MIB closed at 11.3% gaining 2,053 points; 302 in Paris, where CAC-40 increased of 9.6%; IBEX-35, Madrid's benchmark stock market index, showed a 14% growth with 967 points and finally DAX scored a plus 5.3% gaining 320 points. The different dimension of the absolute variation depends on the average quotation price, which is different across each market. The greatest impact materialised on the day of the announcement, which was a significant result especially for Piazza Affari; the second biggest boom ever. The raise was determined by a mix of factors, first of all the maxi-plan launched during the weekend in order to protect the Euro currency: a package of measures that guaranteed a financial stability in European markets, which provided bilateral loans from Eurozone countries for € 440 billion, one third of which came from the "substantial" IMF contributions. This package, was interpreted by investors as a way to defend the most exposed financial institutions to any possible sovereign debt crisis; namely, the credit institutions. Therefore, as the banks had slashed the price lists on the previous weekend, after seven days they took them into orbit. It is not a coincidence that in Milan the bundle of blue chips raised to a higher level than the general index of the list (Ftse all share, + 9.16%), or it can not be surprising that the French Stock Exchange, which financial sector had been hardly hit in the previous Friday, rebounded more than in London (+ 4.57%) and Frankfurt (+ 5.3%). By the way, the euphoria did not last long. The following day, in fact, the European stock exchanges after a decisively declined opening, widened in the middle of the session, and recovered at the end, behind the wake of Wall Street that, after having fluctuated above and below the parity, archives the daily prices with the following result: Dow Jones loses 0.43% and S&P 500 0.34%. Nevertheless, with the exception of Frankfurt index, the rest of the indexes turned negative at the end of the day (all the Δy_t are negative, out of the German one, which however remains at very low levels compared to the previous day) since the operators fear that the EU aid plan would not be able to stabilize the Euro-area. For this reason, the single currency started to fall, even if it did not reach the minimum levels of the previous week, when it stopped just above $ 1.25.

It can be noticed that the overall impact shows a certain persistence for 4 days from the announcement. Over a period of 5 days, the trend shows a considerably reduction, signalling a profit taking (i.e. a negative impact) on the fifth day. However, regardless fo the market considered, the most important result occurs on day 1. DAX is the only exception, as the price increases with the increase in the width of the window, except for what has been said about the fifth day. Therefore, it can be seen that after 3 days the impact is still positive, in fact, on 12/05 the main European prices closed sharply: they welcomed the austerity plan announced by the head of the Spanish government, Jose Luis Rodriguez Zapatero. In Milan FTSE MIB earns 0.74%, Paris closes at + 1.10%, Madrid at + 0.81% and finally the Frankfurt at + 2.41%. Starting from the 4th day something changes, the pressures come from the ECB asking for greater commitment to the Eurozone governments to restore public finances. In fact, the Monthly Bulletin states that it will generally be necessary to intensify the efforts, in order to correct the large imbalances. The consolidation has to substantially exceed the structural adjustment of 0.5% of GDP on an annual basis established as a minimum requirement in the Stability and Growth Pact.

The 5th day was really tense in the Eurozone, as the depreciation of the euro against dollar was still on going. In one session, the European currency firstly fell to 1.25 and then below 1.24 against the US currency. Euro also weakened against yen and pound, while it remained stable compared to the Swiss franc. Sales started at the opening of the European markets and found fertile ground in the news that the French president, then in office, Nicholas Sarkozy threatened the exit of France from the monetary union if Germany had not accepted the Greek aid plan, forcing the German chancellor, Angela Merkel to support the Greek bailout.

Turning to the sovereign bond market, the effects of the unconventional policy have been much more heterogeneous. Namely, according to Table 1.5, France 10-year government bond has not even reacted to the Governing Council decision, while effects on German sovereign bonds have been mostly mild. In contrast, Italy and Spain bond market reaction has been 1% statistically significant, and even in a 5-day window such effects have been quite persistent, as displayed in Table 1.6. It is worth saying that also some specific US macroeconomic data determined the drop of Euro currency (Michigan confidence index, industrial production and sales, which recorded the greatest increase since November thanks to the car sector), displaying the better health state of the US economy. This led financial operators to guess for a future increase of interest rates, that could have been shortly announced from Fed, and therefore they moved capital towards the dollar.

We conclude by stressing that SMP financial effects have been highly significant for the countries analysed, even though France and Germany bond market reaction has been quite negligible.

LTRO. The Governing Council of ECB on October 6, 2011 decided to conduct two long-term refinancing operations, one starting in October 2011 with a maturity of 12 months, and the second starting in December with a maturity of 13 months. Moreover, on December 8, 2011 the Governing Council also decided for an additional credit support measure, as a way to sort out lending and liquidity issues of European banks. This brought the maturity of LTROs to be extended over 36 months with the option of early repayment after one year. Therefore, for this empirical exercise we have considered two important dates to analyse: 06/10/2011 and 8/12/2011. This implies that despite the structure of the original model presented in (1.1) and (1.2) remains unchanged, we now accommodate a second dummy variable as follows:

$$\Delta y_t = c + \sum_{j=1}^{2} \beta_j D_{j,t} + \epsilon_t \tag{1.3}$$

$$\Delta y_t = c + \sum_{j=1}^{2} \beta_j D_{j,t} + \beta_3 News_t + \epsilon_t \tag{1.4}$$

where $j = 1, 2$ refers to a dummy variable of the aforementioned days. We proceed as in the SMP exercise, namely we evaluate the reaction of country-specific financial variables in a 2- and 5-day window. Results of a 2-day window are displayed in Table 1.7, 1.9 and 1.11, where we report the daily change for both dates in a classical and controlled experiment. Last column on the right reports the algebraic sum of variations across both announcements. We perform the F test on the overall variation, as we aim to test the hypothesis that both dates have been jointly significant. Results for the benchmark stock market and bank indexes are quite homogeneous, as in no case (other than UniCredit group) we have a statistically significant evidence.

In fact, despite the long-awaited day, the markets remained lukewarm from one side because of the semi-freezing of the interbank market - with institutions that refuse to grant loans to each other, preferring the safest deposits with the ECB – and from the other side because of the recessionary effect that budget containment policies were producing on the national economic systems. The latter has been an effect generated by the credit crunch too. People, in brief, paid more taxes, remained more easily unemployed and consumed less. Whereas companies, already subject to the consequences of the declined demand, were struggling to be financed by any bank. Finally, the distrust and bearish speculation increased the yields of sovereign bonds by increasing the pressure on public debts in a clear vicious circle.

The pressure exerted by the Basel Committee, which imposes more stringent capital requirements on institutions, favoured in practice the increase on deposits; playing in favour of the credit crunch. Therefore, only a small part of the available funds was collected by government agencies, making the pressure of public deficits light. The uncertainty was still evident, the rain of loans from ECB was not very convincing, and the main European stock markets closed in negative. The negative closing was also a result of the worrying statements claimed by Fitch, which put under observation the debt of six European nations including France and Germany, despite their triple A. According to a spokesman of the rating agency in fact, the probability of a cut in the French rating over the next two years exceeded the 50%.

The effects of the second announcement were also very poor, in fact the goal was to normalize the credit parameters in the Eurozone and avoid a credit crunch: the banks were essentially encouraged to buy back part of the European sovereign debt, in which months, especially in peripheral Europe, displayed too high rates. However, a significant portion of these loans was used by banks to buy back their bonds and to restructure their capital in view of the application of the strictest requirements of the European Banking

Authority, which required the consolidation of the European credit system. As before, the same regressive test over a broader time horizon (5 days) is performed. Table 1.8, 1.10 and 1.12 show that both announcements have produced insignificant effects even on a longer time span. In fact, the sovereign bond market never turns negative in response of any announcement. There are some mild effects on a 2-day window for France, Italy and Spain, but as the sign of results is economically ambiguous, we expect that such reactions rely to a different event.

OMT. The last unconventional policy investigated is the outright monetary transactions (OMT), which was announced by the Governing Council on September 6, 2012, despite the anticipation of August 2, 2012. However, in this case, we follow Altavilla *et al.* [2014] by taking into consideration also the 26^{th} of July 2012, when Mario Draghi (former president of ECB at that time) at the Global Investment Conference in London claimed: "the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough." Therefore the original model is updated as:

$$\Delta y_t = c + \sum_{j=1}^{3} \beta_j D_{j,t} + \epsilon_t \tag{1.5}$$

$$\Delta y_t = c + \sum_{j=1}^{3} \beta_j D_{j,t} + \beta_4 News_t + \epsilon_t \tag{1.6}$$

where the dummy variables are now 3, one for each corresponding date. 2-day window results are reported in Table 1.13, 1.15 and 1.17, and similar to the SMP announcement, the F test in the last column of each table show that the impact effects have been highly significant. This evidence is also reported in Altavilla *et al.* [2014], but as remarked in section 1.1, we have expanded the original empirical exercise by investigating two additional financial indexes. In particular, we have found that the reaction of German benchmark stock market index has been mild, while for the remaining countries the evidence is 1% statistically significant. More homogeneous results are displayed for the banking sector, in which the index of all banks investigates has been highly influenced by the 3 announcements in both classical and controlled experiment. Therefore, in few words, Draghi's speech has been enough to overturn the main financial indexes, while the Governing Council announcements also affected the US market, where the Down Jones closed at +230 points and automatically the European indexes closed in positive as well. Sovereign market results are in line with Altavilla *et al.* [2014], as we have used the same regression methodology. Therefore, also in our case Spain and italy have been affected the most, while the response of German and French bonds has been mild.

The impact on a 5-day window is shown in Table 1.14, 1.16 and 1.18, where unlike the previous case of SMP, optimism is growing until day 5.

1.4 Dynamic Effects Following a Monetary Policy Shock

In this section we evaluate the monetary transmission mechanism following a one-standard deviation exogenous structural shock to monetary policy, by considering the alternative financial measures analysed in section 1.3. Even though the economic literature has not yet converged to a common belief about the identification schemes to adopt in order to identify a monetary policy shock, economists agree on the qualitative effects of such disturbance. Therefore, in this paper we propose to construct a multi-country VAR, where each country-specific variable is collected in one large VAR. Suppose we wish to start from an unrestricted stochastic system specified as follows

$$Y_t = c + \Phi_1 Y_{t-1} + ... + \Phi_p Y_{t-p} + \varepsilon_t, \qquad \varepsilon_t \sim N(0, \Sigma) \tag{1.7}$$

where Y_t is a vector $n \times 1$ of observed endogenous variables, and c is a vector of intercepts; Φ_p is an $n \times n$ matrix of coefficients, with $p = 1, \ldots, 4$ indicating the number of lags, and ε_t is a white noise innovation vector. In our case, for each country we consider the gross domestic product (GDP_t), the harmonised consumer price index ($HICP_t$), in turn the 10-year government bond, benchmark stock market index, and bank index price for each exercise, and two international variables common for all countries: European volatility index ($STOXX50_t$) and the Euro OverNight Index Average

$(EONIA_t)$[5]. This implies a total of 3 endogenous variables $\times$ 4 countries analysed, + 2 fixed additional regressors; namely, 14 dependent variables analysed over a sample period running from 2000M1 through 2020M12. Now, in order to derive the impulse response functions (IRFs) from equation (1.7), we re-write the multi-country VAR(4) in a companion VAR(1) form. Namely, suppose to set $\mathbf{e_t'} = (\epsilon', 0, \dots, 0)$, $\mathbf{y_t'} = \left(y_t', y_{t-1}', \dots, y_{t-p+1}'\right)$ and define

$$\mathbf{\Phi} = \begin{bmatrix} \Phi_1 & \Phi_2 & \dots & \Phi_{p-1} & \Phi_p \\ I_N & 0 & \dots & 0 & 0 \\ 0 & I_N & \dots & 0 & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & \dots & \dots & I_N & 0 \end{bmatrix}$$

Therefore, the *companion* form of equation (1.7) may be written as $\mathbf{y_t} = \mathbf{\Phi y_{t-1}} + \mathbf{e_t}$. By substituting backward for infinite periods (under the hypothesis that the eigenvalues of $\mathbf{\Phi}$ are less than one in absolute value) the system is re-parameterized as: $\mathbf{y_t} = \mathbf{e_t} + \mathbf{\Phi e_{t-1}} + \mathbf{\Phi^2 e_{t-2}} + \dots$.
By writing $\mathbf{y_t} = \mathbf{\Phi}(\mathbf{L})\,\mathbf{e_t}$, where $\mathbf{L}$ is the lag operator and $\mathbf{e_t} \sim N(0, \Sigma)$, the first upper-left $N \times N$ matrices of $\mathbf{B^j}$ describe the effects of ε_t on $\mathbf{y_{t+j}}$. However, it is common practise to study the dynamic effects by re-parameterizing the unrestricted version in (1.7) as a structural VAR (SVAR). The choice is based on the structure of Σ, that in the unrestricted case is supposed to be a full covariance matrix, which effects are in contrast with the mainstream macroeconomics. Thus, without loss of generality we can write

$$\Sigma = \left(A^{-1}\right)\Lambda\left(A^{-1}\right)' \qquad \text{and} \qquad \Sigma^{1/2} = \left(A^{-1}\right)\Lambda^{1/2}$$

where A^{-1} is a lower diagonal matrix with ones on the main diagonal describing the immediate effects of the disturbance term on the endogenous variable Y_t, and Λ is a diagonal matrix reporting the structural shocks. In

[5]This variable is commonly used to measure standard monetary policy actions.

this way equation (1.7) can be rewritten in the equivalent structural form as follows:

$$Y_t = c + \Phi_1 Y_{t-1} + ... + \Phi_p Y_{t-p} + A^{-1}\Lambda^{1/2}\epsilon_t, \qquad \epsilon_t \sim iid\ N(0, I_N) \quad (1.8)$$

where ϵ_t is the independent shock. Therefore, we have identified the structural VAR (SVAR) in a Cholesky way, as also performed in Christiano *et al.* [1999]. There are many studies in which this methodology has been applied (see for example Sims [1980], Amisano and Giannini [2012] or Kilian [2009]). The main idea is to identify a covariance matrix in which the first shock only affects the first dependent variable, the first and the second shock impact on the second dependent variable, and so on up to the last dependent variable, which is affected by all shocks produced in the stochastic system. For a detailed economic interpretation in the use of this identification scheme, see Christiano *et al.* [1999]. The triangular identification of A for our case, in which $n = 14$ is specified as follows:

$$A\epsilon_t = \begin{bmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ \alpha^0_{2,1} & 1 & 0 & 0 & \cdots & 0 \\ \alpha^0_{3,1} & \alpha^0_{3,2} & 1 & 0 & \cdots & 0 \\ \alpha^0_{4,1} & \alpha^0_{4,2} & \alpha^0_{4,3} & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & 0 \\ \alpha^0_{14,1} & \alpha^0_{14,2} & \alpha^0_{10,3} & \alpha^0_{14,4} & \cdots & 1 \end{bmatrix} \begin{pmatrix} {\epsilon_t}^{GDP\ \text{(Germany)}} \\ {\epsilon_t}^{GDP\ \text{(France)}} \\ {\epsilon_t}^{GDP\ \text{(Italy)}} \\ {\epsilon_t}^{\text{GDP (Spain)}} \\ \vdots \\ {\epsilon_t}^{\text{STOXX50}} \end{pmatrix}$$

We estimate the coefficients Φ in a Bayesian fashion by applying a Gibbs sampling methodology. In particular, coefficients Φ are restricted in a Minnesota way and we perform 15,000 independent draws (5,000 of which are discarded). We use quarterly data, and assume that a monetary shock does not produces contemporaneous effects on both GDP and consumer price index, as they both take at least one quarter to react to a policy announcement. More details are provided in appendix .3.

Figure 1.1 depicts the dynamic effects of the GDP for each country following a one-standard deviation structural shock. As we can see, the impulse response functions show a cross-country heterogeneity in the response to the structural shock. In particular, Italian real economy displays the highest response in terms of IRF shape, in Spain after few months of growth, there is a smoothly decline of national economy. In most of the cases Germany and France GDP response is homogeneous. With the same approach, Figure 1.2 depicts the dynamic effects of HICP for each country following a one-standard deviation structural shock. Results are now much more equivalent across each country. In fact, ss expected, after an initial surge of inflation following the monetary injection shock, cross-country inflation smoothly declines.

This work serves as a sort of expansion of the empirical work of Altavilla *et al.* [2014], since we have covered additional unconventional policies not explored by the authors, and have investigated the policy effects on alternative financial variables.

1.5 Conclusions

The unconventional policies SMP, LTRO and OMT have generated cross-country heterogeneous effects between Germany, France, Italy and Spain financial markets. In particular, the impact effect on benchmark stock market and bank index prices displays that SMP and OMT announcements have been 1% statistically significant for each country analysed, whereas LTRO impact effect has been quite mild. More heterogeneous cross-country effects are visible on the bond market side. In fact, SMP and OMT have been still highly significant for Italy and Spain, while in France and Germany the variation of 10-year government bonds can be considered statistically negligible. Both announcements associated with LTRO policy, have been not relevant for any market considered in this analysis.

High frequency values have also been collected in a quarterly form and endogenised in a large multi-country VAR, in order to evaluate their volatility when a monetary shock is transmitted at a macroeconomic level. We found out that following a positive monetary structural shock, the real economy of Italy and France show positive and persistent effects, in contrast with Germany and Spain, where after two years the gross domestic product smoothly decreases. More homogeneous effects are instead depicted when the inflation level is shocked by a monetary disturbance variable. In fact, for each country, after a positive impact effect the harmonised consumer price index smoothly decrease.

This paper contributes to shed light on the effects that unconventional monetary policies generate on financial markets, as alternative economic variables have been investigated.

Table 1.1: Effect of SMP announcement on stock market indexes.
2-day window

Country	Index	Announcement		Total
		10/05/2010	11/05/2010	
Classic				
DE	DAX	-0.03	0.05	0.02**
FR	CAC 40	-0.05	0.10	0.05***
IT	FTSE MIB	-0.03	0.11	0.08***
SP	IBEX 35	-0.03	0.14	0.11***
Controlled				
DE	DAX	-0.02	0.03	0.01***
FR	CAC 40	-0.03	0.05	0.02***
IT	FTSE MIB	-0.02	0.07	0.05***
SP	IBEX 35	-0.02	0.10	0.08***

Note: Results rely on daily closed price variations of the main stock market indexes for countries listed in column 1. DE=Germany, FR=France, IT=Italy and SP=Spain. Last column reports the overall sum between closed price variation of 10/05/2010 and 11/05/2010. *,**,*** represent the jointly significance at 10%, 5% and 1% respectively for classical and controlled regression, based on Test F.

Table 1.2: Effect of SMP announcement on stock market indexes.
5-day window

Country	Index	Day 1	Day 2	Day 3	Day 4	Day 5
Classic						
DE	DAX	-0.03	0.02	0.02	0.05	0.06
FR	CAC 40	-0.05	0.05	0.04	0.06	0.05
IT	FTSE MIB	-0.03	0.08	0.07	0.08	0.07
ES	IBEX 35	-0.03	0.11	0.08	0.09	0.08
Controlled						
DE	DAX	-0.02	0.01	0.00	0.01	0.03
FR	CAC 40	-0.03	0.02	0.02	0.01	0.03
IT	FTSE MIB	-0.02	0.05	0.05	0.04	0.05
ES	IBEX 35	-0.02	0.08	0.05	0.05	0.05

Note: Table above reports the impact of SMP policy on stock index closed prices from 10/05/2010 through 14/05/2010.

Table 1.3: Effect of SMP announcement on bank stock prices.
2-day window

		Announcement					
		10/05/2010		11/05/2010			
Country	**Index**	***Classic***	***Controlled***	***Classic***	***Controlled***	**Total**	
DE	DBK	-0.02	0.00	0.10	0.05	0.08***	0.05***
DE	CBK	0.02	0.03	0.08	0.04	0.10**	0.07***
FR	BNP	-0.06	-0.04	0.21	0.17	0.15***	0.12***
FR	ACA	-0.07	-0.05	0.19	0.14	0.12***	0.09***
IT	UCG	-0.03	-0.02	0.21	0.17	0.18***	0.15***
IT	ISP	-0.04	-0.02	0.20	0.15	0.16***	0.13***
ES	SAN	-0.04	-0.02	0.23	0.19	0.19***	0.17***
ES	BBVA	-0.04	-0.02	0.22	0.18	0.18***	0.15***

Note: In column 1, DE=Germany, FR=France, IT=Italy and ES=Spain. In column 2, DBK=Deutsche Bank, CBK=Commerzbank, BNP=BNP Paribas, ACA=Credit Agricole, UCG=UniCredit, ISP=Intesa San Paolo, SAN=Santander, BBVA=Banco Bilbao Vizcaya Argentaria. left-hand side of last column reports results of classic regression, while the right-hand side the controlled one. Results rely on daily closed price variations of bank stock prices . We have selected two banks with the largest total assets value per country. *,**,*** represent the jointly significance at 10%, 5% and 1% of dummies and controlled variables, based on Test F.

Table 1.4: Effect of SMP announcement on bank stock prices.
2-day window

	Day 1		**Day 2**		**Day 3**		**Day 4**		**Day 5**	
Index	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
DBK	-0.02	0.00	0.08	0.05	0.09	0.06	0.09	0.05	0.08	0.05
CBK	0.02	0.03	0.10	0.07	0.08	0.06	0.10	0.06	0.13	0.10
BNP	-0.06	-0.04	0.15	0.12	0.13	0.10	0.14	0.10	0.13	0.10
ACA	-0.07	-0.05	0.12	0.09	0.09	0.07	0.11	0.07	0.07	0.04
UCG	-0.03	-0.02	0.18	0.15	0.16	0.14	0.16	0.12	0.15	0.13
ISP	-0.04	-0.02	0.16	0.13	0.13	0.11	0.15	0.11	0.11	0.09
SAN	-0.04	-0.02	0.19	0.17	0.16	0.14	0.16	0.12	0.15	0.13
BBVA	-0.04	-0.02	0.18	0.15	0.15	0.13	0.16	0.12	0.15	0.13

Note: Table above reports the impact of SMP policy on bank stock prices from 10/05/2010 through 14/05/2010. Index description is provided in Table 1.3 above. For the sake of space, (1) and (2) stand for equation (1) and (2), namely classical and controlled regression.

Table 1.5: Effect of SMP announcement on 10Y sovereign bond.
2-day window

Country	Maturity	Announcement		Total
		10/05/2010	11/05/2010	
Classic				
DE	10 Years	0.16	-0.02	0.14***
FR	10 Years	0.07	-0.01	0.07
IT	10 Years	-0.30	-0.02	-0.32***
SP	10 Years	-0.51	0	-0.51***
Controlled				
DE	10 Years	-0.08	-0.09	-0.17*
FR	10 Years	-0.43	-0.51	-0.94
IT	10 Years	-0.31	-0.03	-0.34***
SP	10 Years	-0.48	0.03	-0.45***

Note: Results rely on yield-to-maturity differences for countries listed in column 1. DE=Germany, FR=France, IT=Italy and SP=Spain. Last column reports the overall variation from 10/05/2010 through 11/05/2010. *,**,*** represent the jointly significance at 10%, 5% and 1% respectively for classical and controlled regression, based on Test F.

Table 1.6: Effect of SMP announcement on 10Y sovereign bond.
5-day window

Country	Maturity	Day 1	Day 2	Day 3	Day 4	Day 5
Classic						
DE	10 Years	0.16	0.14	0.15	0.14	0.06
FR	10 Years	0.07	0.07	0.06	0.04	-0.03
IT	10 Years	-0.30	-0.32	-0.34	-0.40	-0.37
SP	10 Years	-0.51	-0.51	-0.52	-0.51	-0.50
Controlled						
DE	10 Years	-0.08	-0.17	-0.08	-0.08	-0.08
FR	10 Years	-0.43	-0.94	-0.45	-0.46	-0.54
IT	10 Years	-0.31	-0.34	-0.37	-0.45	-0.43
SP	10 Years	-0.48	-0.45	-0.44	-0.40	-0.35

Note: Table above reports the impact of SMP policy on yield-to-maturity differences from 10/05/2010 through 14/05/2010.

Table 1.7: Effect of LTRO announcements on stock market indexes.
2-day window

		Announcement I		**Announcement II**		
Country	**Index**	06/10/2011	07/10/2011	08/12/2011	09/12/2011	**Total**
Classic						
DE	DAX	0.03	0.01	-0.02	0.02	0.04
FR	CAC 40	0.03	0.01	-0.03	0.03	0.04
IT	FTSE-MIB	0.04	0.01	-0.04	0.03	0.04*
ES	IBEX 35	0.03	0.01	-0.02	0.02	0.04
Controlled						
DE	DAX	0.01	0.01	0.00	0.00	0.03
FR	CAC 40	0.02	0.02	0.00	0.01	0.03
IT	FTSE MIB	0.02	0.02	-0.02	0.02	0.03
ES	IBEX 35	0.01	0.02	0.00	0.01	0.03

Note: Results rely on daily closed price variations of the main stock market indexes for countries listed in section 2. Last column reports the overall variation from 06/10/2011 through 07/10/2011 and from 08/12/2011 through 09/12/2011. *,**,*** represent the jointly significance at 10%, 5% and 1% between dummies and controlled variables according to a Test F.

Table 1.8: Effect of LTRO announcements on stock market indexes.
5-day window

Country	**Index**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Classic						
DE	DAX	0.01	0.03	0.03	0.03	0.04
FR	CAC 40	0.01	0.04	0.04	0.03	0.02
IT	FTSE MIB	-0.01	0.04	-0.04	0.03	0.03
ES	IBEX 35	0.01	0.04	0.02	0.01	0.01
Controlled						
DE	DAX	0.01	0.04	0.01	0.02	0.02
FR	CAC 40	0.01	0.03	0.01	0.01	0.01
IT	FTSE MIB	-0.01	0.03	0.01	0.01	0.02
ES	IBEX 35	0.01	0.03	-0.01	-0.01	-0.01

Note: Table above reports the impact of LTRO policy on stock index closed prices on a 5-day window for each announcement.

Table 1.9: Effect of LTRO announcements on bank stock prices.
2-day window

		Announcement I				**Announcement II**					
		06/10/2011		07/10/2011		08/10/2011		09/10/2011			
Country	**Index**	*Classic*	*Controlled*	*Classic*	*Controlled*	*Classic*	*Controlled*	*Classic*	*Controlled*	**Total**	
DE	DBK	0.03	0.01	-0.03	-0.03	-0.05	-0.03	0.05	0.03	-0.01	-0.02
DE	CBK	0.03	0.01	-0.03	-0.03	-0.1	-0.08	0.4	0.02	-0.07	-0.08
FR	BNP	0.09	0.07	-0.02	-0.01	-0.06	-0.04	0.05	0.03	0.06	0.05
FR	ACA	0.05	0.03	-0.02	-0.01	-0.04	-0.02	0.04	0.02	0.04	0.03
IT	UCG	0.04	0.02	0.04	0.05	-0.07	-0.05	0.07	0.05	0.08***	0.07***
IT	ISP	0.06	0.04	0.03	0.04	-0.09	-0.07	0.08	0.06	0.08*	0.07*
ES	SAN	0.03	0.01	0.01	0.02	-0.02	0.00	0.02	0.01	0.04	0.04
ES	BBVA	0.03	0.01	0.01	0.02	-0.03	-0.01	0.02	0.01	0.04	0.03

Note: In column 1, DE=Germany, FR=France, IT=Italy and ES=Spain. In column 2, DBK=Deutsche Bank, CBK=Commerzbank, BNP=BNP Paribas, ACA=Credit Agricole, UCG=UniCredit, ISP=Intesa San Paolo, SAN=Santander, BBVA=Banco Bilbao Vizcaya Argentaria. left-hand side of last column reports results of classic regression, while the right-hand side the controlled one. Results rely on daily closed price variations of bank stock prices . We have selected two banks with the largest total assets value per country. *,**,*** represent the jointly significance at 10%, 5% and 1% of dummies and controlled variables, based on Test F.

Table 1.10: Effect of LTRO announcements on bank stock prices.
5-day window

	Day 1		**Day 2**		**Day 3**		**Day 4**		**Day 5**	
Index	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
DBK	-0.02	-0.02	-0.01	-0.02	-0.01	-0.04	-0.01	-0.02	0.04	0.02
CBK	-0.07	-0.07	-0.07	-0.08	-0.11	-0.14	-0.16	-0.17	-0.05	-0.10
BNP	0.03	0.03	0.06	0.05	0.04	0.02	0.04	0.01	0.03	-0.03
ACA	0.01	0.01	0.04	0.03	-0.01	-0.03	-0.01	-0.02	-0.05	-0.06
UCG	-0.03	-0.03	0.08	0.07	0.14	0.12	0.17	0.16	0.16	0.15
ISP	-0.03	-0.03	0.08	0.07	0.08	0.05	0.07	0.05	0.11	0.09
SAN	0.01	0.01	0.04	0.04	0.01	-0.02	-0.02	-0.04	-0.02	-0.04
BBVA	0.00	0.00	0.04	0.03	0.01	-0.02	-0.03	-0.04	0.00	-0.02

Note: Table above reports the impact of LTRO policy on bank stock prices for intervals 06/10/2011 - 07/10/2011 and 08/12/2011 - 09/12/2011. Index description is provided in Table 1.7 above. For the sake of space, (1) and (2) stand for equation (1) and (2), namely classical and controlled regression.

Table 1.11: Effect of LTRO announcements on 10Y sovereign bonds. 2-day window

		Announcement I		**Announcement II**		
Country	**Maturity**	06/10/2011	07/10/2011	08/12/2011	09/12/2011	**Total**
Classic						
DE	10 Years	0.10	0.06	-0.09	0.13	0.21*
FR	10 Years	0.09	0.01	0.14	-0.09	0.14
IT	10 Years	-0.07	0.07	0.47	-0.10	0.37*
ES	10 Years	-0.08	-0.02	0.38	-0.07	0.22*
Controlled						
DE	10 Years	0.05	0.00	0.01	0.23	0.30*
FR	10 Years	-1.32	-1.40	-2.39	-2.62	-7.72
IT	10 Years	-0.22	-0.08	0.47	-0.10	0.08*
ES	10 Years	-0.13	-0.08	1.42	0.96	2.16*

Note: Results rely on yield-to-maturity differences for countries listed in column 1. Last column reports the overall variation from 06/10/2011 through 07/10/2011 and from 08/12/2011 through 09/12/2011. *,**,*** represent the jointly significance at 10%, 5% and 1% between dummies and controlled variables according to a Test F.

Table 1.12: Effect of LTRO announcements on 10Y sovereign bonds. 5-day window

Country	**Maturity**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Classic						
DE	10 Years	0.02	0.21	0.16	0.17	0.17
FR	10 Years	0.23	0.14	0.27	0.28	0.30
IT	10 Years	0.40	0.37	0.62	0.79	1.02
ES	10 Years	0.31	0.22	0.26	0.22	0.30
Controlled						
DE	10 Years	0.06	0.30	0.30	0.35	0.39
FR	10 Years	-3.71	-7.72	-11.53	-15.45	-19.37
IT	10 Years	0.25	0.08	0.19	0.22	0.30
ES	10 Years	1.28	2.16	3.18	4.11	5.16

Note: Table above reports the impact of LTRO policy on yield-to-maturity differences on a 5-day window for each announcement.

Table 1.13: Effect of OMT announcements on stock market indexes.
2-day window

Index	Maturity	Announcement I		Announcement II		Announcement III		Total
		26/07/2012	27/07/2012	02/08/2012	03/08/2012	06/09/2012	07/09/2012	
Classic								
DE	DAX	0.00	0.03	-0.02	0.04	0.00	0.03	0.08*
FR	CAC 40	0.00	0.04	-0.02	0.04	0.00	0.03	0.09***
IT	FTSE MIB	0.01	0.06	-0.04	0.06	0.00	0.04	0.12***
ES	IBEX 35	0.01	0.06	-0.05	0.06	0.00	0.05	0.13***
Controlled								
DE	DAX	0.00	0.01	-0.02	0.02	0.01	0.01	0.03*
FR	CAC 40	0.00	0.02	-0.02	0.03	0.00	0.01	0.05***
IT	FTSE MIB	0.01	0.04	-0.04	0.4	-0.01	0.02	0.08***
ES	IBEX 35	0.01	0.04	-0.04	0.04	0.00	0.03	0.08***

Note: Results rely on daily closed price variations of the main stock market indexes for countries listed in section 2. Last column displays the overall sum between closed price variation of 6 days running from 26/07/2012 through 07/09/2012. *,**,*** represent the jointly significance at 10%, 5% and 1% between dummies and controlled variables according to a Test F.

Table 1.14: Effect of OMT announcements on stock market indexes.
2-day window

Country	Index	Day 1	Day 2	Day 3	Day 4	Day 5
Classic						
DE	DAX	0.01	0.08	0.10	0.12	0.14
FR	CAC 40	-0.02	0.05	0.13	0.15	0.15
IT	FTSE MIB	-0.04	0.12	0.19	0.24	0.24
ES	IBEX 35	-0.04	0.13	0.21	0.26	0.26
Controlled						
DE	DAX	0.01	0.03	0.03	0.06	0.08
FR	CAC 40	-0.01	0.09	0.05	0.08	0.09
IT	FTSE MIB	-0.03	0.08	0.12	0.17	0.17
ED	IBEX 35	-0.03	0.08	0.14	0.19	0.19

Note: Table above reports the impact of OMT policy on stock index closed prices on a 5-day window for each announcement.

Table 1.15: Effect of OMT announcements on bank stock prices.
2-day window

		Announcement I				Announcement II				Announcement III					
		26/07/2012		27/07/2012		02/08/2012		03/08/2012		03/08/2012		03/08/2012			
Country	**Index**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**Total**	
DE	DBK	-0.02	-0.02	0.04	0.02	-0.06	-0.05	0.09	0.07	0.00	0.01	0.07	0.05	0.12***	0.07***
DE	CBK	0.01	0.01	0.07	0.05	-0.07	-0.06	0.07	0.05	0.00	0.00	0.05	0.03	0.05***	0.08***
FR	BNP	0.00	0.00	0.09	0.07	-0.04	-0.03	0.09	0.07	0.02	0.02	0.06	0.03	0.21***	0.16***
FR	ACA	0.01	0.01	0.09	0.07	-0.08	-0.07	0.08	0.06	0.01	0.01	0.08	0.06	0.19***	0.15***
IT	UCG	0.01	0.01	0.09	0.08	-0.07	-0.07	0.08	0.07	0.00	0.00	0.08	0.06	0.20***	0.15***
IT	ISP	0.01	0.01	0.09	0.07	-0.10	-0.09	0.13	0.11	0.00	0.01	0.06	0.04	0.20***	0.15***
ES	SAN	0.01	0.01	0.11	0.09	-0.07	-0.06	0.08	0.06	0.00	0.00	0.05	0.03	0.18***	0.13***
ES	BBVA	0.00	0.00	0.11	0.09	-0.06	-0.06	0.08	0.06	0.00	0.00	0.05	0.03	0.18***	0.13***

Note: In column 1, DE=Germany, FR=France, IT=Italy and ES=Spain. In column 2, DBK=Deutsche Bank, CBK=Commerzbank, BNP=BNP Paribas, ACA=Credit Agricole, UCG=UniCredit, ISP=Intesa San Paolo, SAN=Santander, BBVA=Banco Bilbao Vizcaya Argentaria. left-hand side of last column reports results of classic regression, while the right-hand side the controlled one. Results rely on daily closed price variations of bank stock prices . We have selected two banks with the largest total assets value per country. *,**,*** represent the jointly significance at 10%, 5% and 1% of dummies and controlled variables, based on Test F. For the sake of space, (1) and (2) stand for equation (1) and (2), namely classical and controlled regression.

Table 1.16: Effect of OMT announcements on bank stock prices.
5-day window

	Day 1		Day 2		Day 3		Day 4		Day 5	
Index	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
DBK	-0.08	-0.07	0.012	0.07	0.25	0.18	0.26	0.18	0.30	0.23
CBK	0.00	-0.06	0.05	0.08	0.22	0.14	0.27	0.19	0.31	0.24
BNP	-0.02	-0.01	0.21	0.16	0.31	0.24	0.37	0.30	0.36	0.29
ACA	-0.06	-0.05	0.19	0.15	0.34	0.27	0.51	0.44	0.50	0.43
UCG	-0.06	-0.05	0.20	0.15	0.28	0.20	0.39	0.32	0.40	0.32
ISP	-0.08	-0.07	0.20	0.15	0.27	0.20	0.36	0.27	0.34	0.27
SAN	-0.06	-0.05	0.18	0.13	0.30	0.22	0.36	0.29	0.37	0.30
BBVA	-0.06	-0.05	0.18	0.13	0.29	0.22	0.36	0.29	0.36	0.29

Note: Table above reports the impact of OMT policy on bank stock prices on a 5-day window for each announcement.

Table 1.17: Effect of OMT announcements on 10Y sovereign bonds.
2-day window

Index	Maturity	Announcement I		Announcement II		Announcement III		Total
		26/07/2012	27/07/2012	02/08/2012	03/08/2012	06/09/2012	07/09/2012	
Classic								
DE	10 Years	0.06	0.08	-0.14	0.20	0.08	-0.04	0.23*
FR	10 Years	-0.06	0.00	-0.04	0.06	0.02	-0.05	-0.05
IT	10 Years	-0.40	-0.1	0.40	-0.30	-0.25	-0.20	-0.30***
ES	10 Years	-0.45	-0.18	-0.02	0.43	-0.38	-0.4	-0.32***
Controlled								
DE	10 Years	0.14	0.16	-0.12	0.21	0.31	0.20	0.89
FR	10 Years	-1.64	-1.58	-1.38	-1.28	0.29	0.85	-4.11
IT	10 Years	-1.46	-1.17	0.39	-0.28	-0.32	-0.27	-3.12***
ES	10 Years	-0.86	-0.59	0.54	-0.21	-0.91	-0.93	-2.96***

Note: Results rely on yield-to-maturity differences for countries listed in column 1. Last column reports the overall variation in-between the three dates of the announcements. *,**,*** represent the jointly significance at 10%, 5% and 1% between dummies and controlled variables according to a Test F.

Table 1.18: Effect of OMT announcements on 10Y sovereign bonds.
2-day window

Country	Maturity	Day 1	Day 2	Day 3	Day 4	Day 5
Classic						
DE	10 Years	0.08	0.23	0.21	0.20	0.30
FR	10 Years	-0.08	-0.05	-0.09	-0.23	-0.21
IT	10 Years	-0.25	-0.30	-0.68	-0.76	-1.03
ES	10 Years	-0.39	-0.32	-1.46	-1.21	-1.29
Controlled						
DE	10 Years	0.33	0.89	1.20	1.53	1.95
FR	10 Years	-2.1	-4.11	-6.14	-8.30	-10.30
IT	10 Years	-1.40	-3.12	-4.12	-5.34	-6.77
ES	10 Years	-1.23	-2.96	-3.96	-4.55	-5.46

Note: Table above reports the impact of OMT policy on yield-to-maturity differences on a 5-day window for each announcement.

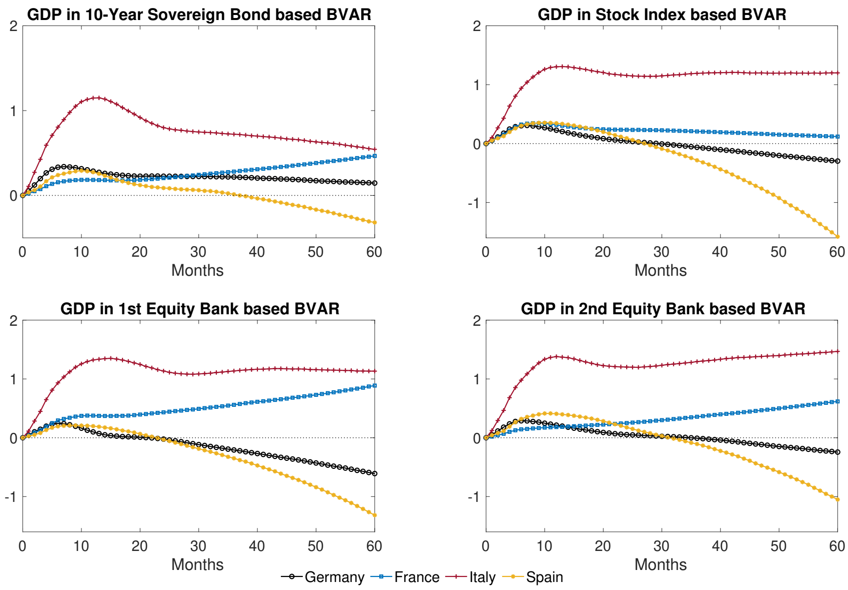

Figure 1.1: GDP dynamic impulse response functions following a one-standard deviation structural effect to monetary policy. The reactions describe the 50% median posterior of each country

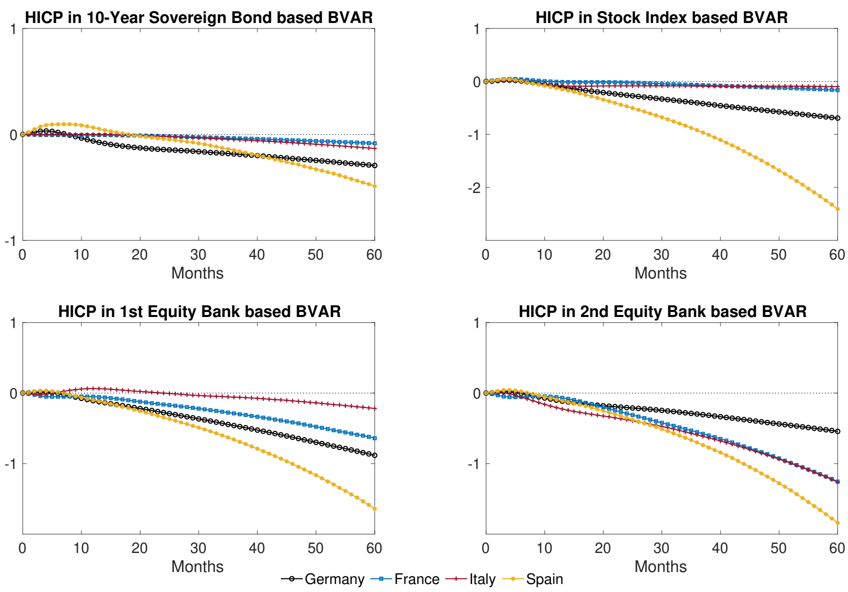

Figure 1.2: HICP dynamic impulse response functions following a one-standard deviation structural effect to monetary policy. The reactions describe the 50% median posterior of each country

Chapter 2

The Spillover Effects Following Brexit Announcements

This work quantifies the financial and macroeconomic effects of the most significant Brexit events from 23 June 2016 up to 31 December 2019 on fifteen economies. The study uses high-frequency data and shows that following the referendum outcome, overall the 10-year government bond yield of the UK decreased of 21 percentage points. In Sweden, Australia and the US the result generated a reduction of 40, 12 and 11 percent respectively. In the remaining European countries instead, the sovereign bond rate approximately dropped by 15 and 24 percentage points. The analysis has also been performed on the benchmark stock market index prices, finding that Italian and Belgian economies have been the most affected, followed by China and France. After that, a vector autoregression model is performed in order to show the country-specific gross domestic product (GDP) dynamic effects following a UK uncertainty shock. Empirical evidence suggests that a reduction in bond yields and in equity market indexes is associated with a reduction in the real activity for all countries except for the US and Japan.

keywords: Brexit · event-study · global vector autoregression · bootstrap after bootstrap · Metropolis-Hastings algorithm.

2.1 Introduction

On 23 June 2016, the United Kingdom voted to leave the European Union. This withdrawal has yielded to a dramatic impact (economically and politically speaking) for both the UK and the entire European continent. In fact, the shock generated by the referendum result and the general elections of 12 December 2019 immediately materialized in the first quarter of 2020, and according to the Office for National Statistics (Ons), UK food and drink exports to the European Union dropped by 75%, while the export of medical devices reduced by 25% in comparison to the last quarter of 2019.

The political decision to leave the EU has long been considered quite uncommon by policymakers, because the direction that the UK could have run across after the referendum result of June 2016 has been unknown for three years[1]. This has generated a persistent uncertainty, materialized in a reduction of investments and gross domestic product (GDP) of 11% and 2% respectively (see Bloom *et al.* [2019]). However, quantifying an accurate lost following the Brexit decision is a hard work if we consider that the biennium 2020-2021 has been largely affected by the devastating consequences of Covid-19 pandemic on global economy.

A number of studies have investigated the economic consequences following the Brexit vote, for example Bloom *et al.* [2019], Hassan *et al.* [2020], and Steinberg [2019] report the persistent uncertainty that the decision to quit the EU has generated at a firm level. Dhingra *et al.* [2016], McGrattan and Waddle [2020] and Busch and Matthes [2016] investigate the reduction of foreign investments following the Brexit announcement. Portes and Forte [2017] and Simionescu *et al.* [2017] study the impact of Brexit on migration. The literature is huge and it is quite impossible to list all works here individually. However, to my knowledge there is still no paper that quantifies the uncertainty effects that the main Brexit events have generated on financial markets of the largest trading partners of the UK, and how these real economies have responded to such shocks.

[1] Remember that three main scenarios stood out: Access to the European Economic Area (like Norway), Bilateral Agreement (like Switzerland), Third Country-Status (so called hard Brexit); see Lehmann and Zetzsche [2016].

In this paper, we evaluate the effect that nine major Brexit events described in Table 2.1 have generated on financial markets of the United Kingdom and fourteen trading partners that, based on data provided by Ons Pink Book for 2017 Goods and Services, are in-between the top 20 trading partners of the UK. Brexit events are observed from the referendum result of June 2016 through the general elections of December 2019. Overall, the study is conducted in two stages and finds the following results.

In the first part, we use daily data from 01/01/2010 through 31/12/2019 and perform an event study in order to isolate the effects of nine Brexit events on the 10-years government bond yield and on the benchmark stock market index price of each economy. The strategy follows Altavilla and Giannone [2014], by regressing the daily change of equity and asset prices on event dummies, whose value is one on the date of the event (nine of them considered for a total of nine dummies), and zero for the remaining observations. As a robustness exercise, in a second analysis we replicate the previous regression, but we also consider a *controlling* variable, defined as X_{News}, which capture the surprise effect of the main financial and macroeconomic variables listed in Table 9. In particular, for the sovereign bond analysis, the "news" describing the surprise effect, results from the difference between the actual released value of a macroeconomic variable and the one estimated by Bloomberg economists until the day before. This factor is evaluated by looking at 164 estimated variables of countries object of this analysis (Italy, France, Spain, Germany, Netherlands, Belgium, Finland, Portugal, UK, Sweden, Switzerland, USA, China, Australia and Japan), made available on Bloomberg. In contrast, for the benchmark stock market index analysis, the surprise effect is obtained from the difference between the observed value of S&P 500 and the one estimated through an autoregressive (AR) process with 12 lags. We quantify the impact of nine Brexit events on bond yields and stock market prices finding that, in-between the nine different events, the day in which the referendum result was made public and the general elections of December 2019 describe the episodes that generated the highest negative impact for all countries. In particular, overall the UK sovereign bond rate dropped by 21 percent, in Sweden the bond yield lost approximately 40 percentage points, in Australia and in the US approximately 12 and 11 percent. The western European countries (such as France, Spain, Germany, Netherlands, Belgium, Finland and Portugal), lost in the region of 15 and 24 percentage points, while Italy was the mostly unaffected. On the equity market side, Italy and Belgium have instead been the most affected countries, followed by China and France. This financial impact is proportional to the size of each country commercial relationships with the UK. In fact, even after Brexit, the US and the western European countries still remain the largest trading partners of the UK (see Kristjánsdóttir *et al.* [2020]).

In the second part, the work presents a multi-country macroeconomic model in the form of a global vector autoregression (GVAR), aiming to support the empirical evidence found in the first exercise and quantify the dynamic effect following a UK uncertainty shock on the GDP of the main UK trading partners. The analysis is outlined as follows. In the first step, country-specific VARs (commonly known as *VARXs*) are used to study the dynamic behaviour of single outcomes conditionally to the rest of the world. Each model includes 3 country-specific variables (real GDP, consumer price index, 10-year government bond rates\equity market indexes), plus the Economic Policy Uncertainty index of the UK as a common explanatory factor. We follow the work of Georgiadis [2015], and set the number of lags $p = 4$. The estimation includes quarterly data starting from 1996Q1 through 2019Q1. In a second step, single VARXs are stacked and included in a common large VAR model, which is used to analyse the macroeconomic effects over a horizon of 3 years, by comparing two different scenarios: the case of "Brexit" and the case of "no-Brexit". The contribution of this exercise is twofold. First it displays that following a one-time structural change of UK volatility, the gross domestic product of all countries drops in the first quarter. The structural shock is more persistent for Spain and Australia, while the GDP of the remaining economies comes back to its steady-state within 2 years. Second, forecasting results are consistent with the spillover effects. In fact, for the US there is no difference between the two scenarios, while in China the lost is very small and most likely it has been generated by additional circumstances. On the contrary, all European partners show the largest drop in their real activity. Based on the empirical evidence, it may be inferred that the decision of the UK to leave the European community has generated a negative effect in the real activity for all countries out of the US and Japan. This sounds rationale, since the 55% of the British imports come from the EU. Thus, the referendum result has been interpreted as a negative shock by the equity market. The reason why the US stock market has been untouched comes from the fact that north America is a massive market, and could hardly be affected by a singular economy, even though it is the United Kingdom.

This paper is related to several other works in the literature. First, it is linked to the literature about uncertainty for two main reasons. From one side the referendum result has been quite unexpected, with the leaving campaign winning for only the 51.89% of votes, which has brought the former prime minister David Cameron to resign. From the other side, the political decisions following this outcome have been quite uncommon, because for three years from the original vote it has never been made clear which direction the UK would have taken at the end of 2019. This has generated a high level of uncertainty on stock markets, which has inevitably led to a reduction of investments. There is a very rich academic literature related to the effects that uncertainty shocks generate on investments and real economy. See for example Hartman [1972], Bernanke [1983], Pindyck [1990], Bloom *et al.* [2007], Fernández-Villaverde *et al.* [2011], and Baker *et al.* [2016].

Second, this paper analyses the impact that Brexit decision has generated on the GDP of fifteen economies. This is linked to the academic literature on trade reforms which usually yield to positive growth impacts, especially when the reform reduces the uncertainty and people have positive expectations about the future (see for example my first chapter). In our case, Brexit can be seen as a reverse trade reform, since it yielded to a reduction of GDP for the 90% of countries investigated. Similar examples in academic literature are Rodriguez and Rodrik [2000], Edwards [1997], Mendoza [1997], Greenaway *et al.* [1998], Henisz [2000], Irwin [2019], and many others.

Finally, this study also contributes to the lively literature which investigates the Brexit impact on different fields of research such as labour, immigration, financial markets, energy, imports and exports, and so on. See for example Crowley *et al.* [2018], Ziv *et al.* [2018], Hohlmeier and Fahrholz [2018], Simionescu *et al.* [2017] and Bloom *et al.* [2019].

The remainder of this work is structured as follows. Section 2.2 offers a detailed overview of the main Brexit events, by highlighting the associated costs and benefits following this political decision. Section 2.3 provides the literature review and motivates the choice of event-study as a well-suited methodology for this study. Section 2.4 and 2.5 report the empirical results, and section 2.6 concludes.

2.2 Brexit Events: an Overview

Since the referendum result of the last 23 June 2016, many Brexit steps have been made; but what is Brexit, really? And what does this term really mean? It describes the process that has brought the UK out from the European Union, whose terms and conditions lie in art. 50 of Lisbon Treaty.

Several reasons have brought the UK to leave the European Union. First of all, the desire to take back the sovereignty with respect to the powers that were slowly and irreversibly moving to Brussels; which is probably true, it cannot be denied. But this "loss" of national sovereignty has taken place over the years. Therefore, what is really hard to understand is why the matter of the loss of sovereignty, a slow and constant process, has suddenly become a priority in voters' agenda. The second main reason is that voters need to control English borders or, in other words, to reduce immigration. In the last years European immigration to the UK has peaked, and in particular over the past three years has steadily increased, coinciding with the enlargement of the European Union. It may be wrongly believed that the anti-immigration "leave" vote has been caused by xenophobia feelings, but, most likely, it comes from economic reasons. In fact, it should not be ignored that the UK has been affected by a long austerity period since the beginning of the financial crisis of 2008, where low and middle-income families have probably suffered more than other citizens from cuts in public spending made by the conservative government. Hand in hand with the anti-immigration sentiment, it must not be ignored the prejudice according to which the increase in foreigners would have taken English workers out of employment opportunities and would have halved salaries and public services; as in the case of the British National Health Service (the National health service, NHS). This preconception still plays an important role in-between low- and middle-income families of England and Wales. In fact, they did not take into consideration Labor party's advice and, in the referendum, voted against "Remain".

If from one side many economists took the side of exit from the EU, a lot of them supported the "Remain" campaign, offering a general framework about the consequences Brexit would have caused in case of "Leave": inflation, increases in the unemployment rate, weaker currency, recession and negative impact on English business. None of these reasons persuaded the voters enough; citizens of modest social background preferred to leave.

It may be inferred that "Leave" campaign convinced people that immigration was the main cause of their economic problems and economists' point of view was just kibosh.

The strategy that assured the Brexiters a huge number of votes was the economic problem that the UK spends £350 million a week because of the EU and in case of exit this sum could have been spent in NHS. This persuasive trap revealed to be totally wrong. First of all because the net amount is far less than the £350 million signalled and second, there was no reason for planning new balance commitments of this kind. However, from the other side, "Remain" campaign failed to transmit and explain in a fair way all the negative consequences from Brexit. Thus, understanding who has the main responsibility is hard to explain, Brexit has been doubtless moved by economic reasons, the same that (according to experts) would suggest remaining and not to leave. According to Her Majesty's Treasury (HM Treasury) the Brexit process will cost to the UK the 7,5% of their GDP in terms of lack of economic growth over a period of 15 years. Negative forecasts belong to sterling too: a very strong devaluation of the currency in the short run is unavoidable. What about the rest of the European countries? The bill is high for the EU too; about 10 billion euros a year that Great Britain paid as its share, are now less.

As previously stated, many Brexit steps have been made after the referendum, and as long as this work aims to quantify the impact of each of them, it would be interesting to present a general overview. Once the referendum outcome was officialized, the actual British Prime Minister David Cameron, a supporter for the presence of the United Kingdom in the European Union, resigned and after twenty days, Theresa May, a Eurosceptic who voted against Brexit became the prime minister (whereas Boris Johnson became minster of foreign affairs). After a period of adjustment, on 17 January 2017 Theresa May outlined her hard Brexit plan, stating that the United Kingdom could not continue to be part of the single market because of immigration issue and on 29 March of the same year she activated the Article 50 of the Lisbon Treaty. So, the process of exiting the EU officially started. The official divorce was scheduled for 29 March 2019. Theresa May, wishing to establish her authority before starting the negotiations with the EU, scheduled early legislative elections for 8 June 2017, but the outcome was a reversal: the conservative party lost the absolute majority and, in order to govern, she was forced to ally herself with the small ultra-conservative Northern Irish party Dup. On 8 December 2017 Theresa May announced that she had reached an agreement with EU commission president Jean-Claude Juncker; the second phase of the process of exiting the economic union officially started. Unexpectedly, on 6 July 2018 Theresa May set out her plan for a post Brexit business relationship. The intent was to keep industrial and agricultural exchanges by creating a "free trade area" with the remaining twenty-seven countries and a "new customs model". This strategy was no longer considered a hard Brexit as previously stated. Therefore, this softening of the British position brought the Brexit minister David Davis and Boris Johnson (two big men of the government) to resign; replaced by the Eurosceptic Dominic Raab and Jeremy Hunt respectively. On 13 November 2018 Downing Street announced that British and European negotiators had finally reached a technical agreement. The next day a very divided council of ministers approved the agreement, but four members of the government resigned; including Dominic Raab. Nine days later, Donald Tusk announced that the EU and the UK had concluded a draft agreement on their post Brexit relations, in the form of a "political declaration". The exit agreement, like the "political declaration", was approved on November 25 in an EU summit. The agreement regulated in particular the issue of the exit account that London would have to pay to the EU, estimated around 40 and 50 billion euros, and provided the controversial agreement of the "backstop". That is, the last hypothesis to consider in case the negotiates between

London and the remaining twenty-seven EU countries would have failed; a special status for Northern Ireland in order to avoid the return of a physical border between Ireland and Northern Ireland. Theresa May invited British MPs to support the divorce agreement in a vote set for December 11, but the day before she postponed the vote, given the almost certain rejection due to the "backstop" point. Theresa May, on 12 December 2018, passed the no-confidence motion organized by deputies of her conservative party who rejected the divorce agreement with 200 votes in her favour and 117 against. The examination of the Brexit agreement by the British resumed on January 9 but the government suffered two heavy defeats: on January 9 the deputies adopted an amendment that forced, in case of Parliament rejection, the executive power to present an alternative reform plan within three days. The day before they had adopted another amendment to a budget law, aimed to limit the government's power to change fiscal policy in case of Brexit without agreement. On 12 March 2019 the new agreement proposed by May was rejected. Even though she found a new agreement with Brussels, Theresa May could not find the Parliamentary support. Westminster rejected for the second time, after mid-January, the proposal of Prime Minister May with 391 votes against 242, a gap of 149 deputies (they had been 202 in mid-January). The next day, Westminster also rejected an exit from the EU without an agreement. The House of Commons, in fact, voted against the option of a no-deal Brexit. The motion, extensively amended by a moderate and Labor-based Tory amendment, went against the will of the government. This outcome described a new defeat for Theresa May, who commented: the "no deal" option remains the "default" outlet in the absence of an agreement or postponement. Then, after offering her resignation in exchange for the yes to the divorce agreement from the EU, Theresa May submitted to the House of Commons the agreement with Brussels for the third time, but she was defeated again with 286 for and 344 against. Thus, the possibility offered by the EU to postpone the Brexit from March 29 to May 22 was set. The probability of a "no deal" scenario is concrete, with the key date set for 12 April. In the meanwhile, the European Council President Donald Tusk arranged a summit on 10 April. In order to avoid a hard Brexit without agreement and ask Brussels again "a brief extension", May initiated a dialogue with the Labor opposition. On April 4 a law passed (313 yes and 312 no) that forced the May government to avoid the no-deal and to request a further extension of the Brexit to the EU. On 11 April, the 27 Heads of State and Government found a new compromise in Brussels: another six months to find an agreement for the exit from the EU with a deadline of 31 October. This allowance implied that the United Kingdom had to participate in the EU elections, since the approving of an agreement before July was impossible. However, on May 21, the prime minister May opened to the possibility of the House of Commons to vote on an amendment for a second Brexit referendum. The reaction of the Labor leader Jeremy Corbyn who confirmed his "no" to Tory leader was immediate. At this stage, on May 24, Premier May announced her resignation by June 7 stating: "I did everything possible to find an agreement for Brexit and I regret not having succeeded". On 23 July 2019 Boris Johnson won the 2019 Conservative Party leadership election and became Prime Minister, covering the difficult role of making the British public unite and support his final decision, since everyone was flaunting a personal opinion. The deadline for the exit was firstly scheduled for 29 March 2019, but after a series of meeting was planned for 31 December 2019. The probability of a hard Brexit, which is the exit with a no-deal (third scenario) was then concrete. This state would imply the introduction of customs tariffs for goods coming from the EU countries, that will make each imported product as more expensive and would encourage the UK to import these goods from elsewhere. The physiognomy of this phenomenon will be up to each specific industrial sector and geographic area and will therefore affect the employment too. Belgium, Germany and the US represent the main countries that will affect this decreased demand, even though an impact, of smaller size, will also be generated by the remaining twelve markets, which are object of this study. The impact at a firm level varies from country to country, in fact for some Latin American countries like Brazil, the impact concerning the agricultural products will be high, while for other countries like Germany and the Czech Republic the effect is greater with regard to the manufacturing industry (see Brautzsch and Holtemöller [2019]).

Among all the stages in-between 2016 and 2019 cited above, this work con-

Table 2.1: Brexit events considered in the event study

Date	Description
24/06/2016	Brexit Referendum Result
13/07/2016	Teresa May is elected Prime Minister of the UK
29/03/2017	Teresa May activates Article 50 of Lisbon Treaty
06/07/2018	Theresa May set out the Brexit plan
22/11/2018	PM statement in Downing Street
13/03/2019	Westminster rejects the exit without agreement
07/05/2019	UK is offered to participate to European elections
24/05/2019	Teresa May resigns
12/12/2019	Conservative Party won the general elections

siders for the computation of the event-study the events listed in table 2.1. Whether or not the UK will negotiate a favourable agreement with the EU concerning their future relations, will define the dimension, the costs and the benefits of the Brexit effects. The country will not belong to the single market anymore, so there will be no free exchange of capital, goods, people and service any longer, but in this new scenario in which the UK will make up new bilateral relations with the rest of the world, the British economy can still play an important role.

2.3 Previous Studies

The event study approach describes a well-suited methodology for studying the referendum outcome, since the result came up as a surprise and therefore it would be interesting to understand the markets' response by looking at the associated impact of each following Brexit event. There are some works in the literature which rely on event-study methodologies in order to quantify specific events associated with Brexit. Here we report just few of them. Burdekin *et al.* [2018] for instance, assess the impact of the Brexit vote on global equity markets using an event study method as seen in Campbell *et al.* [1997]. They regress each individual market return on the global market return and an event dummy variable, which takes value 1 the day of the announcement and in the next two days and 0 otherwise. In order to make the analysis more consistent, three different global market return have been used (the MSCI global price index, the S&P Global Equity Index, and the Dow Jones Global Equity Index); all of them display uniform results. The empirical result shows that the negative abnormal returns for PIIGS countries (Portugal, Ireland, Italy, Greece, and Spain) have been far worse with respect to the UK, France and Germany; the result comes from the common idea that countries affected by a higher debt to GDP ratios suffers more severe stock market declines. The study finds an analogy with Sumner [2016]'s work too, in which the 1931 British exit from the gold standard, damaged countries that remained in the old bloc more than the UK itself.

Strongly connected with this study, there is the work of Ramiah *et al.* [2017], in which they argue the impact of the outcome of the Brexit referendum on several sectors of the British economy in the period between June – July 2016. The work presents an event study in order to show the different impact across distinctive sectors. The authors demonstrate that the banking, travel and leisure sectors have been the most negatively affected with a Cumulative Abnormal Return (CAR) of about -15.37%; the method of the writers is almost in line with the one that this study uses. In fact, they also adopt a dummy variable approach, that takes value one on the day of the announcement (and zero otherwise) in order to capture the immediate impact in systematic risk. The main difference concerns the definition of the dependent variable, since they adjust the daily returns (by approximating with the CAPM) to obtain the ex-post-abnormal returns (ARs). In line with the previous ones, Bonchev and Pencheva [2017] examine the effects of the referendum results only in Europe; more specifically, they investigate the impact of Brexit vote on the banking sector. They state that the referendum results have been considered as bad news for the European banking system in the short run and the effects have been worse in the UK with respect the rest of Europe. Starting from these assumptions the authors selected 63 European banks from the STOXX Europe TMI banks and regressed each daily bank stock price on the EUROSTOXX 50 index daily closed price. The analysis follows the structure given in Campbell *et al.* [1997], firstly identifying the event of interest (the referendum day) and then the period of time used in the regression. The writers found that for all banks the impact of the UK leaving the EU was significant enough. In fact, as expected, the abnormal returns were on average -2.26% for all banks. This result again shows how the reaction of markets is immediate when the event affects a consistent market size as the UK one[2].

All these articles highlight that the banking sector is one of the most affected and show that the prediction of the Bank of England about the changes in the short run were right. These expectations find a solid basis from a discussion in the Financial Times too, in which banks were supposed to move out from the UK if no concrete agreement with regard to the current arrangements would have been achieved. Therefore, this consequence has been used to formulate the hypothesis that Brexit is a bad news for the banking sector.

This work, in contrast with the previous ones discussed above does not specifically focus on the banking sector or on the European continent, the study includes a broad range of countries from all over the world, that have been selected according to the size of their volume of trading with the UK. Moreover, the discussion is not limited to the private sector, but it includes the analysis of the macroeconomic effects too[3]. This implies, that the ongoing examinations results as a combination of the previous articles mentioned above, plus the work of Altavilla *et al.* [2014], in which the authors discuss the macroeconomic effects of the non-standard monetary policy Outrigth Monetary Transaction on 10-year bond government yield of Italy, Spain, Germany and France through an event study, and then they provide additional results with a multi-country vector autoregressive model in order to define the macroeconomic impact of each event. Thus, this work provides more insights of the Brexit effects.

[2] Brown and Warner [1980], Brown and Warner [1985], Strong [1992], Binder [1998] and Škrinjarić [2019] apply a similar methodology in order to study the effects of any type of event on stock returns.

[3] Bruno *et al.* [2016]; Dhingra *et al.* [2016]; Simionescu *et al.* [2018]; Belke and Ptok [2018]; and Busch and Matthes [2016] provide an estimation of the Brexit effects on several macroeconomic variables with the associated trade consequences.

2.4 Event-Study Methodology and Empirical Results

To assess the effects that Brexit events outlined in Table 2.1 have generated on the equity and treasury bond market in Italy, France, Spain, Germany, Netherlands, Belgium, Finland, Portugal, UK, Sweden, Switzerland, USA, China, Australia and Japan, the following two equations are estimated for each economy:

$$\Delta y_t = \mu + \alpha D_t + \epsilon_t \tag{2.1}$$

$$\Delta y_t = \mu + \alpha D_t + \beta X_{News,t} + \epsilon_t \tag{2.2}$$

where, Δy_t relates to the first difference of the 10-year government bond yields ($10YTY_t$) in the treasury bond analysis, and to the daily change of benchmark stock market index prices (r_t) in the equity analysis. D_t is a vector of event dummies that take value 1 the day of the event and 0 otherwise. When the dependent variable accounts for the 10-year government bond yield, D_t is set on a 2-day event window and takes value 1 the day of the event and the following day[4]. Whereas, when Δy_t accounts for the individual equity market returns, D_t takes value 1 the day before the event, the day of the event and the next day as well[5]. The event dummies reflect the nine major Brexit steps that occurred between June 2016 and December 2019. The estimation is performed by means of standard regression method and covers a sample period which runs from 01/01/2010 through 31/12/2019[6]

As a robustness exercise, equation (2.2) augments the classical event study with the addition of a controlling variable $X_{News,t}$. In the equity market analysis, $X_{News,t}$ assess the surprise effect resulting from the dif-

[4]This choice is based upon the work of Altavilla *et al.* [2014], in which the authors suggest that bond prices may react slowly after an economic shock

[5]This different choice comes from the common idea that equity markets may react faster in response to an event; see MacKinlay [1997] for a more detailed explanation

[6]Appendix .5 provides the time series of each country for both treasury and equity market.

ference between the observed value of S&P Global Equity Index[7], and the one estimated through an AR(12) in the spirit of Burdekin *et al.* [2018]. In contrast, in the treasury bond analysis, the controlling variable $X_{News,t}$ is expressed by the main news stemming from macroeconomic releases. Namely, it is computed by performing the difference between the observed value of a macroeconomic variable, and the one estimated by multiple economists and made available on Bloomberg; see Altavilla and Giannone [2014] for a detailed explanation.

The controlled event study aspires to consider any surprise effect that could have influenced the financial markets. For the equity market analysis, this factor is the same across all dependent variables, while in the sovereign bond analysis, this factor varies across each country (see Appendix .6 for a detailed description), and displays a time series of (standardized) daily news, which result from the difference between the real released value and the estimated one of all major macroeconomic variables made available in Bloomberg. This time series aims to measure the impact of the news of all the most relevant releases on economic data in the period under analysis[8]. This implies that, if a certain relief is perfectly predicted, then the release cannot be considered as "news", in fact it would have value of 0 and would not affect the dependent variable. In contrast, if it is imperfectly forecasted, some "news" are included in the model and, hence, it would most likely affect the bond rates. The estimated α coefficients yield the effects of the individual Brexit events. Standard tests can be used to evaluate whether the sum of the coefficients of event dummies is statistically different from zero.

Table 2.3 reports in the first panel the empirical results based on equation (2.1), and in the section below the evidence resulting from equation (2.2). Δy_t accounts for $10YTY_t$. The last column reports the overall effect, given by the sum of changes for each event based on a 3-day event window. The controlled event study refers to equation (2.2), in which the daily observations are regressed on event dummies and on 164 time series macroeconomic

[7]The paper uses a time series from June 23^{rd} 2016 to July 1^{st} 2019 available on Bloomberg.

[8]Appendix .6 reports a detailed description of the macroeconomic variables used to control the event study.

news listed in appendix .6. *, **, and *** describe the significance of a t-test for abnormal return at 10%, 5%, and 1%, respectively. Results display that Brexit events have significantly reduced the sovereign bond rate values of the UK, Sweden, Australia and the US, followed by the western European countries, while Italy has been mostly unaffected.

Table 2.4 reports the equity market analysis for both classical and controlled experiment. It is evident that Italy and Belgium are the main affected countries in the classical experiment, while in the controlled regression, even Sweden and China exhibit a large lost. The not consistent impact on Germany, US, Switzerland and Japan may be interpreted as the impossibility of a singular and not so huge economy as the British one, to affect large economies in all the world. Countries like the US and Japan can count on a large set of trade partners around the world; therefore, it would not be so easy to affect such economies. Both tables also show that the main impact on both markets is due to the referendum and general elections result, while the remaining events have not had a concrete statistically significance in terms of negative results. In fact, the bond rates have been unaffected for all economies, while the equity markets of Japan and Portugal have been positively affected on 12/07/2016 and 28/03/2017 respectively; these positive results suggest that they are not consequence of Brexit events. The 7th of May 2019, when Labor Party rejected for the second times a new referendum as suggested by the prime minister, has produced negative results for Belgium and China, since the possibility of a hard Brexit was now real.

In order to realize whether the events may have had only a temporary impact on asset prices, the time span of the event window is increased up to five days in a row. Table 2.5 reports the individual change of each event evaluated in a 5-day window. According to the results it can be inferred that Brexit effects have distressed each economy only in the short run. The United Kingdom is the only exemption, since Brexit announcements have generated a light lost, but the general elections outcome has been much more persistent. Concerning the 10-year government bond yields, the referendum result shows a persistent behaviour common to all economies, while France is the only economy which has been negatively affected after Theresa May resigned.

2.5 The Macroeconomic Effects of Brexit Events

Based on event-study results, the Brexit outcome caused a significant reaction of the benchmark stock market index prices and long-term bond yields for many countries, showing that the panic across markets was concrete. This event might be interpreted as a structural exogenous shock, hence it would be interesting to understand the spillover effects that a UK uncertainty shock generates on the output of the remaining countries, and then compare the actual effects with the "no-Brexit" scenario in order to quantify the differences (and maybe the losses) between the main macroeconomic country-specific variables. We do that by performing a global vector autoregression (GVAR) model, which has a flexible structure aiming to capture the international financial and macroeconomic cross-country linkages between the 15 country-specific economies. GVARs have long been used as a method to treat the long-run properties through the cointegration of more country data. See Pesaran *et al.* [2004], Dees *et al.* [2007] and Pesaran *et al.* [2009] for example.

The GVAR takes into consideration three variables (real GDP, consumer price index, rates of government bonds with remaining maturities of ten years) per country, and the Economic Policy Uncertainty index (EPU) of the UK as a foreign variable common and exogenous to all countries. This implies a stochastic model with 45 dependent variables specified as follows:

$$y_{i,t} = \mu_i + \sum_{j=1}^{p} \Phi_{i,j} y_{i,t-j} + \sum_{k=1}^{q} \Theta_{i,k} x_{t-k} + \nu_{i,t} \tag{2.3}$$

where $i = 1, \ldots, 15$, $t = 1, \ldots, T$, $\nu \sim$ iid $N(0, \Sigma)$ is a n-dimensional vector of white noise, p and q represent the lag order of country-specific and global variables respectively, Φ and Θ are the reduced form coefficients linked to the lagged country-specific variable y_i and the lagged global factors x. We set $p = q = 4$, leaving all possible interactions among variables and countries unrestricted in order to allow for cross-country heterogeneity. UK EPU index is based on the recent work of Baker *et al.* [2016], in which the authors develop a novel series of uncertainty by using natural language processing methodologies on the main UK newspapers.

Equation (2.3) is based on the study originally suggested by Pesaran *et al.* [2004], where the model proposes an efficient way for modelling iterations in a complex high-dimensional system for credit risk analysis. This methodology was then extended to numerous empirical studies (see Chudik and Pesaran [2016] for a concrete example of his application). The study of the macroeconomic effects following a UK uncertainty shock, is based on a two-step procedure.

In the first step, small-scale country-specific models are estimated conditional on the rest of the world. These models are represented as augmented VAR models, denoted as VARX* and feature domestic variables and weighted cross-section averages of foreign variables, which are also commonly referred to as 'star variables' and are treated as weakly exogenous (or long-run forcing). VARX* are useful in order to depict the country-specific dynamic response following an uncertainty shock.

In the second step, individual country VARX* models are stacked and solved simultaneously as one large global VAR model. The solution is used for forecasting as it is usually done with standard low-dimensional VAR models. Results are then used in comparison to the actual values of macroeconomic variables in order to show the differences between "Brexit" and "no-Brexit".

2.5.1 Dynamic Analysis of UK Uncertainty Shock

This section investigates the spillover effects that a UK EPU shock generates on country-specific outcomes. The analysis is structured as follows. We first assume that rates of government bonds with remaining maturities of ten years enter the VAR as a third variable in order to represent the financial market behaviour, then we include the stock market index in place of bond yields and perform a second dynamic analysis for the sake of consistency. In particular, suppose we wish to start from equation (2.3). Each subsystem in (2.3) has a VARX* form, namely a country-specific VAR conditioning on a set of foreign and global variables, which can be specified as follows:

$$
\begin{aligned}
y_{01,t} &= \mu_{01} + \sum_{j=1}^{p} \Phi_{01,j} y_{01,t-j} + \sum_{l=1}^{r} \Phi^{*}_{01,l} y^{*}_{01,t-l} + \sum_{k=1}^{q} \Theta_{01,k} x_{t-k} + \nu_{01,t} \\
y_{02,t} &= \mu_{02} + \sum_{j=1}^{p} \Phi_{02,j} y_{02,t-j} + \sum_{l=1}^{r} \Phi^{*}_{02,l} y^{*}_{02,t-l} + \sum_{k=1}^{q} \Theta_{02,k} x_{t-k} + \nu_{02,t} \\
&\vdots \\
y_{15,t} &= \mu_{15} + \sum_{j=1}^{p} \Phi_{15,j} y_{15,t-j} + \sum_{l=1}^{r} \Phi^{*}_{15,l} y^{*}_{15,t-l} + \sum_{k=1}^{q} \Theta_{15,k} x_{t-k} + \nu_{15,t}
\end{aligned}
$$

Here, differently from (2.3), each y_i is an independent VAR and the foreign variables y_i^* are included as explanatory factors. We set lags $p = r = q = 4$, and estimate the stochastic systems through a traditional approach. Bootstrap confidence bands of impulse response functions are computed using the "bootstrap after bootstrap" method of Kilian [1998]. It is clear from Figure 2.1 and 2.2 that following one standard error positive shock of UK EPU, the GDP of each country falls in the first quarter and then, in most of the cases, GDP approaches to its steady-state within 2 years. This is not the case of Australia, where in both cases, a UK uncertainty shock generates persistent effects even in the long run. The UK exhibits the worst contraction of GDP, but this was expected, since we are specifically investigating the uncertainty index of the English economy[9].

The analysis is improved by considering additional global variables, that can affect multiple economies such as oil and commodity prices. We take data from the World Bank pink sheet, and perform the principal component analysis in order to reduce the number of factors to two, which explains the 98% variation of data. Now, the number of factors has been drastically increased and a traditional econometric methods such as ordinary least square and maximum likelihood estimation might perform poorly. For this reason,

[9]China is not included in this exercise, since observations of macroeconomic variables are not available before 2002. This choice does not create any problem in the analysis, as we have seen in **Table 2.3** China's sovereign bond rate did not react to any Brexit event. Therefore, we would not expect a strong negative reaction of China's GDP following a UK uncertainty shock.

Table 2.2: Sub-periods when variance switches regime

Start	End	Description
1996Q1	2015Q1	**Period Pre-Brexit**
2015Q2	2019Q1	**Period Post-Brexit**

we switch to Bayesian theory and use a Metropolis-Hastings algorithm as in Baumeister and Hamilton [2019], by considering 20000 independent draws, 10000 of which are discarded. Details of this methodology are provided in Appendix .8.

In this exercise, it is convenient to identify VARXs via heteroskedasticity, as we can capture any change in volatility pre- and after-Brexit. This methodology was initially proposed in Rigobon [2003], where the variance is allowed to switch regime according to a hypothetical probability state matrix. However, this standard approach would probably identify several variance regimes, as our sample runs across the financial crisis and other economically meaningful events. On the contrary, we are interested to capture the change in volatility pre- and after-Brexit, therefore we adopt the methodology used in Brunnermeier *et al.* [2021], in which all regimes are *a priori* exogenously identified. In particular, the whole sample period is split in two different sub-samples (see Table 2.2). The first runs from 1996Q1 through 2015Q1 and the second from 2015Q2 up to 2019Q1. This choice come from the logic assumption that starting from 2016Q2 and setting p =4 lags, the first observed variable would be in 2017Q2 and the effects coming from the referendum result would be missing. Therefore, the second period starts from 2015Q2. This approach implies that ν is allowed to change across samples, while reduced form coefficients remain fixed. In this way, as long as samples are continuous and well defined, the structural response has the same shape, but different scale dimension in line with the variance values.

Results are depicted in Figure 2.2 and 2.4. Once again, it is clear that US and Japan are the economies less affected by the UK EPU shock. Their median response does not show any strong reaction. On the contrary, GDP of European economies drops at the impact, and for some countries (see

Netherlands and Sweden) it comes back to its steady-state, while in other cases (see Italy, Spain, Belgium, Finland, Germany) the negative effects are more persistent. This is reasonable, since Italy, Spain, Germany and Belgium are in-between the 10 largest trading partners of the UK.

2.5.2 Multy-Country VAR model: Evaluation of Brexit Effects

We now turn to the evaluation of Brexit effects by comparing two scenarios: the case of "Brexit" and the case of "no-Brexit". As mentioned at the beginning of the section, VARXs* are now collected in one global system, which is outlined in equation (2.3).

The counterfactual analysis is provided by starting from 2016Q1 (period before the exit from the EU was announced), and performing a forecast of three years. This is structured as follows. The model is estimated over the sample period 1996Q1-2016Q1. The no-Brexit scenario is constructed by the unconditional forecast of the VAR over a projection horizon of three years. The Brexit scenario has the features summarized in Figure 2.1. Specifically, UK uncertainty shock is assumed to reduce the gross domestic product for all countries in the fist six months, and then it gradually comes back to its steady-state.

Empirical results about the difference between Brexit and no-Brexit scenario are given in terms of percentage deviation from the situation of no-Brexit. Table 2.6 reports, for country and variable pairs, the effects associated with the Brexit events, evaluated three years after the announcements. The evidence shows that Brexit events are likely to be associated with negative effects on the GDP for all countries except for the US and Japan. The US outcomes display that the UK decision to leave the EU has not affected the north American real activity. This effect is justified since the US market is extremely large and it can hardly be affected by events related to a singular economy. In the case of Japan instead, the results are in line with the event-study analysis too, in which the Asian country is the less affected economy in both equity and bond markets. There is no general outcome to describe the behaviour of the consumer prices, since the variable exhibits more country heterogeneity, dropping in France, Finland, Portugal, Switzerland, Australia and Japan, whereas the rest of countries it is mostly unaffected. This last exercise leads us to conclude this work, by assessing that Brexit outcome has negatively affected the real activity of the largest trading partners of the UK, and that these consequences mostly come from the uncommon political decisions, which yielded a high level of uncertainty on financial markets.

2.6 Conclusions

In this paper, event-study analysis and global vector autoregression are used to shed light on the impact effect that nine important Brexit events have generated on the real economy of 15 countries. Empirical results show the following evidence. First, the referendum result and the general election of December 2019 represent the main events that have generated the largest effects on the economies taken into consideration. In particular, the sovereign bond yields of the UK, Sweden, Australia and the US exhibits the largest drop, followed by the one of European countries. In regard to the equity market, Italy and Belgium are the most affected countries. Second, a UK positive volatility shock generates a drop in the real economy of all countries at the impact, which is persistent in the long run for Spain and Australia. Finally, a comparison between two scenarios of "Brexit" and "no-Brexit" highlights that, other than US and Japan, the decision of the UK to leave the European community has generated a negative impact on the gross domestic product of all countries considered. The effect comes from the strong dependence the British manufacturer sector holds with the European continent.

A number of extensions of this research are possible, of which only few are mentioned here. First, we can examine the impact effect of more financial variables and investigate if the outcome is in line with the event-study performed here. Second, we can consider additional macroeconomic variables and depict the impulse response not only for the gross domestic product, but also for other variables which are strongly connected with the level of uncertainty perceived on financial markets (i.e. unemployment rate, interest rate, and so on). However, these tasks are left for further analysis.

Table 2.3: Reaction of individual sovereign bond markets to Brexit events (raw data results)

Country	**1st Event**	**2nd Event**	**3rd Event**	**4th Event**	**5th Event**	**6th Event**	**7th Event**	**8th Event**	**9th Event**	**Total**
	24/06/16 - 28/06/16	13/07/16 - 15/07/16	29/03/17 - 31/03/17	06/07/18 - 10/07/18	22/11/18 - 26/11/18	13/03/19 - 15/03/19	07/05/19 - 09/05/19	24/05/19 - 28/05/19	12/12/19 - 14/12/19	
Classic										
Italy	-1	3	15.7	-6	-20	-4.4	10.4	4.5	9.1	12.1
France	-21 ***	4	0.9	1.2	-2.7	-1.5	-1.3	-3.2	2.5	-21.3
Spain	-9.2 **	4.5	-0.7	-3.9	-4.5	1.6	0.6	-7.8 *	0.7	-19.5
Germany	-20.5 ***	9.7	-6	2.1	-1.5	2.9	-5.3	-4.1	-10.6 *	-33.3
Netherlands	-19.2 ***	3.7	-5.5	1.9	-2.1	2.6	-3.7	-4.4	3.7	-23
Belgium	-15.2	5.2	-1.3	-5.1	-7.3	1.9	0.5	-6.5	2.4	-25.4
Finland	-19.5 ***	2.3	-4.7	1.5	-2.1	1.9	-2.9	-4.2	1.8	-25.9
Portugal	5.5	0.2	-9.3	-4.6	-7.9	-2.6	-0.6	-9.3	2.4	-26.2
U.K.	-41.2 ***	0.6	-5.3	4.4	1.4	4.8	-9.4	-6.1	4.8	-46
Sweden	-29.2 ***	1.8	-4.1	-0.5	-1.2	2.5	-10.2	-3.3	2.7	-41.5
Switzerland	-12.7 ***	5.2	-3.2	4.8	-1.7	1.9	-2.4	-3.4	1.8	-9.7
USA	-27.9 ***	4.1	-3	2	-0.6	-1.4	-2.7	-5.8	7.99	-27.41
China	-8	0	1.9	3.9	2.6	-8	-5.8	1.1	1	-4.1
Australia	-26.1 ***	2.8	2	3.9	-5.4	-5.4	-2.5	-4.6	0.2	-36.9
Japan	-7.5 **	4.5	1.2	7	-3	-6	-8	-1.3	-1.4	-5.5
Controlled										
Italy	33	-100	-73	73	-7	-92	30	24	6.5*	-105.5
France	71 ***	7	-41	-49	116	31	-122	-124	-4.7*	-114.7
Spain	-192.8 **	70.5	141	230	125.6	218.7	0.6	-299.4 *	1.3	296.3
Germany	116 ***	-31.2	-30	86.6	183	-92.6	62.6	-40.3	-11.4*	242.6
Netherlands	-74 ***	-51	20	13.1	-47.8	12.3	-33.8	78	4.7	-78.5
Belgium	-15.2	5.2	-1.3	-5.1	-7.3	1.9	0.5	-6.5	5*	-22.8
Finland	100.6 ***	122.4	-36.8	24.5	7.6	32	-44.4	23.7	6.8*	236.8
Portugal	75.4	-39.6	-37.2	125.5	-109	-102.6	-100.6	-109.3	3.7	-292.6
U.K.	-141.2 ***	67.5	77.2	-55.4	39.1	-34.4	65.8	33.1	10.3	62
Sweden	-101.1 ***	-24.2	64.8	-12	-51	-76.1	-133.9	-94.3	-2.4	-430.4
Switzerland	13.7 **	-50.6	49.1	40.6	-34.4	3.9	-37.1	-12.3	2.5	-24.6
USA	-8.2 ***	-8	-21.4	-47	-68.7	26.8	-5.8	30.1	3.8	-98.4
China	11.2	1.4	-50	-34.7	-52	40	-70	-25.9	-4.3	-184.3
Australia	26.9 ***	-30	36.8	-50.4	37	-40.7	37.7	-39.8	3	-94.7
Japan	-43.1 **	-57.9	23.2	47.6	59.1	25.8	-30.6	36.8	-0.8	60.2

Table 2.4: Reaction of individual equity market returns to Brexit events (raw data results)

Country	**1st Event**	**2nd Event**	**3rd Event**	**4th Event**	**5th Event**	**6th Event**	**7th Event**	**8th Event**	**9th Event**	**Total**
	23/06/16 - 27/06/16	12/07/16 - 14/07/16	28/03/17 - 30/03/17	05/07/18 - 09/07/18	21/11/18 - 23/11/18	12/03/19 - 14/03/19	06/05/19 - 08/05/19	23/05/19 - 27/05/19	11/12/19 - 13/12/19	
Classic										
Italy	-12.79 ***	3.2	1.2	1.6	1.3	1.2	-2.6	-0.8	0.9	-7.5
France	-9.1 ***	2.8	1.4	1.5	0.5	1.6	-2.4	-0.8	1.2	-5.3
Spain	-12.1 ***	3	1	1.7	0.6	0.4	-1.9	0.9	2.6	0.9
Germany	-8 ***	2.4	2.1	1.8	1.1	0.4	-1.9	-0.8	1.6	-1.4
Netherlands	-6.7 ***	1.7	1.3	1.5	0.7	1.6	-1.7	-0.7	0.5	-1.9
Belgium	-9.1 ***	1.7	1.5	2	0.3	1.1	-3.8 **	-0.4	0.2	-6.4
Finland	-4.5 **	2.3	0.5	2	0	1.7	-2.5	-1.2	1.6	0.2
Portugal	7.8 ***	0.7	5.4 ***	2.3	-0.6	1.7	-3.4	0.7	1.1	0.9
U.K.	-4.4 ***	-0.4	1	1.5	0.2	0.8	-1.1	-0.9	1.9*	-1.4
Sweden	-5.4 ***	1.1	0.6	1.2	1.4	1.3	-3.1	-1.7	2	-2.6
Switzerland	-4.8 ***	0.7	1.3	1.1	0.9	1.5	-1.3	0.7	0.4	0.4
USA	-3.6 ***	1.5	0.8	2.5	0.8	0.2	-2	-1.7	0.9	0.4
China	-0.3	2	-1.7	2	-2.5	-1.2	-6 **	0	0.9	-5.7
Australia	-3 *	1.8	1.9	-0.4	1.2	0.3	-0.9	-0.5	0.5	-0.5
Japan	-4.4 **	4.3 **	0.2	1.1	0.4	0.4	-3	-0	2.6	2.2
Controlled										
Italy	-7.4 ***	2.6	1.3	-0.3	0.7	0	-0.3	-0.8	-0.5*	-4.7
France	-3.7 ***	2.1	1.6	-0.5	-0.2	0.4	-0.1	-0.6	-0.3*	-1.3
Spain	-6.7 ***	2.3	1.1	-0.2	-0.1	-0.8	0.3	2.3	1.1*	-0.6
Germany	-3 ***	1.7	2.3	-0.1	0.5	-0.8	0.4	-0.6	0.2*	0.9
Netherlands	-1.4 ***	1	1.4	-0.4	0	0.5	0.5	-0.5	-1*	1.4
Belgium	-3.8 ***	1	1.6	0.1	-0.3	0	-1.6 **	-0.2	-1.2*	3
Finland	-3.3 **	1.6	0.6	0.2	-0.6	0.5	-0.3	-1	0.2*	-2.1
Portugal	-2.5 ***	0	5.5 **	0.4	-1.2	0.5	-1.1	0.9	-0.4*	2.1
U.K.	-0.9 **	-1.1	1.1	-0.4	-0.6	-0.4	0.4	-0.3	0.5*	-0.5
Sweden	-4.2 ***	0.4	0.7	-0.7	0.8	0.1	-0.7	-1.5	0.6*	-4.5
Switzerland	0.6 ***	0	1.4	-0.1	0.2	0.3	1	0.9	-1*	2.7
USA	1.8 **	0.9	1	0.5	-0.5	-0.9	0.2	-1.1	-0.5	1.4
China	5	1.3	-1.6	0.1	-3	-2.4	-3.7 **	0.2	-0.5	-4.7
Australia	2.3 *	1.2	2	-2.3	0.6	-0.9	1.3	-0.3	-0.9*	-2.3
Japan	1 **	3.7 **	0.3	-0.8	0.8	-0.7	-2.3	0.3	1.2	3.3

Table 2.5: Asset price reaction to Brexit steps in a 5-day windows (raw data results)

Country	1^{st} Event		2^{nd} Event		3^{rd} Event		4^{th} Event		5^{th} Event		6^{th} Event		7^{th} Event		8^{th} Event		9^{th} Event	
	Classical	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*	*Classical*	*Controlled*
Equity Market																		
Italy	-7.2 **	-5.1 **	3.1	2.5	0.6	0.9	0.1	-1.5	3.7	1.1	2.9	1	-4.1	-0.4	2.8	-1.8	2.2	-0.1
France	-3.8	-1.7	2.2	1.6	1.4	1.7	0.6	1	1.2	-1.3	2.8	1	-4	-0.3	-2.9	-1.9	2	-0.3
Spain	-6.1 **	-4 *	2.6	2.1	0.2	0.5	-0.2	-1.8	2.4	0	2.6	0.7	-3.1	0.6	0.5	2.7	3.1	0.8
Germany	-4.3 *	-2.2	2.3	1.8	2.2	2.5	0.8	-0.8	2.2	-0.3	1	-0.8	-2.8	0.9	-2.7	-1.7	1.7	-0.6
Netherlands	-2.2	-0.2	1.7	1.1	0.8	1.1	0.7	-0.9	1.8	-0.7	3.1	1.3	-3.1	0.6	-2.2	-1.2	1.1	-1.2
Belgium	-4.2 *	-2.1 *	1.5	0.9	1.6	1.9	1.6	0	1.6	-0.9	2.6	0.8	-5.7 **	-2 **	-1.6	-0.6	0.9	-1.4
Finland	-0.5	-0.9	2	1.5	0.7	1	1.9	0.3	0.1	-2.4	2.7	0.9	-2.8	0.9	-3.2	-2.3	3.2	0.9
Portugal	-3.6	-1.5	0.5	0	5.1 *	5.5 *	2.1	0.6	0.1	-2.4	1.9	0.1	-4	-0.2	-1.2	-0.2	1.4	-0.9
U.K.	1.7	3.8	0.1	-0.4	-0.1	0.1	0.3	-1.3	1	-1.5	2.3	0.5	-2	0.9	-1.6	-0.2	4.3**	2***
Sweden	-1.8	-2.3	1.3	0.8	-0.2	0	0.3	-1.3	2.7	0.2	2.2	0.4	-4.2	-0.3	-3.6 *	-2.6	3.2	0.9
Switzerland	0.2	2.3	0.5	0	0.5	0.7	0.2	-1.4	1.5	-1.1	1.7	-0.1	-2.7	1	-1	-0.1	1.4	-0.9
USA	-0.4	1.7	1.7	1.1	0.5	0.7	2.2	0.6	3.7 *	0.6	1	-0.7	-2.1	1.6	-2.4	-1	1.4	-0.9
China	0.9	3	1.6	1	0.1	0.5	0.7	-0.9	-2.7	-5.2	2.3	0.5	-4.4	-0.6	0.8	1.8	4.1	1.8
Australia	-1.3	0.8	2.6	2	0.5	0.8	-1.1	-2.7	1.1	-1.4	1.7	0	0	3.7	-0.9	0	2.1	-0.2
Japan	-2.6	-0.5	5.9 **	4.5 **	-0.5	-0.1	0.5	-1	1.7	0.3	2	0.2	-4.4 *	-2.2 *	-0.6	0.3	2.8	0.5
10-Year gov. bond																		
Italy	-14.2	19.1	1	34.3	11.5	-77.7	-10.6	68	-21.5	-8.5	-4.6	-56.9	12.1	-75.2	1.8	21.4	13.4	10.8
France	-27 ***	65 ***	1.3	3.9	-3.4	-45.3	-0.5	-50.7	-3.7	115	-0.7	-105	-2.6	30.4	-4.6	-125	6.1	-1.1
Spain	-21 ***	-204 ***	1.4	67.4	-3.8	138.8	-3.2	230.9	-5.7	124.3	0.2	217.3	0.8	0.8	-10.4 *	-302 *	1.7	-53
Germany	-22 **	114 ***	6.1	-34.8	-13.1	-37	5.8	90.3	-2.7	182	4.2	-91.3	-7.6	60.3	-5.5	-41.7	-9.1	-86
Netherlands	-23 **	-78 **	1	-54.7	-12.7	128	2	289	-4	-49.6	3.9	136	-5.8	-35.9	-5.8	76.6	6.4	96
Belgium	-30.3 *	-30.3 *	1.3	1.3	-6.3	-6.3	-4.3	-4.3	-9.2	-9.2	2	2	7	7	-8.8	-8.8	5.5	8.1
Finland	-24 **	96.1 **	-2.8	117.3	-11.6	-43.7	-0.8	22.2	-3.2	6.5	3	33.1	-5.6	-47.1	-5.3	22.6	5.8	10.8
Portugal	-8.4	61.5	-4.7	65.2	-14.5	-42.3	-5.4	124.7	-9.4	-9.4	-3.4	-103.4	3.2	-96.8	-14.9	-114.9	3.6	4.9
U.K.	-51 ***	16 ***	-2.7	64.2	-12.5	70	2.4	-57.4	-1.9	35.8	2.3	-36.9	-11.8	63.4	-6.7	32.5	1	1.6
Sweden	-38 ***	-110 ***	-3.3	80.8	-6.4	-140.3	-3.9	-14.7	-3.2	-53.7	4.1	-74.5	-11	-134.7	-8.9	-99.9	3.1	-2
Switzerland	-20 ***	-55 ***	5.4	31.8	-6.8	13.9	3.1	38.9	-1.7	-23.4	2.3	20.9	-3.2	-1.2	-7.4	-42.1	3.5	4.2
USA	-23 **	-3 **	4.3	-7.8	-5.7	-24.1	1.6	-150.6	-3.3	-71.4	1.1	29.3	-6.8	-9.8	-19.4	16.5	12.6	-28.4
China	-8	11.2	-1	0.4	3.6	-48.3	1.2	-37.4	1.3	-52.9	-1.6	-65.6	-9	-9	-1.7	-28.7	5	3.1
Australia	-27 **	26.1 **	-2.4	-34.9	-9.4	27.2	2.5	-50.8	-6.9	35.5	-10	-62	-1.4	-1.4	-4.7	-39.9	5.2	2.3
Japan	-7.7 *	-43.3 *	3.8	-58.6	0.8	22.8	0.2	47.1	-1.3	58.1	-1.2	-30.9	-0.8	-30.6	-2	36.1	-1.5	-1

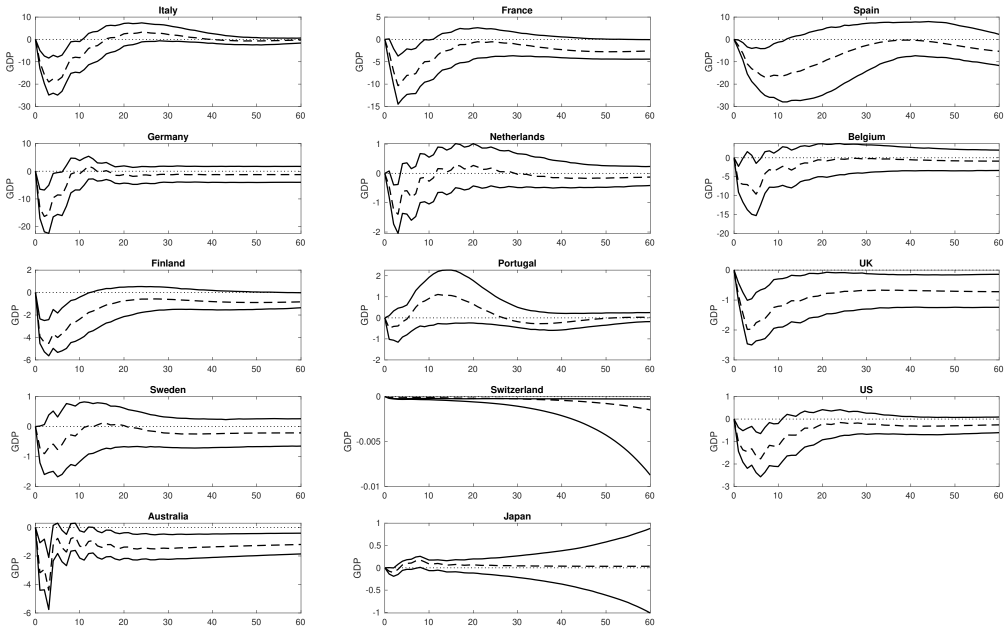

Figure 2.1: Impulse response functions showing country-specific gross domestic product reaction to a one standard error positive shock of UK EPU. Dotted line is the median response, while upper and lower solid lines describe the region of 68% of credible set. VARX coefficients are estimated in a traditional way, while lower and upper bounds are computed by following "bootstrab after bootstrap" of Kilian [1998]. Bond yields are used to describe financial markets behaviour.

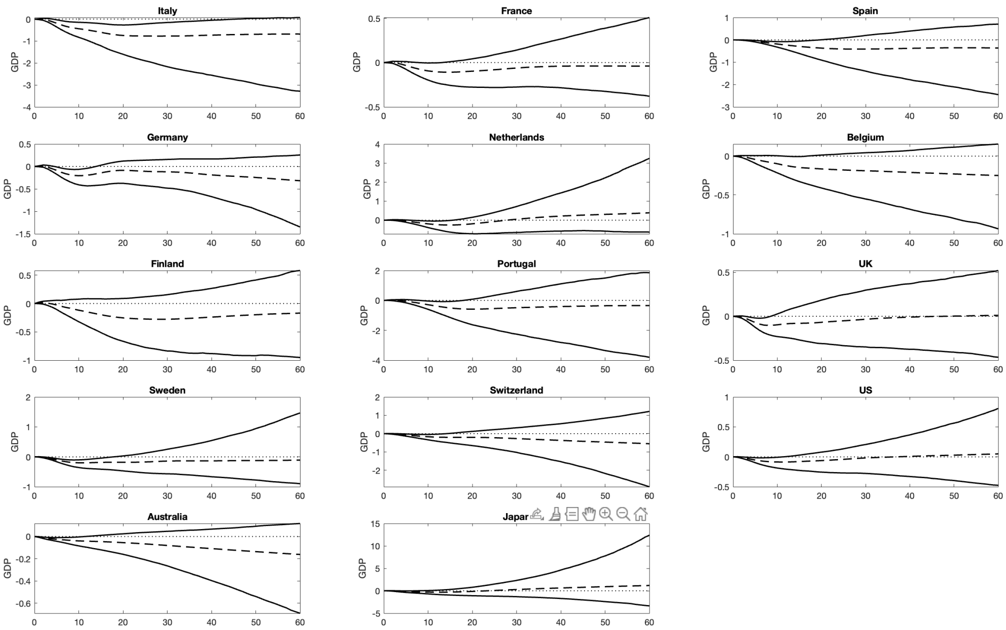

Figure 2.2: Impulse response functions showing country-specific gross domestic product reaction to a one standard error positive shock of UK EPU. Dotted line is the median response, while upper and lower solid lines describe the region of 95% of credible set. VARX coefficients are estimated in a Bayesian fashion by using a Metropolis-Hastings algorithm. Bond yields are used to describe financial markets behaviour.

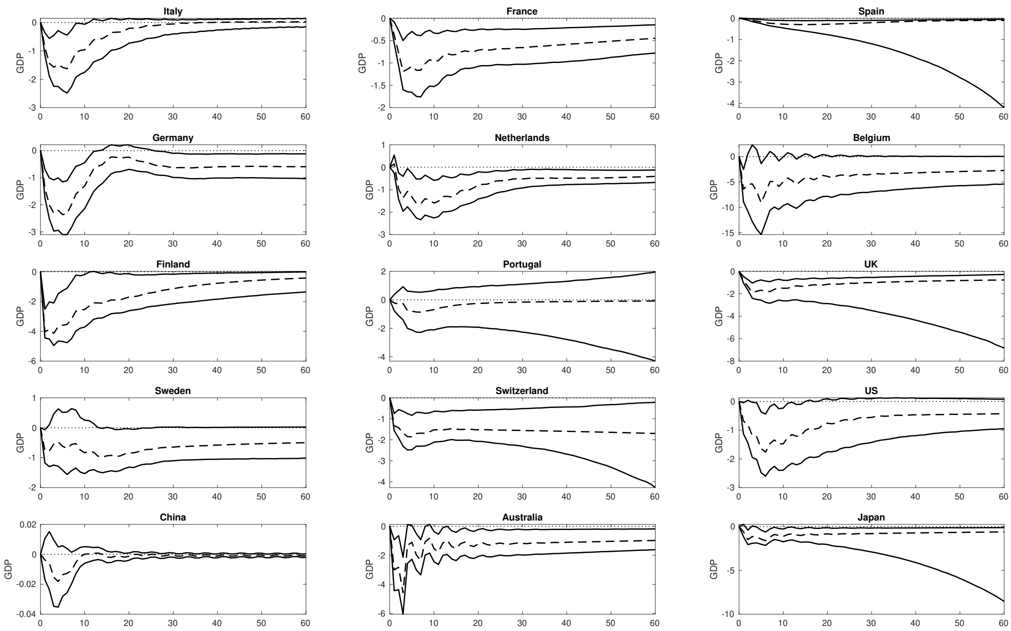

Figure 2.3: Impulse response functions showing country-specific gross domestic product reaction to a one standard error positive shock of UK EPU. Dotted line is the median response, while upper and lower solid lines describe the region of 68% of credible set. VARX coefficients are estimated in a traditional way, while lower and upper bounds are computed by following "bootstrab after bootstrap" of Kilian [1998]. Stock market indexes are used to describe financial markets behaviour.

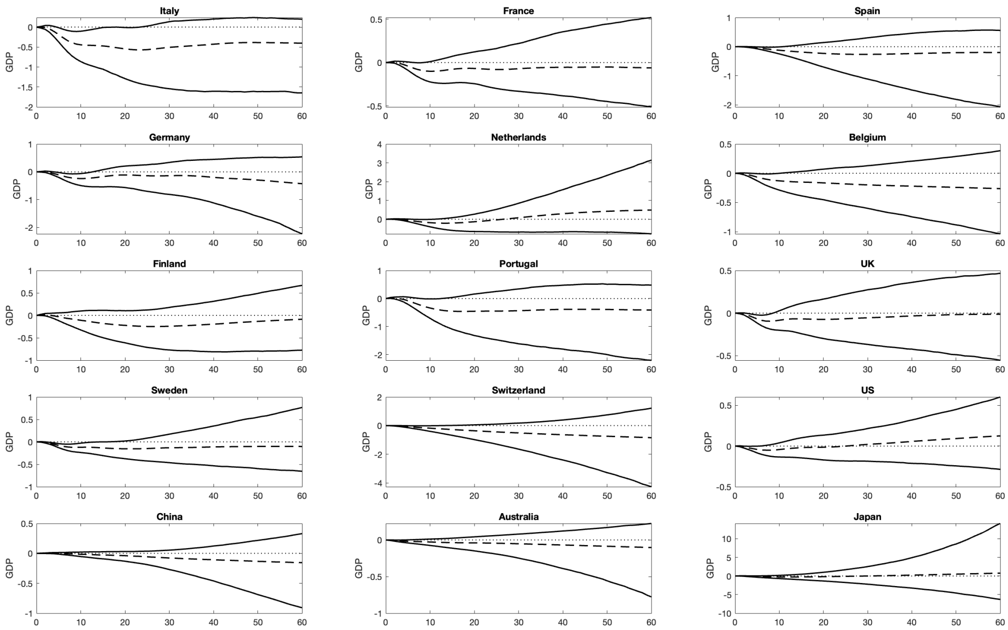

Figure 2.4: Impulse response functions showing country-specific gross domestic product reaction to a one standard error positive shock of UK EPU. Dotted line is the median response, while upper and lower solid lines describe the region of 95% of credible set. VARX coefficients are estimated in a Bayesian fashion by using a Metropolis-Hastings algorithm. Stock market indexes are used to describe financial markets behaviour.

Table 2.6: The macroeconomic effects associated with the Brexit events

Country	Variable	Effects	Country	Variable	Effects
Italy	GDP	-0.29	**U.K.**	GDP	-0.17
	Price	0.03		Price	0.23
France	GDP	-0.23	**Sweden**	GDP	-0.37
	Price	-0.01		Price	0.04
Spain	GDP	-0.23	**Switzerland**	GDP	-0.26
	Price	0.08		Price	-0.04
Germany	GDP	-0.24	**USA**	GDP	0
	Price	0.04		Price	-0.04
Netherlands	GDP	-0.17	**China**	GDP	-0.04
	Price	0.15		Price	0.03
Belgium	GDP	-0.24	**Australia**	GDP	-0.14
	Price	0.03		Price	-0.11
Finland	GDP	-0.36	**Japan**	GDP	0.03
	Price	-0.07		Price	-0.07
Portugal	GDP	-0.02	**All countries**	GDP	-0.19
	Price	-0.02		Price	0.02

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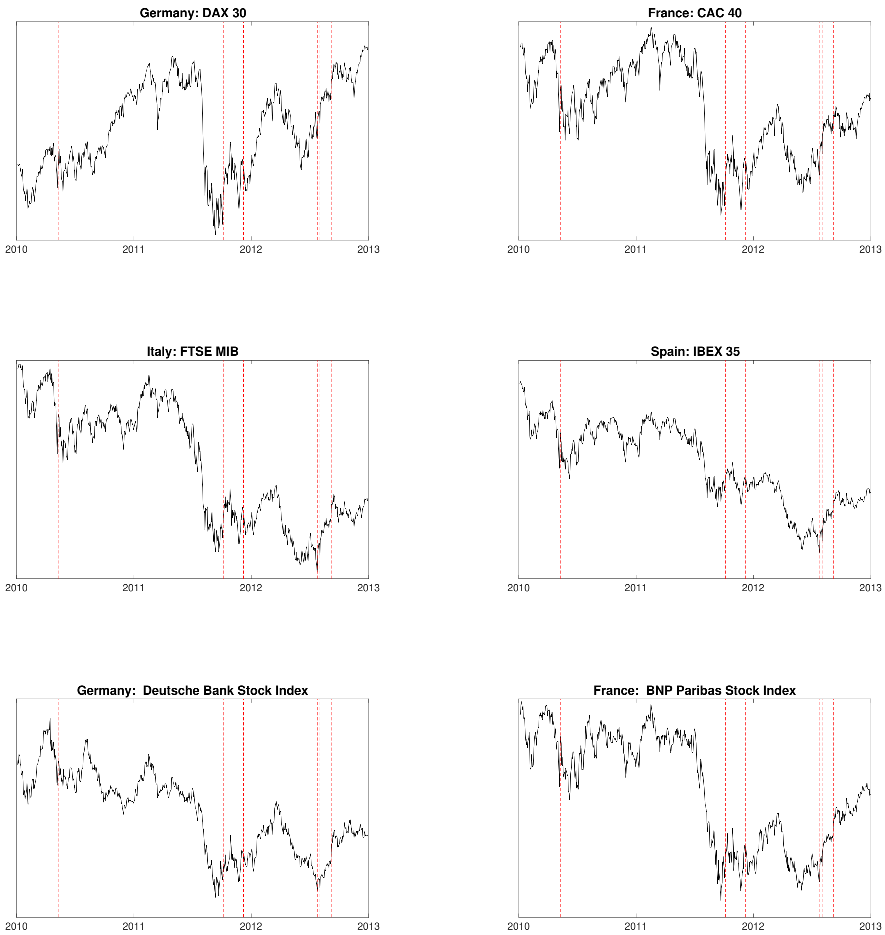
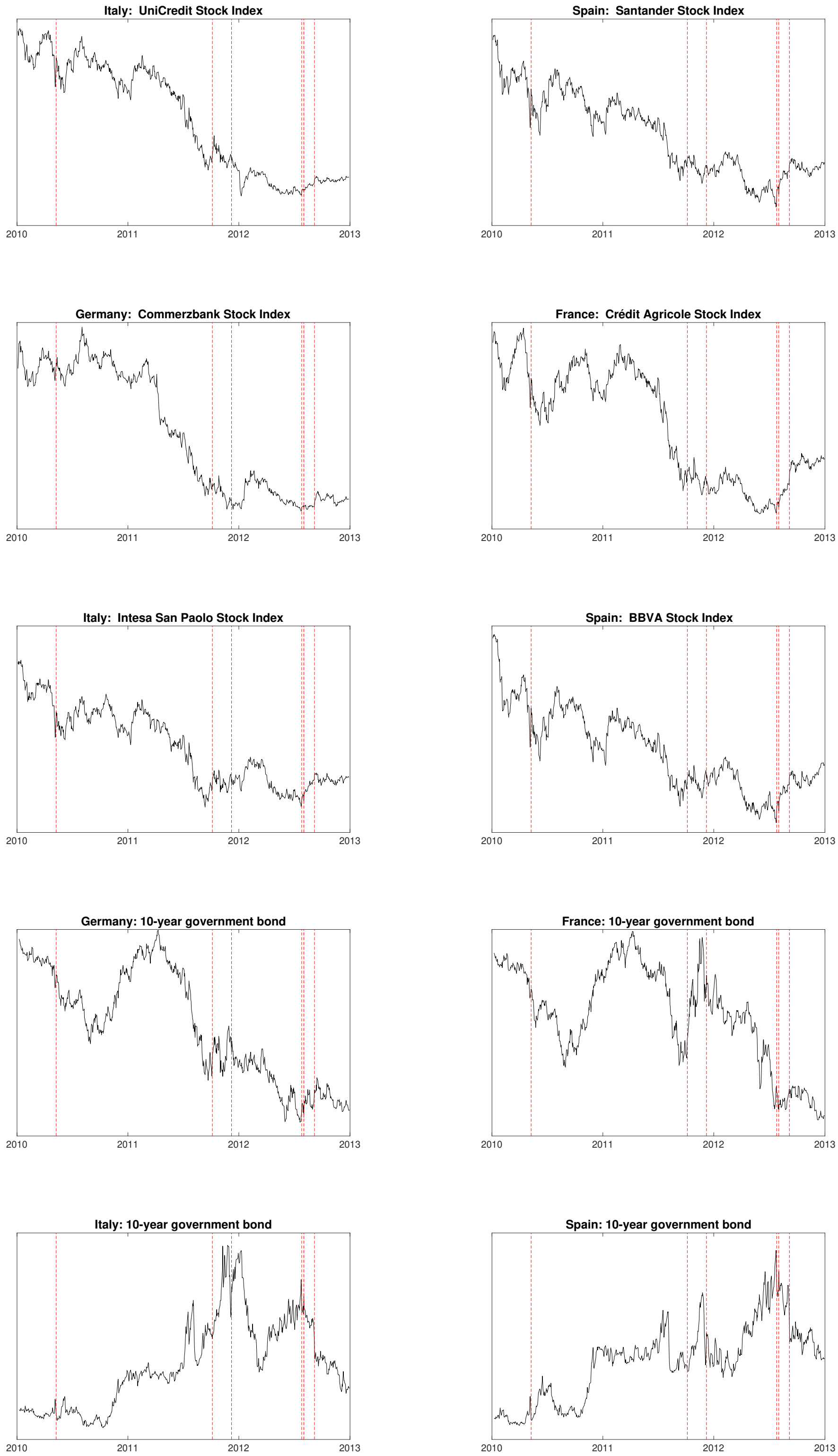
Appendices

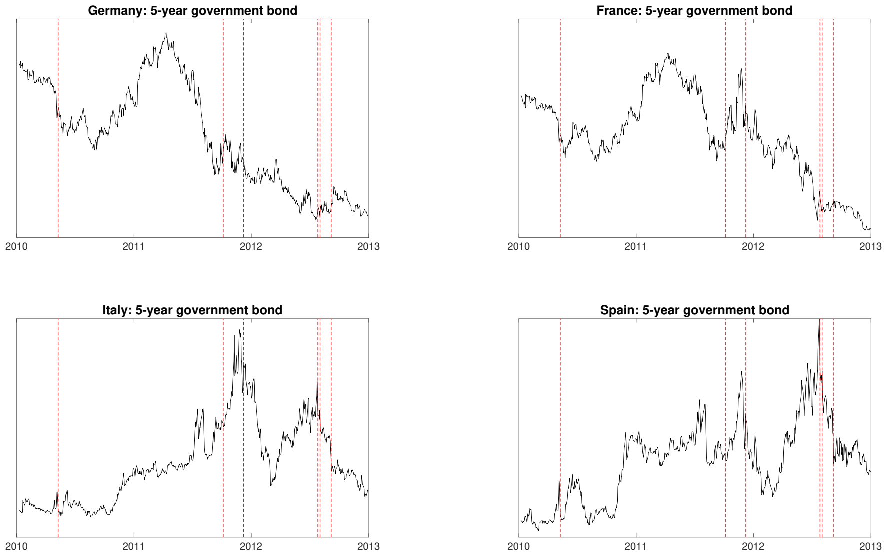
.1 Event-Study analysis: daily effects of unconventional policies

Figure 5 below depicts the time series of indexes studied in section 3 and 4. Red dotted lines highlight the day in which the unconventional policy is announced. Remember from the empirical exercise that we investigate one date for the SMP program, two for LTRO and three for OMT. Even though the event-study relies on daily data running from 2002M1 through 2012M12, plots here only draw the last two years in order to facilitate the observations of closed price behaviours on the day of the announcements.

Figure 5: Time series behaviour on the date of policy announcements




Italy: UniCredit Stock Index
Spain: Santander Stock Index
Germany: Commerzbank Stock Index
France: Crédit Agricole Stock Index
Italy: Intesa San Paolo Stock Index
Spain: BBVA Stock Index
Germany: 10-year government bond
France: 10-year government bond
Italy: 10-year government bond
Spain: 10-year government bond
2010
2011
2012
2013



.2 Event study analysis: list of News variables

Table 7 reports the 105 macroeconomic variables used to compute the surprised effect described by the variable News. Daily data have been collected from Bloomberg and cover a period running from 01/01/2002 through 31/12/2012. The analysis is implemented as follows.

Each variable has been forecasted by economists or private institutions (banks, consulting companies), and the estimate has been made available on Bloomberg. We have made the difference between the actual and official value that the variable has effectively achieved, and the average of the forecasted ones in a sort of averaging prediction error. We have constructed a sparse time series vector collecting the prediction errors of a specific variable, as in many days the forecasts are not available on Bloomberg, and we have summarised 164 sparse vectors in order to generate what we have defined throughout the paper as variable *News*. The same procedure has been performed in Altavilla and Giannone [2014] and Altavilla *et al.* [2014].

Table 7: Macroeconomic *News* variables

Germany	France	Italy	Spain
Business Expectations	Business Industry Sentiment	Budget Balance	Business Confidence
CPI (MoM)	Business Production	Budget Def. Sur.	CPI Harm. (MoM)
CPI (YoY)	Consumet Spending (MoM)	Business Manufacturing	CPI Harm. (YoY)
Economic Growth	Consumet Spending (YoY)	Consumer Confidence	CPI (MoM)
Factory Orders (MoM)	CPI Ex Tobacco	CPI (MoM)	CPI (YoY)
Factory Orders (YoY)	CPI (MoM)	CPI (YoY)	CPI Core (MoM)
GDP (QoQ)	CPI (YoY)	GDP (QoQ)	CPI Core (YoY)
GDP (YoY)	GDP (QoQ)	GDP (YoY)	GDP (QoQ)
HICP (MoM)	GDP (YoY)	HICP (MoM)	GDP (YoY)
HICP (YoY)	Housing Rerm. 3M	HICP (YoY)	HICP (MoM)
IFO Business Climate	Housing Rerm. 3M Start	Industrial Orders (MoM)	HICP (YoY)
Import Price Index (MoM)	Industrial Production (MoM)	Industrial Orders (YoY)	House Price (QoQ)
Import Price Index (YoY)	Industrial Production (YoY)	Industrial Production (MoM)	House Price (YoY)
Industrial MFC Orders (MoM)	Jobseekers Net Change	Industrial Production (YoY)	ICO Cons. Conf.
Industrial Production (MoM)	Jobseekers Total	Industrial Sales (MoM)	Industrial Production (YoY)
Industrial Production (YoY)	Manufacturing Production (MoM)	Industrial Sales (YoY)	Industrial Production WDA (YoY)
Manufacturing Orders (YoY)	Manufacturing Production (YoY)	MLF Unemployment	Mortgages (YoY)
PMI Services	Manufacturing Sentiment	New Car Registration (YoY)	PPI (MoM)
Private Consumption	Non Farm Payroll (QoQ)	PPI (MoM)	PPI (YoY)
PPI (MoM)	PMI Manufacturing	PPI (YoY)	Retail Sales (YoY)
PPI (YoY)	PMI Services	Retail Sales (MoM)	Retail Sales Adj (YoY)
Retail Sales (MoM)	PPI (MoM)	Retail Sales (YoY)	Trade Balance
Retail Sales (YoY)	PPI (YoY)	Trade Balance	Unemployment Rate (MoM)
Sentiment	Trade Balance	Trade Balance EU Countries	Unemployment Rate (YoY)
Trade Balance	Unemployment (ILO)	Unemployment Rate (QoQ)	
Unemployment Rate (QoQ)	Unemployment (ILO) Mainland	Unemployment Rate SA	
Wholesale Prices (MoM)	Unemployment Rate SA	Wage (YoY)	

.3 MCMC Methodology

As remarked in section 1.4, the unknown coefficients of equation (1.7) are estimated in a Bayesian fashion, by using a Gibbs sampling methodology. In particular we assume that Φs evolve as a random walk and the variance of their distribution has a Minnesota structure as suggested by Doan *et al.* [1984] and Litterman [1980]. Therefore, we start by manipulating equation (1.7) as

$$\begin{bmatrix} A'_{0,Y} \\ A'_{0,p} \end{bmatrix} \begin{bmatrix} Y_t \\ P_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} A'_Y \\ A'_p \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ P_{t-1} \\ \vdots \\ Y_{t-p} \\ P_{t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$$

where, $A_{0,Y}$ and $A_{0,P}$ are top and bottom row vectors of matrix A_0, A_Y and A_P are top and bottom row vectors of matrices $\{A_1, A_2, \ldots, A_p\}$, and $A_0 \times A_p = \Phi_p$. By supposing $A_{0,Y}$ as the only unknown elements, we can write

$$\begin{aligned} y_t &= -\left[Y_{t-1}, P_{t-1} \ldots Y_{t-p}, P_{t-p}\right] A_Y - c_1 \\ y_t(L) &= -\left[Y_t, P_t\right] \end{aligned}$$

and the model can be finally rewritten as

$$y_t = y_t(L) A_{0,Y} + \epsilon_t, \qquad \varepsilon_t \sim N(0,1)$$

which is the short form of the structural transformation of equation (1.7). Draws from $p\left(A_{0,Y}|A_{0,p}, A_Y, A_p, c, data\right)$ can therefore be simulated by standard Markov Chain Monte Carlo Simulation, and the algorithm is implemented as follows

$$\begin{aligned} A^i_{0,Y} &\propto p\left(A_{0,Y}|A^{i-1}_{0,p}, A^{i-1}_Y, A^{i-1}_p, c^{i-1}, data\right) \\ A^i_{0,p} &\propto p\left(A_{0,p}|A^i_{0,Y}, A^{i-1}_Y, A^{i-1}_p, c^{i-1}, data\right) \\ A^i_Y &\propto p\left(A_Y|A^i_{0,Y}, A^i_{0,p}, A^{i-1}_p, c^{i-1}, data\right) \\ A^i_p &\propto p\left(A_p|A^i_{0,Y}, A^i_{0,p}, A^i_Y, c^{i-1}, data\right) \\ c^i &\propto p\left(c|A^i_{0,Y}, A^i_{0,p}, A^i_Y, A^i_p, data\right) \end{aligned}$$

This sequence converges in distribution to a stable density $p(\Phi, c)$, and the median of this probability density function can be used to make inference on coefficient estimates of equation (1.7). We perform 15,000 independent draws (5,000 of which are discarded).

.4 Event-Study on Foreign Exchange Rates

For the sake of robustness, tables below report the reaction of international exchange rates to Brexit events in a 3- and 5-day window respectively. This variable is of crucial importance, since exchange ratio movements, inevitably bring changes in the volume of international trades and gross domestic product, which is what we are investigating in this paper. It is clear again that the main Brexit events that have affected the cross correlation between foreign currencies and British pound are the referendum result and the general election outcome. In particular, following the decision to leave the European community on 24 June 2016, the British pound has depreciated in both 3- and 5-day window. On the contrary, the outcome of UK election on 12 December 2019 has led to the appreciation of British pound, perhaps because people have realized that a serious political programme would have finally chased up.

Table 7: International exchange rates reaction to Brexit events in a 3-day windows (in basis points)

Country	1^{st} Event	2^{nd} Event	3^{rd} Event	4^{th} Event	5^{th} Event	6^{th} Event	7^{th} Event	8^{th} Event	9^{th} Event	Total
	24/06/16 - 28/06/16	13/07/16 - 15/07/16	29/03/17 - 31/03/17	06/07/18 - 10/07/18	22/11/18 - 26/11/18	13/03/19 - 15/03/19	07/05/19 - 09/05/19	24/05/19 - 28/05/19	12/12/19 - 14/12/19	
Classic										
Euro/GBP	7.8***	0.2	-2.3	0.0	-0.7	-1.3	0.8	-0.2	-0.9	3.4
SEK/GBP	6.8***	-0.1	-2.3	-1.2	-0.8	-0.2	-0.1	0.1	-0.7***	1.6
CHF/GBP	8.7***	1.1	-1.8	-0.2	-1.1	-1.1	0.1	-0.4	-0.9***	4.4
US/GBP	11.3***	0.5	-0.8	-0.4	-0.2	-1.6	0.7	0.0	-1.1***	8.4
YUAN/GBP	10.2***	0.3	-0.7	-0.5	-0.5	-1.7	-0.3	0.0	-0.5***	6.3
AUD/GBP	8.3***	-0.3	-0.8	0.6	-0.8	-1.6	0.6	0.4	-0.9***	5.5
YEN/GBP	15***	0.3	-1	-0.7	-0.7	-1.7	1.6	0.3	-1.9***	11.2
Controlled										
Euro/GBP	13.2***	-5	-2.2*	-1.9	-1.4	-2.5	3.1	0.0	-2.8	5
SEK/GBP	12.2***	-0.8	-2.2**	-2.1	-1.5	-1.4	2.1	0.3	-2.6***	4
CHF/GBP	14.1***	0.5	-1.7	-2.2	-1.3	-2.3	3.2	-0.2	-2.8***	7.3
US/GBP	16.7***	-0.2	-0.6	-2.4	-0.9	-2.8	2.9	0.2	-2.9***	10
YUAN/GBP	15.6***	-0.4	-0.6	-2.3	-1.1	-2.9*	2.0	0.3	-2.3***	7.7
AUD/GBP	13.6***	-1.1	-0.7	-1.4	-1.4	-2.8*	2.9	-0.6	-2.8***	5.7
YEN/GBP	20.3***	-0.4	-0.9	-2.7	-1.6	-2.9	3.8	0.5	-3.8***	12.3

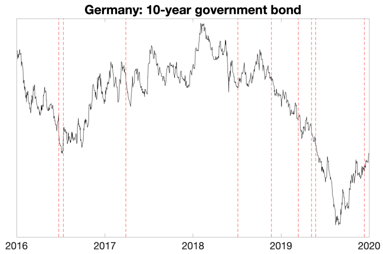
Table 8: International exchange rates reaction to Brexit events in a 5-day windows (in basis points)

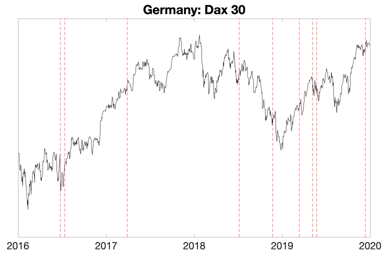
Country	1^{st} Event	2^{nd} Event	3^{rd} Event	4^{th} Event	5^{th} Event	6^{th} Event	7^{th} Event	8^{th} Event	9^{th} Event	Total
	24/06/16 - 30/06/16	13/07/16 - 19/07/16	29/03/17 - 04/04/17	06/07/18 - 12/07/18	22/11/18 - 28/11/18	13/03/19 - 19/03/19	07/05/19 - 13/05/19	24/05/19 - 30/05/19	12/12/19 - 18/12/19	
Classic										
Euro/GBP	8.4***	0.7	-1.2	0.0	-0.5	-0.9	1.3	-0.1	0.7	8.4
SEK/GBP	7.6***	0.2	-1.9	-1.1	-0.3	0.3	0.4	1.1	0.5	6.8
CHF/GBP	9.6***	1.4	-0.9	-0.7	-0.3	-0.6	2.2	-0.1	1.2	11.8
US/GBP	11.5***	1.1	1.1	0.1	-0.4	-1.5	1.1	0.4	0.1	13.5
YUAN/GBP	10.6***	0.9	0.0	-0.4	-0.8	-1.5	-0.6	0.5	1.4	10.1
AUD/GBP	9.4***	-0.5	-0.8	0.4	0.2	-1.4	0.4	0.6	0.6	8.9
YEN/GBP	14.8***	-0.3	0.5	-1.6	-0.9	-1.5	2.4	0.4	0.0	17.4
Controlled										
Euro/GBP	10.5***	0.1	-0.9	-1.6	-3.1	-2.7	5.1	0.9	-1.1	8.1
SEK/GBP	9.7***	-0.3	-1.6	-2.7	-2.7	-1.5	4.2	2.1	-1.3***	5.9
CHF/GBP	11.8***	0.9	-0.6	-2.4	-2.8	-2.4	6.0	0.9	-0.6***	10.8
US/GBP	13.7***	0.5	0.4	-1.5	-2.9	-3.3	4.8	1.4	-0.9***	12.2
YUAN/GBP	12.7***	0.3	0.3	-2.0	-3.3	-3.3	3.2	1.5	-0.4***	9
AUD/GBP	11.5***	-1.1	-0.5	-1.2	-2.3	-3.2	4.2	1.5	-1.2***	7.7
YEN/GBP	16.9***	-0.8	0.8	-3.2	-3.4	-3.3	6.2	1.3	-1.8***	12.7

.5 Event Study analysis: daily effects of Brexit events

Figure 15 reports the 10-year government bond rates and the benchmark stock market index prices of the 15 countries considered. Vertical red lines indicate the day of each significant Brexit event. For the sake of clarity, the sample period considered here is January 2016 - January 2020. In this way red vertical lines can depict with much more emphasis the likely downturn of the financial asset analysed.

Figure 15: 10-year sovereign bond rate and equity market index


Germany: 10-year government bond
2016
2017
2018
2019
2020


Germany: Dax 30
2016
2017
2018
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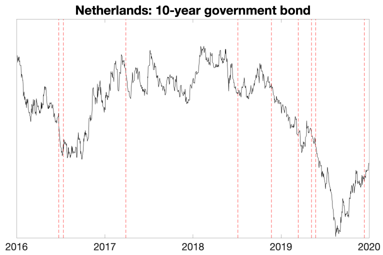
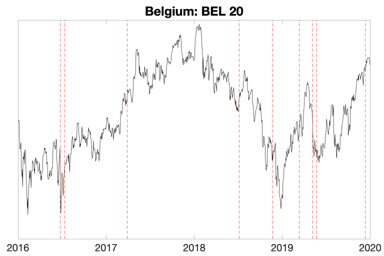

Netherlands: 10-year government bond
2016
2017
2018
2019
2020

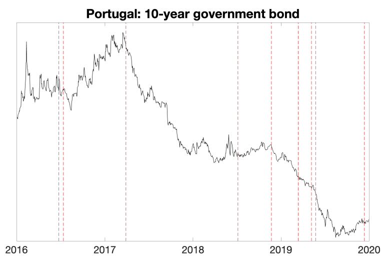

Netherlands: AEX
2016
2017
2018
2019
2020

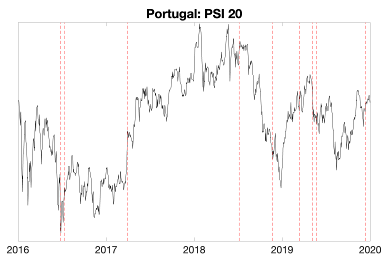

Belgium: 10-year government bond
2016
2017
2018
2019
2020

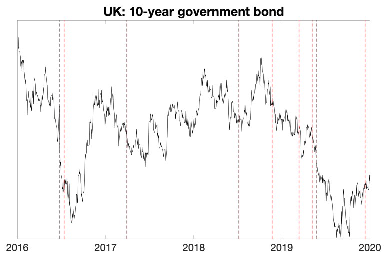

Belgium: BEL 20
2016
2017
2018
2019
2020

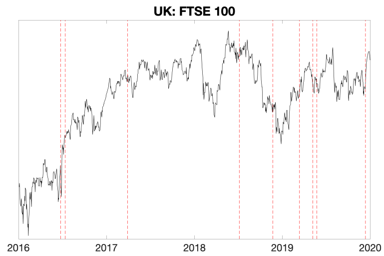

Finland: 10-year government bond
2016
2017
2018
2019
2020

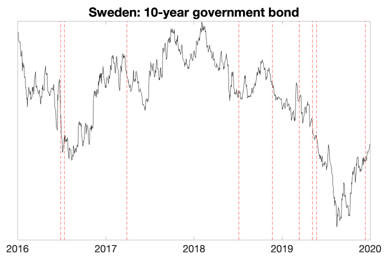

Finland: OMXH 25
2016
2017
2018
2019
2020

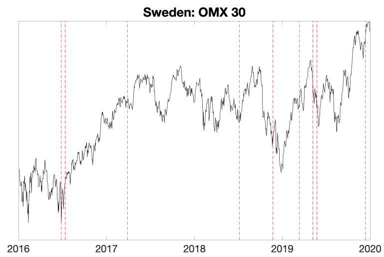

Portugal: 10-year government bond
2016
2017
2018
2019
2020

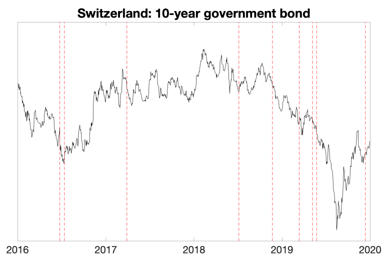

Portugal: PSI 20
2016
2017
2018
2019
2020

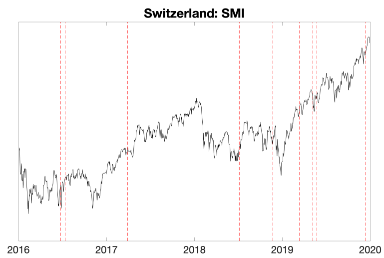

UK: 10-year government bond
2016
2017
2018
2019
2020

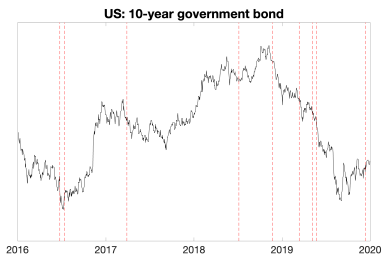

UK: FTSE 100
2016
2017
2018
2019
2020

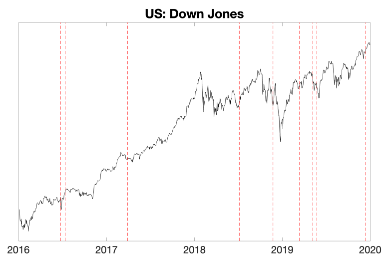

Sweden: 10-year government bond
2016
2017
2018
2019
2020

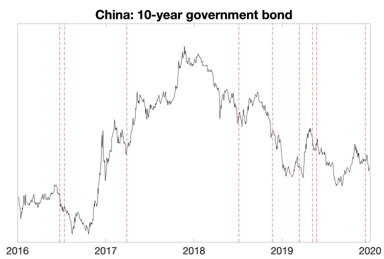

Sweden: OMX 30
2016
2017
2018
2019
2020


Switzerland: 10-year government bond
2016
2017
2018
2019
2020

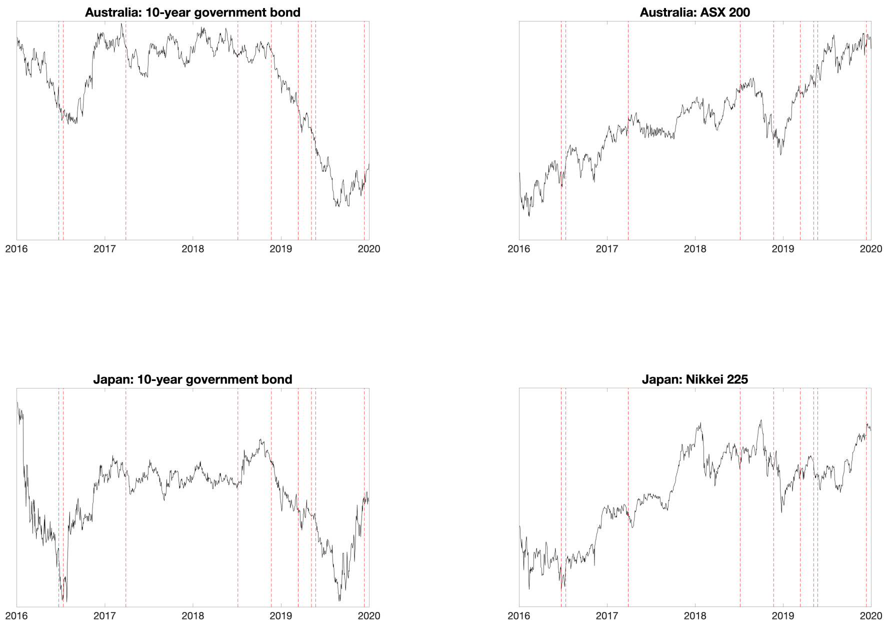

Switzerland: SMI
2016
2017
2018
2019
2020


US: 10-year government bond
2016
2017
2018
2019
2020


US: Down Jones
2016
2017
2018
2019
2020


China: 10-year government bond
2016
2017
2018
2019
2020


China: CSI 1000
2016
2017
2018
2019
2020



.6 Event study analysis: list of News variables

Table 9 reports the 164 macroeconomic variables used to perform the surprised effect described by the variable News. Daily data have been collected from Bloomberg and cover a period running from 01/01/2010 through 31/12/2019. The analysis is implemented as follows.

Each variable has been forecasted by economists or private institutions (banks, consulting companies), and the estimate has been made available on Bloomberg. We have made the difference between the actual and official value that the variable has effectively achieved, and the average of the forecasted ones in a sort of averaging prediction error. We have constructed a sparse time series vector collecting the prediction errors of a specific variable, as in many days the forecasts are not available on Bloomberg, and we have summarised 164 sparse vectors in order to generate what we have defined throughout the paper as variable *News*. The same procedure has been performed in Altavilla and Giannone [2014] and Altavilla *et al.* [2014].

Table 9: Macroeconomic *News* variables

Italy	**France**	**Spain**	**Germany**
Budget Balance	Consumer Spending (MoM)	CPI (MoM)	CPI (MoM)
CPI (MoM)	Consumer Spending (YoY)	CPI (YoY)	CPI (YoY)
CPI (YoY)	CPI (MoM)	CPI core (MoM)	GDP (QoQ)
Deficit to (GDP)	CPI (YoY)	CPI core (YoY)	GDP (YoY)
Industrial Orders (MoM)	GDP (MoM)	GDP (QoQ)	Industrial Production (MoM)
Industrial Orders (YoY)	GDP (YoY)	GDP (YoY)	Industrial Production (YoY)
Industrial Production (MoM)	Industrial Production (MoM)	House Price (QoQ)	PMI Manufacturing
Industrial Production (YoY)	Industrial Production (YoY)	House Price (YoY)	Private Consumption
Industrial Sales (MoM)	Manufacturing Production (MoM)	Industrial Production (MoM)	Producer Prices (MoM)
IndustrialSales(YoY)	ManufacturingProduction(YoY)	IndustrialProduction(YoY)	ProducerPrices(YoY)
PMI Manufacturing	PMI Manufacturing	PMI Manufacturing	Retail Sales (MoM)
PMI Manufacturing (MoM)	PPI (MoM)	PPI (MoM)	Unemployment Rate
PMI Manufacturing (YoY)	PPI (YoY)	PPI (YoY)	
Private Consumption (QoQ)	Production Outlook Indicator	Real Retail Sales (YoY)	
Retail Sales (MoM)	Trade Balance	Trade Balance	
Retail Sales (YoY)		Unemployment Rate	
Trade Balance			
Unemployment Rate			
Unemployment Rate (SA)			

Netherlands	**Belgium**	**Finland**	**Portugal**
Consumer Spending (YoY)	Employment Rate	CPI (MoM)	CPI (MoM)
CPI (MoM)	GDP (MoM)	CPI (YoY)	CPI (YoY)
CPI (YoY)	GDP (QoQ)	GDP (QoQ)	GDP (QoQ)
GDP (QoQ)	GDP (YoY)	GDP (YoY)	GDP (YoY)
GDP (YoY)	Industrial Activity	Industrial Manufacturing	PMI Manufacturing
Industrial Sales (MoM)	Unemployment Rate	Industrial Production (MoM)	Unemployment Rate NSA
Industrial Sales (YoY)		Industrial Production (YoY)	
PMI Manufacturing		PPI (MoM)	
Retail Sales (YoY)		PPI (YoY)	
Unemployment Rate 7-15		Retail Sales	
		Trade Balance	
		Unemployment Rate	

U.K.	Sweden	Switzerland	USA
CPI (MoM)	CPI (MoM)	CPI (MoM)	CPI (MoM)
CPI (YoY)	CPI (YoY)	CPI (YoY)	CPI (YoY)
GDP (QoQ)	GDP (QoQ)	GDP (QoQ)	GDP (QoQ)
GDP (YoY)	GDP (YoY)	Industrial Production (YoY)	Industrial Orders (MoM)
Industrial Production (MoM)	Industrial Orders (MoM)	Producer Prices (MoM)	Industrial Production (MoM)
Industrial Production (YoY)	Industrial Orders (YoY)	Producer Prices (YoY)	PMI Manufacturing
Manufacturing Production (MoM)	Industrial Production (MoM)	Retail Sales (YoY)	Retail Sales (MoM)
Manufacturing Production (YoY)	Industrial Production (YoY)	Trade Balance (MoM)	Trade Balance
PPI (MoM)	Manufacturing Orders	Unemployment Rate	Unemployment Rate
PPI (YoY)	PMI Manufacturing	Unemployment Rate NSAq	
Retail Sales (MoM)	Trade Balance		
Retail Sales (YoY)	Unemployment Rate		
Trade Balance	Unemployment Rate NSA		

China	Australia	Japan
CPI (YoY)	CPI (MoM)	CPI (YoY)
GDP (QoQ)	CPI (YoY)	Deficit Balance
GDP (YoY)	GDP (QoQ)	GDP (QoQ)
PMI Manufacturing	Retail Sales (MoM)	Industrial Production (MoM)
PMI Non-Manufacturing	Trade Balance (MoM)	Private Consumption (QoQ)
Retail Sales (YoY)	Unemployment Rate	Retail Sales (MoM)
Retail Sales Cumulative (YoY)		Retail Sales (YoY)
Trade Balance		Trade Balance
		Unemployment Rate SA

.7 VAR analysis: multi-country variable definition

Table 10 reports, for each country (columns 1 and 4), the variables used (columns 2 and 5) in VARX and GVAR, with the associated transformation (columns 3 and 6).

Table 10: VAR variable transformation

Country	Variable	Transformation	Country	Variable	Transformation
	Real GDP	Log-levels		Real GDP	Log-levels
Italy	CPI	Log-levels	**U.K.**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Raw
	Real GDP	Log-levels		Real GDP	Log-levels
France	CPI	Log-levels	**Sweden**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Raw
	Real GDP	Log-levels		Real GDP	Log-levels
Spain	CPI	Log-levels	**Switzerland**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Raw
	Real GDP	Log-levels		Real GDP	Log-levels
Germany	CPI	Log-levels	**USA**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Raw
	Real GDP	Log-levels		Real GDP	Log-levels
Netherlands	CPI	Log-levels	**China**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Not used
	Real GDP	Log-levels		Real GDP	Log-levels
Belgium	CPI	Log-levels	**Australia**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Raw
	Real GDP	Log-levels		Real GDP	Log-levels
Finland	CPI	Log-levels	**Japan**	CPI	Log-levels
	10-year bond rates	Raw		10-year bond rates	Raw
	Real GDP	Log-levels		Oil price	Raw
Portugal	CPI	Log-levels	**All countries**	Commodity price	Raw
	10-year bond rates	Raw		UK EPU	Raw

.8 VARX Identification via Heteroschedasticity: Metropolis-Hastings Algorithm

Suppose to start from the structural re-parameterization of the reduced form VARX depicted in section 5.1:

$$
\begin{aligned}
A_{01,0}y_{01,t} &= \mu_{01} + \sum_{j=1}^{p} A_{01,j}y_{01,t-j} + \sum_{l=1}^{r} A^{*}_{01,l}y^{*}_{01,t-l} + \sum_{k=1}^{q} A_{01,k}x_{t-k} + \varepsilon_{01,t} \\
A_{02,0}y_{02,t} &= \mu_{02} + \sum_{j=1}^{p} A_{02,j}y_{02,t-j} + \sum_{l=1}^{r} A^{*}_{02,l}y^{*}_{02,t-l} + \sum_{k=1}^{q} A_{02,k}x_{t-k} + \varepsilon_{02,t} \\
&\vdots \\
A_{15,0}y_{15,t} &= \mu_{15} + \sum_{j=1}^{p} A_{15,j}y_{15,t-j} + \sum_{l=1}^{r} A^{*}_{15,l}y^{*}_{15,t-l} + \sum_{k=1}^{q} A_{15,k}x_{t-k} + \varepsilon_{15,t}
\end{aligned}
$$

where A_0 is a lower triangular $N \times N$ Cholesky factorized matrix of Σ of equation (2.3) displaying the simultaneous relationship among exogenous and endogenous variables, A_j, A_l and A_k are $N \times N$ matrices of coefficients related to the lag operator j, l and k respectively, μ is a $N \times 1$ vector of constants and ε_t is the independent shock with zero mean and diagonal variance matrix $\left(\Lambda = diag\left[\lambda_1^2, \lambda_2^2, ..., \lambda_N^2\right]\right)$. Stochastic systems are identified in a Bayesian fashion by imposing a prior density distribution, and sampling the posterior densities as described below.

Prior densities. Suppose to start from the contemporaneous relation matrices $A_{(01,0)}, A_{(02,0)}, \ldots, A_{(15,0)}$, that we can generalize as $A_{(z,0)}$ for $z = 1, \ldots, 15$. Informative priors on single elements $\alpha^0_{i,j}$ are represented in the form of a density function $p\left(\alpha^0_{i,j}\right)$, where a high value of $p\left(\alpha^0_{i,j}\right)$ implies a strong information about the generic i, j element of $A_{(z,0)}$, whereas $p\left(\alpha^0_{i,j}\right) = 0$ when no useful prior information is available. Single elements inside $A_{(z,0)}$ are supposed to follows a Student t-distribution, in which the scale parameter values are chosen according to the prior belief we have on the specific elasticity. In case of lower triangular and heteroskedasticity identification all α_{ij} have $c = 0$, $\sigma = 0$ and $\phi = 3$, because we suppose to know nothing about their potential value.

Prior $p\left(\Lambda|A_{(z,0)}\right)$. Prior information about Λ conditional on $A_{(z,0)}$ is described by a $\Gamma\left(\underline{\kappa}_i, \underline{\tau}_i\right)$ distribution for each λ_{ii}^{-1} reciprocal of element in row i and column i of matrix Λ. Namely:

$$p\left(\Lambda|A_{(z,0)}\right) = \prod_{i=1}^{n} p(\lambda_{ii}|A_{(z,0)})$$

$$\Rightarrow\; p\left(\lambda_{ii}^{-1}|A_{(z,0)}\right) = \begin{cases} \frac{\underline{\tau}_i^{\underline{\kappa}_i}}{\Gamma(\underline{\kappa}_i)}\left(\lambda_{ii}^{-1}\right)^{\underline{\kappa}_i - 1} exp\left(-\underline{\tau}_i\lambda_{ii}^{-1}\right) & \text{for}\lambda_{ii}^{-1} \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

where, $\left(\underline{\kappa}_i/\underline{\tau}_i\right)$ is the prior mean of λ_{ii}^{-1} and $\left(\underline{\kappa}_i/\underline{\tau}_i^2\right)$ is its variance. We set $\underline{\kappa}_i = 0.5$ and $\underline{\tau}_i = \underline{\kappa}_i A_{(z,0)} S A_{(z,0)}$, where S is the $N \times N$ OLS variance of y_t. It is supposed that $\underline{\tau}_i$ depends on $\left(A_{(z,0)}\right)$, while $\left(\underline{\kappa}_i\right)$ does not.

Prior $p\left(A_{(z,j)}, A_{(z,l)}, A_{(z,r)}|\Lambda, A_{(z,0)}\right)$. Prior information regarding the lagged structural coefficients $A_{(z,j)}$, $A_{(z,l)}$ and $A_{(z,r)}$ are represented with a Normal conditional probability density function $p\left(A_{(z,j)}, A_{(z,l)}, A_{(z,r)}|\Lambda, A_{(z,0)}\right)$ where $A_{(z,j)}, A_{(z,l)}, A_{(z,r)} \sim N\left(\underline{m}_i, \lambda_{ii}^{-1}\underline{M}_i\right)$, which can be summarized as follows:

$$\begin{aligned} p\left(A_{(z,j)}, A_{(z,l)}, A_{(z,r)}|\Lambda, A_{(z,0)}\right) &= \prod_{i=1}^{n} p(\alpha_i^j|\Lambda, A_{(z,0)}) \\ &\Rightarrow p\left(\alpha_i^j|\Lambda, A_{(z,0)}\right) \\ &\Rightarrow \frac{1}{(\pi)^{\frac{\kappa}{2}}\left|\lambda_{ii}\underline{M}_i\right|^{\frac{1}{2}}} \times \\ &\quad exp\left[-\left(\frac{1}{2}\right)\left(\alpha_i^j - \underline{m}_i\right)'\left(\lambda_{ii}\underline{M}_i\right)^{-1}\left(\alpha_i^j - \underline{m}_i\right)\right] \end{aligned}$$

$\underline{M}_i$ incorporates information regarding the Minnesota structure, whose hyperparameters are $\{\lambda_0, \lambda_1, \lambda_2, \lambda_3\}$. We follow Doan [2013] and set $\lambda_0 = 10^9$ to express the weight on prior values; $\lambda_1 = 1$, which implies that lagged coefficients shrink to zero as the lag order increases; $\lambda_2 = 1$ governs the confidence in other-than-own lags; $\lambda_3 = 100$ makes the constant term essentially irrelevant. In this way parameters related to higher lags shrink to zero and prior information about the intercept is essentially irrelevant. Vector m_i indicates the best guess of value α_i^j before seeing the data, where i denotes the i^{th} structural equation of matrix A_j.

Posterior sampling. *Posterior* $p\left(A_{(z,0)}|Y_t\right)$ distribution is given by the product of prior densities outlined above, conditional on having observed the sample Y_T. More specifically, according to Baumeister and Hamilton [2015] the posterior of $p\left(A_{(z,0)}\right)$ can be expressed as:

$$p\left(A_{(z,0)}|Y_T\right) = \frac{K_T p\left(A_z\right)\left[\det\left(A_z\hat{\Omega}_T A_z'\right)\right]^{\frac{T}{2}}}{\prod_{i=1}^{n}\left[\left(\frac{2}{T}\right)\overline{\tau}_i\left(A_z\right)\right]^{\overline{\kappa}_i}}\prod_{i=1}^{n}\underline{\tau}_i\left(A_z\right)^{\underline{\kappa}_i}$$

where K_T is a function of the data and prior parameters, that allows the posterior density to integrate to unity. It does not depend upon $A_{(z,0)}, A_{(z,j)}, A_{(z,l)}, , A_{(z,r)}$ or Λ and does not need to be calculated to determine the posterior. $\overline{\kappa}$ and $\overline{\tau}$ are the posteriors of $\underline{\kappa}$ and $\underline{\tau}$ respectively (see below for the specific value). $p\left(A_{(z,0)}\right)$ is the prior density of matrix $A_{(z,0)}$ and $\hat{\Omega}_T$ is the variance matrix of reduced-form VARX residuals:

$$\hat{\Omega}_T = T^{-1}\left\{\sum_{t=1}^{T} y_t y_t' - \left(\sum_{t=1}^{T} y_t x_{t-1}'\right)\left(\sum_{t=1}^{T} x_{t-1}x_{t-1}'\right)^{-1}\left(\sum_{t=1}^{T} x_{t-1}x_{t-1}'\right)\right\}$$

for X_{t-1} the matrix of lagged observations.

Posterior $p\left(\Lambda|A_{(z,0)}, Y_t\right)$. With the same logic, if the prior of λ_{ii}^{-1} given $A_{(z,0)}$ is $\Gamma\left(\underline{\kappa}_i, \underline{\tau}_i\left(A_{(z,0)}\right)\right)$, the related posterior is shown to be $\Gamma\left(\overline{\kappa}_i, \overline{\tau}_i\left(A_{(z,0)}\right)\right)$, in which:

$$\overline{\kappa}_i = \underline{\kappa}_i + T/2$$
$$\overline{\tau}_i\left(A_{(z,0)}\right) = \underline{\tau}_i\left(A_{(z,0)}\right) + 1/2\overline{\zeta}\left(A_{(z,0)}\right)$$

for $\overline{\zeta}\left(A_{(z,0)}\right)$ being the sum of squared residuals resulting from the regression of $\tilde{Y}_i\left(A_{(z,0)}\right)$ over $\tilde{X}_i$. In which:

$$\tilde{Y}_i\left(A_{(z,0)}\right) = \left[\alpha_i' y_1 \cdots \alpha_i' y_T \quad m_i\left(A_{(z,0)}\right)' P_i\right]$$
$$\tilde{X}_i = \left[x_0 \cdots x_{T-1}' \quad P_i\right]$$

for P_i the Cholesky factorization of $\underline{M}_i = P_i P_i'$

Posterior $p\left(A_{(z,j)}, A_{(z,l)}, A_{(z,r)}|\Lambda, A_{(z,0)}, Y_t\right)$. Finally, the posterior of $p\left(A_{(z,j)}, A_{(z,l)}, A_{(z,r)}|A_{(z,0)}, \Lambda\right)$ turns out to be a Normal density with the following parameters $\left(\overline{m_i}\left(A_{(z,0)}\right), \lambda_{ii}\overline{M_i}\right)$. In which:

$$\overline{m}_i\left(A_{(z,0)}\right) = \left(\tilde{X_i}'\tilde{X_i}\right)^{-1}\left(\tilde{X_i}'\tilde{Y_i}A_{(z,0)}\right)$$
$$\overline{M}_i = \left(\tilde{X_i}'\tilde{X_i}\right)^{-1}$$

In summary, the posterior distribution can be expressed in a closed-form expression, since we are assuming that priors follow a proper parametric distribution. This implies that:

$$p\left(A_{(z,0)}, A_{(z,j)}, A_{(z,l)}, A_{(z,r)}, \Lambda|Y_T\right) \rightarrow p\left(A_{(z,0)}|Y_T\right)p\left(\Lambda|Y_T, A_{(z,0)}\right) \times p\left(A_{(z,j)}, A_{(z,l)}, A_{(z,r)}|Y_T, A_{(z,0)}, \Lambda\right)$$

Posterior values of $A_{(z,0)}$ are sampled by using a random-walk Metropolis Hastings algorithm, with a total of 20,000 draws for each SVARX, 10,000 of which are discarded. The remaining 10,000 draws of $A_{(z,0)}$ are used to generate candidate estimates of λ_{ii} from $\Gamma\left(\overline{\kappa}_i, \overline{\tau}_i\left(A\left(\alpha_{ij}^0\right)\right)\right)$ and estimates of α_{ij}^j from $N\left(\overline{m}_i\left(A\left(\alpha_{ij}^0\right)\right), \lambda_{ii}\overline{M}_i\right)$.