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MACROECONOMIC EFFECTS OF EUROPEAN CENTRAL BANK'S UNCONVENTIONAL MONETARY POLICY

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Abstract (chapter 1)

This chapter of the PhD dissertation reviewed the relevant literature with regards to the conduct of monetary policy by the European Central Bank (ECB) following the Lehman bankruptcy of 2007/08. Firstly, the chapter explained how the ECB conducts its monetary policy in normal times. What follows next is a snapshot of key policy instruments available to the ECB prior to the crisis. Thirdly, the study explained the types of unconventional monetary policy (UMP) implemented during the financial meltdown. In connection to this, the study examined ECB's conduct of monetary policy when the crisis reached its crescendo. Furthermore, the chapter

provided empirical evidence of the effects of ECB's UMP both in the euro area and non-euro area. Lastly, the chapter showed the potential channels of transmission as well as their associated market and information frictions. The conclusion is that the transmission channels of UMP are no different from interest rate policies.

Abstract (chapter 2)

The study employed a country-by-country Bayesian Vector Autoregressive Model (BVAR) to examine the macroeconomic effects as well as the channels of transmission of ECB's unconventional monetary policy (UMP) in the core and peripheries of the euro area. The BVAR model is identified by augmenting sign restrictions with the penalty function method as in Uhlig (2005). The model's parameters (B, Σ) were jointly drawn from the family of normal Wishart priors with the posterior draws been generated from 10,000 Markov Chain Monte Carlo (MCMC) iterations of which 1000 were discarded as burn-ins. A diagnostic analysis was conducted using Fry and Pagan's (2011) median target approach to ascertain whether impulse responses (IRFs) come from a single model or not. The diagnostic checks revealed that the IRFs are unbiased and robust. The main results are summarised as follows. The expansive shock to euro system balance triggered a fall in interest rates leading to higher investment spending and aggregate demand which shoots up industrial production and price inflation at the aggregate euro area level. Following this monetary easing came asset price hikes which increases financial wealth leading to higher consumption and aggregate demand (wealth effect). Whereas the transmission channels of the policy shock in the aggregate euro area were akin to the core and peripheries, the response of industrial production and prices to the shock was asymmetric. Unlike the peripheries where the expansive UMP shock fuelled a reduction in systemic risk (CISS) leading to a fall in bank lending spreads, banks in the core countries on the other hand were induced to increase their lending spreads in order to obtain positive returns.

Abstract (chapter 3)

The aim of the study is to evaluate the combined effect of monetary policy (MP) and macroprudential policy (MAPP) on the macroeconomy of Central and Eastern Europe (CEE). Because the premise of the paper is to examine the effect of two policy shocks, the study includes two policy levers and corresponding macroeconomic indicators. The two policy instruments used in this study are the policy interest rate (MPR) and average limit on loan to value ratio (LTV). In terms of macroeconomic indicators, the consumer price index (CPI) and real output (RGDP) will represent the target indicators for MP whilst credit to GDP gap will be the indicator for MAPP. The empirical analysis was conducted in three parts as follows. By virtue of a recursive identification approach, a dynamic panel model was used to examine the effect of MP and MAPP shocks on residential property prices in CEE. In the second part, the panel model was extended to examine the domestic spill over effects of MP and MPP shocks on the industrial sector of CEE. The third and final part used the random forest algorithm for macroeconomic prediction in CEE.

The main findings are summarised as follows. Firstly, an expansionary MAPP shock which triggered upsurges in LTV increased credit to GDP gap in CEE. Surprisingly, this credit expansion did not increase residential property prices, economic activity, price inflation and industrial production in CEE. Secondly, the policy rate hike which reduced investment expenditure and aggregate demand fuelled a fall in economic activity, price inflation and industrial production in CEE. The upward pressure on the policy interest rate translates into higher mortgage rates which eventually plummeted both housing demand and property prices in CEE.

Lastly, random forest's feature variable selection method indicates that the most important predictor of credit to GDP gap in CEE is the policy interest rate. In the real GDP equation,

production in the mining and quarry is the most important predictor. The euro system balance sheet variable ranked highest in predicting inflation in CEE.

Disclaimer

This PhD thesis is submitted by Shuffield Seyram Asafo to the Department of Economics and Law the University of Macerata on 03/31/2021 as a requirement for the partial fulfilment for a Doctoral of Philosophy degree in Quantitative Methods for Economic Policy. The content of this thesis can be reproduced for teaching or research purposes without any violation to the laws of the University of Macerata and the author.

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Chapter 1

A Review of Unconventional Monetary Policy Implemented by the ECB

1.1 Introduction

The sub-prime mortgage crisis of March 2007 which preceded the fall of Lehman Brothers in September 2008 has changed the conduct of monetary policy by the world's major central banks. The outcome of these developments was manifested in a downturn in the business cycle, dearth of credit and deflationary pressures. For fear of a reoccurrence of the 1929 great depression, central banks in the advanced economies reduced their policy interest rates to low levels and farther into zero territory in a bid to dampen the recessionary fears. Fast forward, these aggressive interest rate cuts led to the zero lower bound constraint on the interest policy rates which rendered the conventional monetary policy tools ineffective. Progressively, central banks in the advanced economies substituted interest rate polices for unconventional monetary policies (UMP) in a bid to shore up asset prices and increase bank lending to the real economy which will eventually spur economic activity and induce inflationary pressures.

Unlike the US Federal Reserve (FED) and the Bank of England (BOE) who started asset purchases in the early periods of the bust, the European Central Bank (ECB) instead was performing its function as a lender of last resort by providing liquidity support to the banking sector to correct the impaired channels of transmission in the euro area. According to Trichet (2009), European Central Bank (2008), a chunk of lending to non-financial firms occurs via the banks therefore, a healthy and effective financial sector is a necessary to ensure a pass-through of ECB's policy stance to the real economy. As a confirmation to the earlier arguments, Draghi (2012) posits that to ensure the efficacy of the transmission mechanism, the ECB implemented monetary policies which were geared towards resuscitating the bank lending channel. Taking these perspectives into consideration, a new strand of research geared towards examining the impact of UMP on financial markets and the real economy is set in motion. In the case of the FED, studies such as (Fratzschser, Lo Duca, & Straub 2013; Chinn 2013; Chen, Fliardo, He, & Zhu 2012 ; Neely 2010) point to the fact that the large-scale asset purchase programme (LSAP) led to a depreciation of the U.S. dollar vis a vis other currency, a rise in foreign stock prices and a fall in credit default swaps. On the macroeconomic front, LSAP is touted to stimulate the US real economy.

Albeit, the euro area was plagued with two negative macroeconomic shocks, that is the US sub-prime mortgage collapse and the GIIPS[1] sovereign debt crisis of 2010, not much study is devoted to examining the transmission mechanism of the ECB's UMP. Akin to the FED and the BOE, euro area studies were also focused on the impact of the ECB's UMP on financial markets and the real economy which was respectively examined using event study technique and vector autoregressive models (VAR). The consensus is that ECB's UMP has a positive impact on financial markets (see for instance Fratzscher, Duca, & Straub 2016; Altavilla, Carboni, & Motto 2015; Szczerbowicz 2015). On the macroeconomic front conclusion points to the fact UMP led to upsurges in economic activity and price inflation in the euro area (see for instance Boeckx, Dossche, & Peersman ; 2017; Gambetti & Musso 2017; Burriel & Galesi 2016; Gambacorta, Hofmann, & Peersman 2014).

[1] According to Moro (2014), the GIIPS countries (Greece, Ireland, Italy, Portugal and Spain) are European countries who were adversely affected by the 2008 financial collapse. These countries experienced banking sector difficulties, government debt crisis, credit crunch and deep recessions).

Against this backdrop, the objective of this chapter is to provide an up to date theoretical and empirical review of the relevant literature with regards to ECB's UMP and its possible transmission channels in euro area and non- euro area member countries.

The rest of the chapter is structured as follows. Section 1.2 explains how ECB conducts monetary prior to the financial crisis. Section 1.3 describes the key monetary policy instruments of the ECB. Section 1.4 describes the transmission channels of monetary policy prior to the financial crisis. Section 1.5 provides the forms of UMP used during the crisis period. Section 1.6 provides theoretical explanation of UMP in the euro during the crisis period. Section 1.7 provides empirical evidence of UMP in the euro during the crisis period. Section 1.8 explains the transmission channel of UMP. Section 1.9 provides the concluding remarks.

1.2 The Conduct of Monetary Policy by the ECB prior to the Financial Crisis

The ECB is the supranational monetary authority of the euro area and it conducts monetary policy for the euro area member states. Its cardinal mandate is to ensure that changes in price levels measured by the harmonized Index of consumer prices (HICP) for the euro-area should be less but close to 2% over the medium term. The literature considers this as the price stability objective of the ECB. By implication, an inflation rate above or below 2% could be described as the inability of the ECB to anchor its inflation expectations, hence missing its medium-term target. The ceremonial stance of monetary policy of the ECB is to take policy decisions that reflects changing economic conditions of the entire euro-area. To achieve price stability, the ECB undertakes some procedures which can be categorized in two complementary steps as follows. (a) Economic analysis phase (b) Monetary analysis phase. The Governing Council[2]

[2] This is equivalent to the FED's Federal Open Market Committee (FOMC)

(GC) of the ECB takes a decision on the stance of monetary policy (expansive or contractionary) given the information set gathered from the two complementary phases. The process is as follows. Firstly, conditional on supply side factors, financial developments and economic activity, the GC examines the potential short-term to medium-term determinants of price build up in the euro-area (economic analysis phase). Secondly, in the monetary analysis phase, the GC examines the trajectory of growth of money supply and inflation in the medium-term to long-term. The bottom line of the monetary analysis phase is to examine the nexus between the growth of money supply and inflation with the intuition that spikes in money growth precedes high inflation[3]. After examining these processes, the GC takes a decision on whether monetary policy should be expansive or contractionary.

1.3 Policy Tools used by the ECB in Normal Times

This section provides the reader with the main policy instruments the ECB used prior to the financial crisis. They are described as follows.

a) **Interest rate on main refinancing operations (MRO).** In these operations, banks can borrow liquidity from the euro system against collateral on a weekly basis, at a pre-determined interest rate.

b) **Interest rate on marginal lending facility (MLF).** Banks can access overnight credit facilities from the euro system at an interest rate (also pre-set) above the main refinancing operations rate.

[3] This stems from Milton Friedman's assertion that, "inflation is always and everywhere a monetary phenomenon."

c) **Interest rate on deposit facility (DF).** financial intermediaries may use this avenue to make overnight deposits with the euro system at a (pre-set) rate lower than the main refinancing operations rate.

d) **Minimum reserve requirement**. This refers to a proportion of customer deposits and notes that financial intermediaries are to keep at their national central banks as reserves. This is normally set for six (6)-weeks period known as the maintenance period. This tool can also be considered one of the alternative tools at the disposal of the central banks to influence the supply of money.

The Figure 1 shows the evolution of the key policy rates of the ECB prior to the financial crisis. The graph clearly shows a positive co-movement between the MRO, DF and MLF. As expected, the MLF is higher than the MRO whereas the DF is lower than the MRO. The next section describes the second-round effect of ECB's policy stance, that is the real economic impact of ECB's policy action. This is captured in the literature as the channels of transmission of monetary policy decisions. These channels include interest rate channel, asset price channel (equity price channel and house price channel), exchange rate channel, credit channel (balance sheet channel and bank lending channel).

Figure 1: Evolution of Key Interest rates Prior to the Crisis

Source: ECB Statistical Data Warehouse.

1.4 Transmission Mechanism of Monetary Policy (Pre crisis)

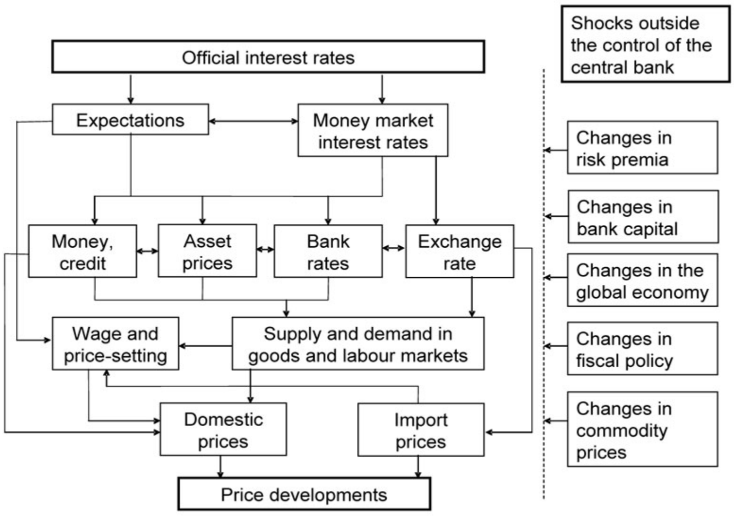
The monetary policy transmission mechanism explains how aggregate demand and inflation are affected by monetary policy decisions. The efficacy of the transmission mechanism of monetary policy is necessary to ensure that the policy stance has its intended pass-through to the real economy. This meant anytime the channels of transmission are impaired, then threats to price stability will likely emerge. In this regard, Taylor (1995) asserts that for the channels of transmission to be effective, a change in the official policy interest rate must affect the money market interest rate. Consequently, studying the transmission mechanism is vital not only for academic research, but it could serve as a guide for policy makers in their policy dialogues. The various channels are explained in the subsequent sections.

1.4.1 Interest Rate Channel and Credit Channels

In the Keynesian literature, the interest rate channel is represented as follows. An expansive monetary policy (Ms↑) leads to a fall in the nominal and real interest rate (r↓) which then reduces the cost of capital thereby spurring increase in investment expenditure (INV↑) and output (Y↑). Based on the principle of nominal rigidities (prices and wages are sticky downwards) and expectations, if a central bank reduces the short-term nominal interest rate, there should be a corresponding reduction in both the real short-term and real long-term interest rates. The reason for this chain reaction depends on the term structure of interest rate which states that the long-term interest rate is a weighted average of future short-term rates. In effect, a fall in the short-term real interest rate should lead to a fall in the long-term real interest rate.

The Figure 2 below shows a graphical description of the transmission mechanism of the official interest rate.

Figure 2: A Graphical Representation of Monetary Policy Transmission



Note: A diagram showing the transmission mechanism of monetary policy taken from ECB's website.

The credit channel is divided into bank lending channel and balance sheet channels. According to Bernanke & Blinder (1988) , Bernanke & Blinder (1992) the bank lending channel works effectively when there is no perfect substitution between bank loans and other sources of funding. Because big firms have alternative sources of funding their operations (debt financing or equity financing), they do not feel the brunt of an inefficient bank lending channel. The narrative is different for smaller firms since they are most dependent on bank loans with no alternative sources of funding. As a result, they are most susceptible to any adverse shock that impairs the bank lending channel. Succinctly, their size is a restraining factor on their credit accessibility potentials. A monetary accommodation which lowers the cost of capital triggers an increase in the availability of credit which consequently leads to increases in investment expenditure leading to spikes in real output. This channel is vibrant in the euro-area since most of the lending to the private sector comes through the banks.

According to Cecchetti (1995), the balance sheet channel evaluates how monetary policy decisions impacts borrower's financial position. A monetary expansion which reduces the interest rate leads to upsurges in equity prices which eventually leads to higher net worth for firms. The increase in net worth reduces the leverage of firms thereby attenuating the probability of default (reduced credit risk). This development reduces the risk premium banks charge when extending a loan facility to these firms. Furthermore, a monetary stimulus also improves the balance sheet of firms (borrowers) due to positive cash flows. This development reduces the credit risk of these firms thereby increasing their chances of accessing credit lines from the banks. On the other hand, a borrower with a lower net worth has a higher chance of loan refusal due to lower owner's equity.

1.4.2 Asset Price Channel

This channel posits that monetary policy can affect the real side of the economy via leaps in the value of other assets such as equity prices and house prices. The channel is explained as follows:

a) Equity Prices

When a central bank engages in a monetary stimulus, there is excess liquidity which leads to a fall in the price of money (interest rates). Following this development, investors have no incentive to hold bonds due to the low rate of return. As a result, investors tend to balance their portfolio by switching to stocks thereby increasing equity prices leading to an increase in financial wealth. This channel could also be looked at via Tobin's q investment theory and the wealth effect on consumption. In the case of the former, monetary expansion affects the real economy via the increase in price of equities whereas the latter explains how financial wealth gained through stock price hikes affects output growth via an upsurge in consumption expenditure. Based on the life cycle model of Modigliani, consumption is examined as a function of human capital, real capital and financial wealth (lifetime resources of the consumer). A key element of financial wealth is stocks, hence a rise in stock prices leads to higher value of financial wealth which translates into increase in household consumption. Tobin's q referred to the market value of firms divided by the replacement cost of capital. A higher q meant that firms have a higher market value which translates into higher share prices. The implication is that firms can acquire more machinery and equipment by raising enough funds from the stock market from less issued stocks. Conversely, a firm's inability to acquire additional machinery for production could be as a result of a low q.

b) House Prices

A loose monetary policy which reduces the cost of mortgages spurs an increase in the demand for new residential properties which increases new investment spending. Given that house price is a component of wealth, an increase in house prices leads to an increase in wealth which increases consumption and eventually boost aggregate demand.

1.4.3 Exchange Rate Channel

This channel works through international trade flows and capital flows. A monetary expansion which leads to a fall in the interest rate makes domestic interest earning assets less attractive compared to foreign interest earning assets. This provides the avenue for capital flight into foreign economies leading to a depreciation of the exchange rate relative to the foreign currency. A fall in the exchange rate which represents depreciation ($E\downarrow$) makes domestic goods cheaper compared to foreign goods leading to an increase in foreign demand for domestic goods, exports (X↑) and a fall in domestic demand for foreign goods, imports (M↓). This eventually improves the current account position (NX↑).

1.5 From Conventional to Unconventional Monetary Policy

Since the introductory section has already explained the trigger for the usage of balance sheet polices during the period of the financial crisis, this section focuses on the various forms of UMP implemented when the crisis reached its crescendo. First and foremost, the reader is introduced to the concept of UMP. According to Stone, Fujita, & Ishi (2011) a policy could be considered as UMP based on the prime aim of the policy, that is whether it is for macroeconomic stability or financial stability. They further argued that balance sheet policies can be categorized into quantitative easing (QE) or credit easing (CE). The former refers to the purchase of long term private and public financial securities whereas the latter is a form of lending support to credit markets. Referenced to Pattipeilohy, Van den End, Tabbae, Frost, & De Haan (2013), in periods of a downturn in the business cycle and financial turmoil, conventional monetary policy may prove inadequate to achieve price stability and full employment. As a result, central banks resorted to policy toolkits outside the conventional toolbox. Cecioni, Ferrero, & Secchi (2011) underscored earlier positions by asserting that UMP is any policy intervention that seeks to rectify a malfunctioning of the monetary transmission mechanism or to provide additional stimulus to the economy at the zero-lower bound (ZLB), unless otherwise described. On the backdrop of these definitions, the next section provides a description of the types of UMP.

1.5.1 Quantitative Easing (QE)

As a prelude to the workings of QE, this section commences with a famous speech by Ben Bernanke in 2014. According to Bernanke (2014), "QE works in practice, but it is theoretically impossible". He asserts that, in a frictionless market[4], QE should have little impact. However, in the real world where financial markets are segmented, the purchase of government bonds by central banks could lead to price hikes and a fall in bond yield.

Gertler & Karadi (2011), Chen, Curdia, & Ferrero (2012) employed a macroeconomic framework to provide a description to the working mechanism of the QE. The premise of QE is that, in the event where the short-term policy interest rate is constrained at the zero-lower bound, a monetary boost could be provided by increasing demand for bonds which increases their prices thereby reducing their yield. Given that financial intermediaries hold reserve accounts at the central bank, bond purchases by the central banks are financed by shoring up those reserve accounts of the financial intermediaries. This increases the ability of banks to make new loans to businesses and households. Apart from the acquisition of government debt securities, QE could also be implemented by directly purchasing private debt securities as in the case of the ECB and the Bank of Japan (BOJ). The former purchased corporate bonds as well as collateralized debts issued by mortgages lenders and banks (CBPP). The latter directly purchased real-estate investment funds, exchange rate traded funds and corporate debts. In the recent past, an uncommon approach known as "yield curve control approach" was adopted by the BOJ where bond purchases are undertaken to meet pre-assigned targets for the short- and long-term yields. However, this approach has its own merits and demerits. In the event where the set targets are credible (market expectations are met), the bond purchases may not be

[4] Markets where all transaction costs and restraints associated with trading is non-existent.

necessary to achieve the set targets. Conversely, if targets are unrealistic, then bond purchases may have to be in enormous quantities to meet that desired targets.

1.5.2 Credit Easing (CE)

The idea of CE is to change the composition of central bank's balance sheet by easing lending conditions to certain impaired segments of the financial markets. Bini Smaghi (2009), posits that credit easing could be done using direct or indirect approaches. In the direct case, the central bank engages in the sale or the exchange of less risky asset classes such as government bonds with asset classes with high risk such as asset backed securities, credit default swaps among others. In the indirect approach, financial intermediaries receive increased lending from the central banks in exchange for risky assets. However, devoid of sterilization (counter sale of assets by the central bank), CE could end up increasing the size of central bank balance sheet just like QE.

1.5.3 Negative Interest Rates

The logic behind implementing a negative interest rate policy is to prompt banks to lend or acquire financial assets with their excess reserves. The aim is to reduce the cost of lending, stimulate credit growth and bid up asset prices. To achieve a negative interest rate policy, the central bank charges an interest rate on reserves financial intermediaries hold at the central bank. For instance, as of September 2019, the ECB charged -0.50 percent on its deposit facility.https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html). The theory surrounding the negative interest rates policy is that economic agents would be reluctant to keep their money in checkable accounts that pay negative interest, instead they will hoard the cash. However, due to the huge transaction cost and risk associated with using cash, charging a benign negative interest rate will deter them from hoarding the cash.

1.5.4 Forward Guidance

In this approach, the central banker gives market participants signals about the future path of the policy rate. The premise is to manage expectations rather than the current stance of monetary policy. Forward guidance (FG) can be implemented on time dependent grounds, qualitative grounds and quantitative grounds. With the time dependent approach, the announcement is made that policy rates will stay low until a specific date into the future. Alternatively, if the central banker announces that the policy rate will be kept low into the future until price stability and real stability is in sight, then that is considered a qualitative approach. In the quantitative approach, the central banker provides the attainment of benchmark value which will warrant an amendment to the current policy rate. For instance, in November 2019, the GC of the ECB announced that its key policy rates will stay and remain at their low levels unless inflation outlook converges to 2% over the forecast horizon. In an earlier meeting of the BOE in August 2013, they announced that until unemployment rate falls to 7 percent, the policy rates will remain low. The literature argues that the credibility of the central bank is necessary condition to ensure the effectiveness of FG as well as eliminate the time inconsistency problem of monetary policy.

1.6 ECB's Unconventional Monetary Policies

This section provides the various monetary measures used by the ECB when the euro area was hit by sub-prime shocks which emanated from the United States. To start with, the ECB reduced its key interest rate that is, MRO close to zero in October 2008. The ECB also provided unlimited liquidity to banks at pre-specified interest rates if the banks can provide the needed collateral against loan repayment. This is known in the literature as fixed interest rate and full allotment policy (FRFA). In addition, the ECB increased the range of collateral accepted for refinancing operations. This made banks to refinance fewer liquid assets thereby increasing the balance sheet of the ECB. Furthermore, the maturity period for ECB's LTROs was extended on numerous occasions that is, 6 months in January 2009 and then to 12 months in June 2009 and to 36 months in December 2011 and March 2012. In addition, the ECB had an agreement with other central banks to provide foreign currency funding in a bid to attenuate difficulties faced by banks in foreign currency financing. Also, the ECB made outright purchases of covered bonds issued by euro-area banks in what is known as the Covered Bond Purchase Programme (CBPP) in June 2009 and October 2012. There was also the Securities Market Programme (SMP) where the ECB bought debts of some distressed euro-area governments in May 2010 and June 2012. There was also the purchase of asset-backed securities from private firms, known as the Asset Backed Securities Purchase Programme (ABSPP). The GC created a two-phase targeted long-term refinancing operation (henceforth TLTRO) to increase bank lending to the non-financial sector. The first TLTRO known as (TLTRO-I) was announced in June 2014 which covers eight quarterly operations starting in September 2014 and maturing in September 2018. In the first two operations, banks could borrow up to a total of 7% of their loans eligible for the programme for onward lending to euro area non-bank private sector. However, in future operations, banks could borrow more money based on the bank's lending activities. There was a reinforcement of TLTRO-I into a second TLTRO known as (TLTRO-

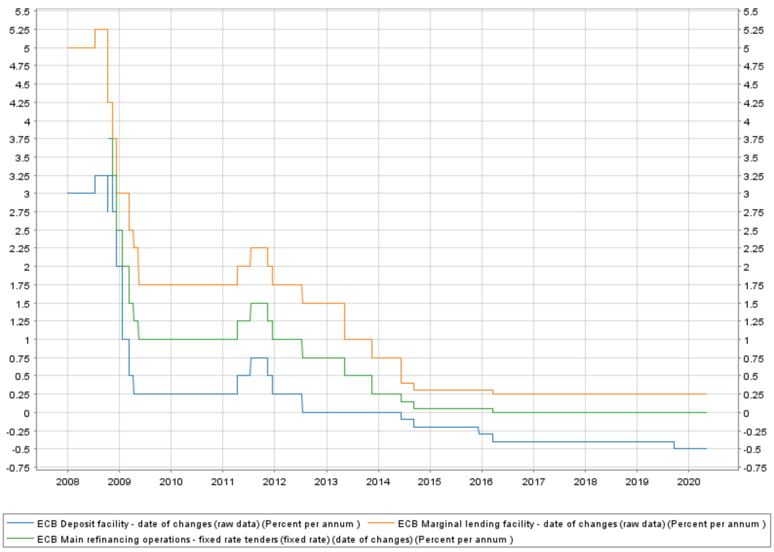
II) which was announced in March 2016 and was conducted in four quarterly operations. The operations started in June 2016 where banks could borrow up to 30% of their eligible loans for the programme minus any outstanding amount from the first two operations of TLTRO-I. The banks which were part of the TLTRO operated either as individual banks or as part of a group of banks and the interest rate charged under the TLTRO programme depended on the lending behaviour of the banks. Also, in January 2015 the GC started an Asset Purchase Programme (APP) announcing a monthly purchase of 60 billion euros of assets which included the existing ABSPP and the third CBPP3 which were both launched in September 2014 and a new Public Sector Purchase Programme (henceforth PSPP) geared at purchasing bonds issued by euro area central governments, European institutions, European agencies which is to start in March 2015 until September 2016. In March 2016, the GC decided to expand the monthly purchases under the APP from 60 billion euros to 80 billion euros, including a new Corporate Sector Purchase Programme (CSPP), starting from April 2016. The GC again in December 2016 extended the monthly purchases of assets until the end of December 2017 or beyond adding a total amount of about 540 billion to the purchases corresponding to 2.3% of euro area 2015 nominal GDP. In January 2018 and October 2018, the GC reduced its asset purchases to 30 billion euros and 15 billion euros respectively. Lastly, in December 2018 the GC completed its asset purchase programme.

Given that ECB's inflation target of 2% is threatened, the GC has decided to restart its APP from 1st November 2019 with 20 billion purchases on monthly basis into the future. Also, there is a launch of a third TLTRO (TLTRO-III) from September 2019 to March 2021. However, on 12th September 2019, the ECB added new changes to the initial plan. The TLTRO-III is expected to run for three (3) years instead of the initial two (2) years and the rate of each operation is now at the average of the MRO over the life span of the programme. In addition, financial intermediaries whose eligible net lending exceeds a benchmark will have a lower rate and it could be further lowered to the average level of the DF. In another development, to dampen the impairment of the euro area monetary policy transmission mechanism posed by the coronavirus pandemic, the GC launched the Pandemic Emergency Purchase programme (PEPP) with an envelope of EUR 750 billion. The PEPP will include all assets classes under the existing APP and it will run till the end of the year 2020.

Figure 3 below provides a graphical evidence of the movement in the ECB's key interest rates during the financial crisis. The evidence showed a sustained decrease in the key policy rates to zero territory with the DF approaching negative territory of -0.5 percent. In

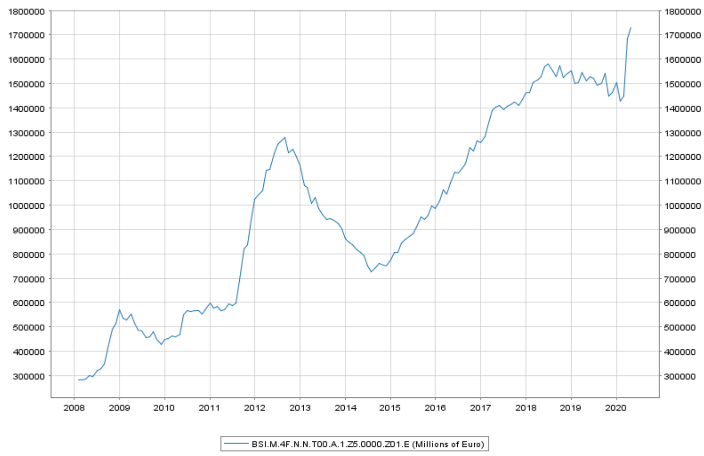
Figure *4*, the increase in the euro system balance sheet could be described as a policy intervention to counter threats to deflation and ensure a resilient transmission mechanism of UMP.

Figure 3: Dynamics in Key Policy Rates



Source: ECB Statistical Data Warehouse

Figure 4: Movement in Euro System Balance Sheet



Source: ECB Statistical Data Warehouse.

1.7 Effects of ECB's Unconventional Monetary Policy

This section provides a review of the empirical literature on the effects of ECB's UMP in the aggregate euro area as well as countries without the euro. The structure of this section is as follows. Firstly, the empirical studies on the euro area are listed starting with old studies to the most recent. Secondly, papers covering non-euro area countries are listed subsequently.

1.7.1 Euro Area Evidence

Based on data for the period 1999m1 to 2009m12, Peersman (2011) employed a structural vector autoregression (SVAR) to evaluate the difference between UMP channels of transmission and standard monetary policy channels. Findings showed that the peak response of output and prices to UMP shocks takes about 6 months whereas in the conventional monetary policy case, the output and price response peaks at 12 months. In effect, macroeconomic response to the conventional monetary policy shock is sluggish. They also found that when there is a positive shock to euro system balance sheet, interest rate spreads plummet. However, they increase when the policy rate goes down. Using a mean group Structural Panel VAR model, Gambacorta, Hofmann, & Peersman (2014) examined the effectiveness of UMP at the zero-lower bound on monthly data on eight economies from 2008 to mid–2011. They found that the increase in central bank assets led to a temporary rise in both economic activity and the price level. They conclude that, the response of output to UMP and conventional monetary policy shocks is largely similar. However, price effects are weaker in the case of UMP shocks relative to the conventional monetary policy shock. In addition, their individual country results suggest differences in the effects of UMP across countries are rather small. In another study, Altavilla, Carboni, & Motto (2015) used an event study technique to examine both the channels of transmission of ECB's APP and the asset price effects. They found that asset price impact of the APP shock is sizeable, albeit the announcement occurred when financial uncertainty was low. In addition, their finding found evidence for the credit channel and they also found spill overs to non-targeted assets. Szczerbowicz (2015) employed an event study technique on daily data from 2007 to 2012 in a bid to examine ECB's UMP on the money market and covered bond spreads (cost of borrowing for banks) and sovereign bond spreads (borrowing cost for governments). Findings showed that OMT, SMP and CBPP led to a reduction in government and bank's borrowing cost. There was also evidence of spill overs to other assets. Briciu & Lisi (2015) also used daily data from 2007 to 2015 to assess the impact of ECB's extended asset purchase programme in the euro area via event study estimation. They found that bond yields in the peripheries decreased as opposed to an increase in the core countries. Falagiarda & Reitz (2015) examined the impact of ECB's announcement speeches from 2008m1 to 2012m09 on sovereign bond spreads. Their findings point to the fact that, in relation to Germany, the announcement reduced bond spreads in Italy, Spain, Ireland and Portugal. Ambler & Rumler (2016) based on daily data, they examined the impact of UMP announcement on ex-ante-real interest rates in the euro area. They found sizeable impact of the UMP announcement on real interest rates at 5 to 10 years maturities via raising inflation expectations. They assert that, UMP announcements which exceeded the expectations of the market led to a fall in the nominal, real interest rates and increased inflation expectations. However, UMP announcement which disappointed market expectations led to an increase in the nominal, real interest rates and reduced inflation expectations.

Andrade, Breckenfelder, De Fiore, Karad, & Tristani (2016) examined the financial market impact of ECB's extended asset purchase programme in an event study approach. They found that banks with a high share of their portfolio in sovereign bonds experienced an upsurge in their share prices. There is also a significant impact of the announcement shock on sovereign bond yields. Burriel & Galesi (2016) also estimated a global VAR model on monthly data from 2007m1 to 2015m9 to ascertain the effect of UMP on the euro-area. They found that a 1 percent increase in the ECB assets led to a 0.1 percent and 0.05 percent increase in output and prices respectively. Haldane, Roberts-Sklar, Wieladek, & Young (2016) used central bank total assets for several central banks, including the ECB from 2009 to 2015. They employed four different alternative identification schemes for UMP shocks. They found statistically insignificant outcomes and the signs of the variables differ from the literature. Wieladek & Garcia Pascaul (2016) used same model as Haldane, Roberts-Sklar, Wieladek, & Young (2016) but they estimated it on data from 2012 to 2016. Their findings are statistically significant, and they also found a 1 percent innovation to asset purchases raises output between 0.07 percent and 0.15 percent. Price responses on the other hand peaked between 0.05 percent and 0.1 percent. Gibson, Hall, & Tavlas (2016) also employed an event study to assess the impact of ECB's UMP. They found that the UMP shock led to a reduction in sovereign spreads, and it dampened the negative of the shock on financial stress. In addition, they found that, although the impact of the shock is statistically significant, the quantitative effects were unpretentious. Their paper also found evidence for portfolio balance channel, signalling channel and exchange rate channel. Damjanovic & Masten (2016) estimated the effect of shadow rate shock on output and prices using a VAR model. They employed the shadow short rate of Krippner as the measure of UMP. They found a 100 basis points increase in the shadow rate reduces euro area output by about 0.7 percent and lowers prices by about 0.2 percent. Fratzscher, Duca, & Straub (2016) employed event study approach on high frequency series from 2007 to 2012 to examine the impact of ECB's UMP on financial market variables. To differentiate ECB policy shocks which caused movement in financial variables, they controlled for other news shock. They found that, on the back of ECB's UMP shock, equity prices increased and bond yields in peripheries (Spain and Italy) fell. However, core countries (Austria, Germany, Finland and Netherlands) experienced a slight increase in their bond yields. Using ECB's balance sheet as proxy for UMP, Boeckx, Dossche, & Peersman (2017) employed a combination of zero and sign restrictions in a SVAR model from 2007 to 2014 to examine the impact of UMP. They identified balance sheet policy by focussing on the signs of the responses to changes in the ECB assets. They found a 1.5 percent increase in the size of the ECB's balance sheet increases both output and prices by about 0.1 percent. Gambetti & Musso (2017) estimated the effects of the announcement of the APP in January 2015 using a model with time varying parameters VAR and stochastic volatility. They found that from the onset, the APP shock had a larger effect on output than prices. However, over the course of the horizon, the effect of the APP on prices increased significantly over the medium term. Elbourne, Ji, & Duijndam (2018) estimated a SVAR on the effect of UMP in the euro-area on monthly data for the period 2009m1 to 2016m11. The identification scheme employed is zero and sign restriction. They found that a negative shock to the shadow rate leads to significant output responses whilst price responses were not significant. Their evidence at the country level showed differences in output responses which occurred via exchange rate channel, confidence channel and liquidity premium channel.

Using data from futures rate as a policy variable, Elbourne & Ji (2019), re-examined the efficacy of UMP by way of a SVAR from 2009m1 to 2016m12. They found that UMP innovations did not positively affect output as reported in earlier studies on the euro area.

1.7.2 Non-Euro Area Evidence

Babecka Kucharakova , Claeys, & VaZieek (2014) investigated spill overs on six (6) EU non-euro area countries, among them three in CEE (Czech Republic, Hungary, Poland). They concluded that the spill overs of UMP shocks are transmitted differently compared to conventional shocks. They also inferred that while exchange rates respond quickly, the effect on inflation is ambiguous. Halova & Horvath (2015) employed a Panel Vector Autoregressive model (PVAR) for eleven economies in Central and Eastern European (CEE). They found that ECB's UMP had sizeable spill overs with a significant amount of output fluctuations in CEE. In another study, Falagiarda, Mcquade, & Tirpak (2015) estimated spill overs of ECB's UMP on financial assets in CEE using an event study technique. They reported strong spill overs on bond yields. They also found that SMP occurred via the portfolio rebalance channel and signalling channels. On the other hand, the OMT announcements went through confidence channel whilst the PSPP happened via signalling channel and confidence channel.

Bluwstein & Canova (2015) employed a Bayesian mixed-frequency VAR model to incorporate both high-frequency financial data as well as low-frequency macroeconomic data. They found that output effects of UMP were insignificant in Czech Republic, Hungary, Poland and slightly negative for Bulgaria, Romania. They further argued that the impact of UMP on inflation was slightly positive for both groups. Horvath & Voslarova (2017) employed a PVAR model to examine spill overs of the ECB's UMP on output and prices in the Czech Republic, Hungary and Poland. Based on results from impulse responses and forecast error variance decomposition, they found stronger output response to UMP than price responses. Ciarlone & Colabella (2016) employed an event study technique on quarterly data from 2008q1 to 2015q4 to examine spill overs of ECB's APP in Central, Eastern and South Eastern European Economies (CESEE). They found that APP announcement led to asset price hikes, an appreciation of the local currency vis a vis the euro coupled a lethargic fall in the long-term bond yields. They further found evidence in favour of portfolio rebalancing channel and bank liquidity channel. Using a Bayesian Global VAR model with stochastic volatility for the period 2000m10 to 2016m6, Feldkircher, Gruber, & Huber (2017) estimated the effect of a reduction in long term yield and spreads in CESEE. Their identification scheme is a mixture of zero, impact and sign restrictions. Their study showed that both policy innovations increased industrial production in CESEE and other non-euro area member states. These real effects occurred via financial channel and trade channel. Potjagailo (2017) estimated spill overs of euro-area monetary policy to fourteen (14) non-euro-area countries using a factor-augmented VAR (FAVAR) model. Findings showed that, a monetary expansion leads to output spikes in non-euro-area countries, a fall in both short-term rates and market uncertainty. Furthermore, large output effects were seen in countries with higher trade openness and high financial integration. In addition, output is larger if the exchange rate regime is fixed. Moder (2017) employed two-country Bayesian vector-autoregressions on monthly data from 2008m1 to 2015m12 to assess spill overs to South-Eastern Europe (SEE) using zero and sign restrictions. She found positive output and price effects that are amplified by second-round effects through international trade links.

1.8 Channels of Transmission of Unconventional Monetary Policy

The transmission mechanism of monetary policy refers to how UMP decisions have an impact on the real economy. However, the functioning of these channels depends on some form of "belief" without it, UMP will not have the desired impact on asset prices and the real economy. This "belief" is referred to as information and market frictions. As explained by Eggertsson & Woodford (2003), Rudebusch & Williams (2008) information friction refers to a situation where economic agents do not have perfect foresight of the macroeconomy, they do not have any lead on the monetary authority's reaction function. From the standpoint of Vayonas & Vila (2009) market frictions will emerge when the following conditions hold. Firstly, an imperfect substitutability between asset of different classes. Secondly, investors preferring bonds of a peculiar credit risk or maturity. Thirdly, limit to arbitrage between certain asset class categories. The Table 1 below which was adapted and modified from Haldane, Roberts-Sklar, Wieladek, & Young (2016) provides a detailed description of the channels of transmission with their associated market and information frictions.

Table 1: Channels of Transmission

Channels of transmission	Description	What do you have to believe for these channels to work (Frictions).	References
Policy signallig	Economic agents learn about the future path of monetary policy	The central banks needs to "put money where their mouth is"	Bauer & Rudebusch (2012), Farmer (2012), Eggertsson & Woodford (2003)
Portfolio balance (duration and loan supply	Asset purchases leads to upsurges in prices of purchased assets as well as prices of other assets. Investors rebalance their allocation of different assets and money.	Prefereces for bonds of specific maturity. Limits to arbitrage. Some investors do not consider bonds of different maturity as perfect substitutes.	Krishnamurthy & Vissing-Jorgensen (2011) , Harrison (2012), Vayonas & Vila (2009) , Andrés, López-Salido, & Nelson (2004),Bernanke, Reinhart, & Sack (2004) , McCallum (2000), Tobin (1961), Tobin (1963), Tobin (1969), Modigliani & Sutch (1967), Brunner & Meltzer (1973) , Friedman (1978)
Market liquity premia	If financial markets are dysfunctional, central bank's asset purchases can improve liquidity by encouraging trading and reducing liquidity premia.	Markets dysfunctional. Transaction costs.	Krishnamurthy & Vissing-Jorgensen (2011)
Exchange rate	Impact on exchanage rate via via variation in interest rate differentials and/risk premia and long-term exchange rate expectations.		Glick & Leduc (2013)
Bank lending	A surge in deposits expands commercial banks' balance sheets.	There is no constraints on bank lending. Economic agents have no perfect substitute for bank credit.	Bridges & Thomas (2012) , Butt, Churm, McMahon, Morotz, & Schanz (2014), Bowman, Cai, Davies, & Kamin (2015)
Confidence/uncertainty	QE improves the economic outlook/reduces risk of bad outcomes (via any mechanism). This could be a reduction in financial stress indices such as CISS, Vstoxx index and VIX.	Economic agents needs to believe asset purchases will improve the economic outlook.	
Fiscal channel	Asset pruchases reduces sovereign bond yields which translates into lower cost of borrowing. This increases the appetite for government debt pile up.	Economic agents needs to believe asset purchases will reduce the long term interest rate	Fiedler, Jannsen, Wolters, & Hanisch (2016)

Note: Adapted from Haldane, Roberts-Sklar, Wieladek, & Young (2016).

1.9 Closing Remarks

Generally, this chapter reviewed the relevant literature with regards to the conduct of monetary policy by the ECB pre crisis and post crisis. Firstly, the chapter explained how economic analysis and monetary analysis helps the ECB to take policy decisions in good times. What follows next is a description of key policy instruments available to the ECB prior to the financial crisis and its' notable transmission channels. Thirdly, the study explained the types of UMP implemented during the financial collapse, that is QE, CE, forward guidance and negative interest rate policies. In connection to this, the study examined ECB's conduct of monetary policy when the crisis reached its crescendo. Furthermore, the chapter provided empirical evidence of the effects of ECB's UMP both in the euro area and non-euro area.

Lastly, the chapter showed the potential channels of transmission as well as their associated market and information frictions. The conclusion is that the transmission channels of UMP are like the channels of interest rate policies.

Chapter 2

Transmission Channels of ECB's Unconventional Monetary Policy: A Bayesian VAR Approach

2.1 Introduction

Following the seminal work of Sims (1980) which led to the introduction of vector autoregressive models (VARs) in macroeconomics, the approach has gone on to become the anchor technique in macro econometrics. Notable scholars such as Peersman & Smets (2003), Christiano, Eichenbaum, & Evans (1999), Bernanke & Blinder (1992), Bernanke & Mihov (1998) have employed VARs to examine the response of macroeconomic variables to interest rate innovations.

Given that the financial meltdown of 2007/08 has shifted the conduct of monetary policy from interest rate policies to balance sheet polices, it is expected that policy makers and academics will devote their studies to evaluating the real impact as well as the transmission channels of the balance sheet policies. Whereas myriad of studies has focused on the impact of balance sheet policies on financial markets, studies geared towards the real economy are scant. A few studies in this topical area from recent to earlier years are as follows. Elbourne, Ji, & Duijndam (2018), Boeckx, Dossche, & Peersman (2017), Gambetti & Musso (2017), Ambler & Rumler

(2016), Briciu & Lisi (2015), Falagiarda & Reitz (2015), Szczerbowicz (2015) and Gambacorta, Hofmann, & Peersman (2014).

Against this backdrop, the aim of this study which doubles as a contribution to the literature is to employ a country-by-country Bayesian Vector Autoregressive (BVAR) model to assess the macroeconomic effects and the transmission channels of ECB's UMP in the aggregate euro area, the core and peripheries. The main premise is to examine the direction (increase or decrease) of the impulse response functions (IRFs) following an expansionary shock to UMP. The BVAR model is identified by augmenting sign restrictions with penalty function[5] as in Uhlig (2005). To examine the paper's goal, the following research questions begs for answers.

i. Does ECB's UMP have macroeconomic effects in the core[6] and peripheries[7] of the euro area? If yes,
ii. What are the transmission channels and how different or similar are they?
iii. How does ECB's UMP affect lending spreads in the core and peripheries?

This study took inspiration from Elbourne, Ji, & Duijndam (2018), but this study differs from its predecessor in the following ways. Firstly, whereas they employed the euro area shadow short rate (SSR) of Wu & Xia (2016) as a proxy for UMP, this paper employed euro system balance sheet as in Gambacorta, Hofmann, & Peersman (2014). Secondly, whereas they identified their BVAR model by way of zero and sign restrictions, this paper identifies the BVAR model by augmenting sign restriction with the penalty function. According to Liu & Theodoridis (2012) augmenting the sign restriction with the penalty function helps to identify the best impulse response functions out of all those that satisfy the sign restriction thereby reducing the uncertainty of identification procedures. Furthermore, this study also explored

[5] The algorithm finds an impulse vector which minimizes a criterion function by penalizing impulse responses functions (IRFs) which violates the imposed sign restriction and rewards IRFs which satisfy the imposed sign restriction.

[6] The study used 3 core countries (Germany, Austria and Netherlands)

[7] The study used 3 peripheries (Italy, Spain and Portugal)

various channels of transmission. Quintessentially, the study added euro area non-energy commodity price index (NECP), final government consumption expenditure (FGC), lending spreads (LS) and share price index to capture further channels of transmission. The inclusion of the NECP and share price index was meant to capture an asset price channel, FGC was added to capture a fiscal channel. Because capital requirements of banks became tighter due to Basel III regulations, bank's return on equity (ROE)[8] will likely experience a negative shock. In a bid to prevent a fall in ROE, banks are likely to increase their lending spread, reduce expenses or invest in riskier assets to have a positive profit margin. In this regard, the study also evaluates the response of LS to the expansive UMP shock.

In the empirical analysis, the model's parameters, (B, Σ) were jointly drawn from the Normal Wishart priors (NW) with the posterior draws (candidate truths) been generated from 10,000 Markov Chain Monte Carlo (MCMC) iterations of which 1000 burn-ins were discarded. Using an optimal lag of 1, the IRFs are kept in the 68 percent error band. The main findings are as follows. Firstly, in the baseline model, a one standard deviation (1 SD) expansionary shock to UMP led to an increase in euro system balance sheet. This development fuelled a reduction in the cost of borrowing which increased investment spending leading to upward pressures on industrial production (IP) and price inflation in the aggregate euro area. These results corroborate Elbourne, Ji, & Duijndam (2018), Boeckx, Dossche, & Peersman (2017), Gambetti & Musso (2017) among others. Using FEVD[9], fluctuations of 11.12 percent in IP and 8.60 percent in prices can be attributed to the expansive UMP shock. These positive real effects were transmitted through the bank lending channel and asset price channel.

The analysis for the core countries is as follows. For Germany, the reduction in the cost of lending to firms which should stimulate loan growth and investment spending did not have the

[8] Mathematically, ROE= $\frac{\text{net income}}{\text{shareholders equity}}$

[9] The FEVD results are consistent with IRFs findings.

intended positive impact on output. Albeit the impact on prices was positive, it was not statistically different from zero. The increase in fiscal deficit through the hike in government spending may have fuelled the upward pressure on lending spreads leading to the crowding out of private sector investment thereby reducing IP[10]. Further evidence showed that asset price channel was weak since the increase in asset prices was also not pronounced enough to increase production in Germany. In terms of percentage of fluctuations in IP and prices due to the UMP shock, a forecast horizon of 1 year showed that 4.83 percent variability in IP and 3.10 percent in prices is attributed to the UMP innovation in Germany.

For Austria, both IP and prices responded positively to the inflationary UMP shock. The study argues that the higher investment spending which might have led to these positive real effects was triggered by the asset price hikes and the lower interest rate environment[11]. The former revealed that a spike in asset prices is expected to increase consumption expenditure via the wealth effect leading to higher investment spending, increased aggregate demand and production. Variability in IP and prices attributed to the UMP shock respectively stands at 2.78 percent and 3.22 percent. For the Netherlands, whereas price response was positive and statistically significant, the response of IP was negative in the first 12 months before rebounding to positive territory over the medium term. Albeit, lending spreads fell temporarily, it later increased but the impact was muted. Per the IRF results, asset price inflation and the lower cost of lending to firms which are expected to spur investment spending and aggregate demand are the dominant transmission channels in the Netherlands.

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[10] For a fiscal expansion to crowd out the private sector depends on the economic situation of the country. For instance, if the economy is at full employment, a fiscal expansion could create competition with the private sector for the available scarce resources leading to spikes in interest rates thereby reducing private investment. In essence, the positive impact of the fiscal stimulus is dampened by the crowding out of the private sector. Conversely, if the economy is below full employment where there is a glut of resources available for investment, government will not be competing with the private sector for the available resources. As a result, the fiscal expansion will achieve the desired results.

[11] it is obvious the increase in the deficit did not crowd out private sector investment.

In the peripheries, whilst price response was positive and persistent in Italy, IP was negative but started increasing after 15 months. The fall in lending spreads which led to the lower cost of lending to firms spurred investment expenditure and production over the medium term. The growth in asset prices which increases household wealth may have trigger consumption which might have put an upward pressure on price inflation. The FEVD showed that the balance sheet shock explained fluctuations of 3.80 percent in IP and 6.24 percent in prices. For Spain, whilst price response was positive and persistent, IP was negative in the first 5 months before increasing over the medium term. These positive real effects of the UMP shock could be attributed to spikes in investment spending which was fuelled by the low cost of lending to firms and asset price inflation. Lastly, in Portugal, IP and prices increased following the inflationary UMP shock. Consistent with earlier narratives, these positive macroeconomic outcomes hinges on the fall in cost of lending to firms.

The paper further performed different robustness checks and diagnostic analysis. The first robustness analysis replaced the euro system balance sheet with the euro area 10-year yield. In the second case, the euro area term spread (difference between 10-year yield and MRO) and the VSTOXX index respectively replaced the euro system balance sheet and CISS index[12]. In the final robustness check, the penalty function algorithm of Uhlig (2005) was replaced with the rejection algorithm of Rubio-Ramirez, Waggoner, & Zha (2010). All in all, findings are generally consistent with the benchmark results. In terms of diagnostic checks, the median target approach of Fry & Pagan (2011) was employed to ensure that IRFs come from a single model. Results suggest that IRFs did come from a single model implying that inference from the structural IRFs is accurate.

The remainder of the paper is structured as follows. Section 2.2 presents the methodology. Section 2.3 gives the Bayesian estimation and inference. Section 2.4 provide a description on

[12] In this study, the VSTOXX and CISS were used as substitute indices for economic uncertainty.

the identification scheme. Section 2.5. explained the penalty function method. Section 2.6 described the data and model specification. Section 2.7 showed the empirical results. Section 2.8, Section 2.9 and Section 2.10 showed the robustness checks, diagnostics and closing remarks respectively.

2.2 Methodology

The VAR specification most often commences with a reduced form, where each dependent variable is regressed on lags of itself and lags of other variables in the VAR system. Following Uhlig (2005), the VAR is specified as follows:

$$Y_t = B_{(1)} Y_{t-1} + \ldots + B_{(l)} Y_{t-l} + u_t \quad \text{for } t=1,\ldots, T \qquad (1)$$

Where in the baseline model Y_t is an m x 1 vector containing endogenous variables taken at monthly frequencies for the period 2008m1 to 2018m7, $B_1 \ldots B_l$ refers to matrix of parameters with size m x m, u_t is the white noise forecast errors, that is $u_t \sim \mathcal{N}(0, \Sigma_u)$.

Because the reduced form forecast errors u_t are assumed to be correlated across the equations, the forecast errors must be decomposed into meaningful fundamental shocks v_t to make for a valid IRFs analysis. The literature posits that the forecast errors u_t are linear combinations of the structural innovations v_t such that $u_t = Av_t$. Following Uhlig (2005), the jth column represents the immediate impact on all variables of the jth fundamental impulse, one standard error in size. The only restriction on matrix A emerges from the covariance structure in equation 2 below.

$$E\,[u_t\ u_t'] = \Sigma = A\ E[v_t\ v_t'] A' = AA' \qquad (2)$$

Since matrix A contained m^2 unknown elements, the commonly used approach is for the researcher to impose at least m (m-1)/2 restrictions on matrix A in order to recover the structural innovations from the forecast errors. However, because this study evaluates the response of the variables to a single shock, the remaining m – 1 fundamental innovation is ignored. In effect the identification procedure used in this study identifies a single column $a \in \mathbb{R}^m$ of matrix A in equation 2. Variant to the agnostic approach used in this paper, the literature provides evidence of some widely used approaches in the macro econometrics literature. Starting from the seminal work by Christopher Sims, a VAR model can be identified by choosing a Cholesky factor $\sum$, such that the endogenous covariates are ordered recursively (see for instance Sims 1986). Another identification method referenced to Sims (1986), Bernanke B. S. (1986), Blanchard & Watson (1986), involves assessing structural relationships between the reduced form forecast errors and the structural economic innovations. In other approaches, fundamental impulses are partitioned into transitory shocks and permanent shocks (see for instance Blanchard & Quah 1989).

Although these identification approaches are widely used in the literature, they come with some shortcomings According to Enders (2004), a classic problem with the Cholesky approach is that if the covariance between the shocks is empirically non-zero, then the IRFs and FEVD will provide misleading results. Canova & Pina (2005) also levelled a criticism towards these identification methods. Their argument is that IRFs generated from the imposition of zero restriction on the variance covariance matrix most often violate theoretical dynamic stochastic general equilibrium models (DSGE). Fast forward, an argument in favour this paper's sign restrictions approach was put forth by (Faust 1998; Canova & De Nicolo 2002; Uhlig 2005). Their argument was that sign restrictions have a more efficient and robust feedback effect because the structural innovations are derived from prior beliefs about the signs of the impacts of certain shocks derived from theoretical models. As a result, this study employs sign restrictions with a penalty function where a chosen impulse vector a minimizes a criterion function by penalizing IRFs for sign violations. The model identification procedure is presented in section 2.4 of the paper.

2.3 Bayesian Estimation

Following Uhlig (2005) equation 1 is stacked as follows:

$$Y = XB + u \quad (3)$$

Where $X_t = [Y_{t-1}', \ldots, Y_{t-l}']'$, $Y = [Y_1, \ldots, Y_T]'$, $X = [X_1, \ldots, X_T]'$, $u = [u_1, \ldots, u_T]'$ and $B = [B_1, \ldots, B_l]'$.

Computing the IRF for the impulse vector, α let $a = [a', 0_{1,m(l-1)}]'$ and $\omega = \begin{bmatrix} B' \\ I_{m(l-1)} \quad 0_{m(l-1),m} \end{bmatrix}$ and estimate $r_{k,j} = (\omega^k a)_j$, k = 0,1,2, 3…, K implies computing the IRF of endogenous variable j at k-steps. The squaring of the IRFs gives the variance of the k-step forecast error due to the impulse vector α. Consequently, the total variance of the impulse vector α is given as $\Sigma = AA'$. Based on the assumption that the disturbance terms u_t are Gaussian, the parameters of the model (B, Σ), are estimated in equation 4 and 5 as follows[13].

$$\hat{B} = (X'X)^{-1}X'Y \quad (4)$$

$$\hat{\Sigma} = \frac{1}{T}(Y - X\hat{B})'(Y - X\hat{B}) \quad (5)$$

Estimation is carried out from a Bayesian perspective where an MCMC algorithm was used to generate the posteriors (candidate truths). The imposed priors and generated posteriors came from the Normal Wishart family (NW)[14](see for instance Uhlig 1994; Zellner 1971) for a detailed explanation. In specifying the probability distribution of the NW, the inverse of the variance covariance matrix, Σ^{-1} follows a Wishart distribution $\mathcal{W}_m\left(\frac{S^{-1}}{v,v}\right)$ with E $[\Sigma^{-1}] = S^{-1}$. Given Σ, the parameter matrix, B follows a normal distribution, $\mathcal{N}$(vec ($B, \Sigma \otimes N^{-1}$). To draw

[13] The model's coefficients are estimated in equation 4 whilst equation 5 estimates the error variance covariance matrix.

[14] This type of prior imposes weak prior knowledge on the model's parameters. The NW is the conjugate prior for the mean and variance of the multivariate normal distribution, that is the regression coefficients are assumed to be Gaussian.

from the Wishart distribution, the variance covariance matrix is estimated and drawn from a normal distribution, $\mathcal{N}(0, S^{-1}/v)$ with zero mean and variance covariance matrix, S^{-1}.

2.3.1 Prior and Posterior Specification

Following Uhlig (1994), Doan (1992) the priors are described as follows: $\bar{B}_0$, N_0, S_0 and v_0 Where $\bar{B}_0$ = mean coefficient matrix S_0 = positive definite mean covariance matrix, N_0 = positive definite matrix v_0= degree of freedom positive real number which determines uncertainty about the parameters (B, Σ) around ($\bar{B}$, S). The posteriors are stated in the following equations 6 to 9 below:

$$v_T = T + v_0 \tag{6}$$

$$N_T = N_0 + X'X \tag{7}$$

$$\bar{B}_T = N_T^{-1} (N_0\bar{B}_0 + X'X\hat{B}) \tag{8}$$

$$S_T = \frac{v_0}{v_T} S_0 + \frac{T}{v_T}\hat{\Sigma} + \frac{1}{v_T}(\hat{B} - \bar{B}_0)' N_0 N_T^{-1} X'X(\hat{B} - \bar{B}_0) \tag{9}$$

By inserting the priors of N_0 = 0, $v_0 = 0$, whereas S_0 and $\bar{B}_0$ are assigned randomly or arbitrarily in above equations, then the posteriors are given as follows:

$$v_T = T \tag{10}$$

$$N_T = X'X \tag{11}$$

$$\bar{B}_T = \hat{B} \tag{12}$$

$$S_T = \hat{\Sigma} \tag{13}$$

2.4 Model Identification

To clearly identify the model’s shock, some identifying assumptions needs to be made. First and foremost, the residuals of the equations are considered as the policy shocks in the various equations for the endogenous variables. However, the partial identification approach employed in this study only considers the residual of the euro system balance sheet as the main and only policy shock. In terms of identification, the residual of the euro system balance (UMP shock) is assumed to be exogenous to the model's covariates and it is restricted to be non-negative ($>= 0$). This can be interpreted as an inflationary UMP shock. The shock is imposed to impact other variables in the VAR system after 2 months when the shock hits (The researcher imposes this arbitrary timeline to make for delays or lags in the response of slow-moving macroeconomic variables to policy impulse). Secondly, to detach exogenous balance sheet shock (UMP shock) from its endogenous reactions to euro area financial jitters, the sign on the financial stress indicator, CISS is constrained to non-positive ($<= 0$). This meant that an expansion in the euro system balance sheet did not increase financial market uncertainty in the euro area. According to Kremer (2016), controlling for financial stress is vital for euro area studies. This identification choice was also adopted in Gambacorta, Hofmann, & Peersman (2014), Boeckx, Dossche, & Peersman (2017), Elbourne, Ji, & Duijndam (2018). Furthermore, equity prices and EONIA-MRO spread were respectively constrained to be positive ($>= 0$) and negative ($<= 0$). This identification restrictions stemmed from Haitsma, Unalmis, & de Haan (2016), Baumeister & Benati (2013), Beirne, et al. (2011). Lastly, no sign restrictions were imposed on IP and HICP. This agnostic identification approach is conducive since it helps to skew the research to the exact causal analysis the researcher seeks to evaluate. The identification scheme for the baseline model is shown in table 2 below.

Table 2:Baseline identification scheme

IP	HICP	CISS	Euro-system balance sheet	EONIA-MRO spread	Equity prices
?	?	<=0	>=0	<=0	>=0

Note: Identification scheme for the benchmark model. The ($<= 0/>= 0$) indicates decrease/increase and (?) is unrestricted.

2.5. The Penalty Function Approach

According to Liu (2008) the pure sign restricted VAR approach where a positive sign or a negative sign on impact implied that the IRFs are constrained to be positive and negative respectively may suffer from the multiple models' problem thereby violating orthogonality of disturbance terms. According to the multiple models' problem, there are many IRFs that can agree with any imposed signs restriction; therefore, the median responses may not come from a single model. Buttressed by Fry & Pagan (2007), Liu & Theodoridis (2012), they argued that the multiple models' problem can result in incorrect model estimates and inaccurate policy conjecture. Liu & Theodoridis (2012) futher explained the merit of augmenting the sign restriction with the penalty function. Their argument is that the approach identifies the best IRFs out of all those that satisfy the sign restriction, thereby reducing the uncertainty of identification procedures. The penalty function approach is presented in equation 14 as follows:

$$f(w) = \begin{cases} w & if\ w \leq 0, \\ 100 * w & if\ w \geq 0 \end{cases} \qquad (14)$$

The penalty function approach assigns penalties to the IRFs in linear proportions. That is, since the algorithm is intended to penalize strongly for sign violation than it rewards for sign satisfaction, the penalty function is considered asymmetric. The working of the algorithm is such that, the reward for negative responses is at a gradient 100 times smaller than the slope for penalties on the positive responses. The minimization problem is presented in equation 15 as follows:

$$\min_{a} \lambda\,(a) =. \sum_{j\in J} \sum_{k=0}^{K} f\left(l_j \frac{r_{j,a}\,(k)}{\sigma_j}\right) \qquad (15)$$

Where , the $r_{j,a}(k)$ is the IRF of the jth variable at time k – horizon, a is an impulse vector which minimizes the penalty for the constrained variables j $\in J$ and for the constrained horizon k $\in K$. σ_j is the standard deviation of the jth variable for the rescaling of the IRFs, l_j is the jth variable in the data vector. To ensure that signs are treated on equal footing, the penalty function must be adjusted both for the scale of the variables and the imposed sign restrictions. The minimum of function is found via the UOBYQA algorithm by Powell (2002)[15].

2.6 Data and Model Specification

The estimation is carried out on data for the period 2008m1 to 2018m7. The data was sourced from ECB Statistical Data Warehouse, Eurostat and Organization for Economic Co-operation and Development (OECD). The benchmark model has 6 endogenous variables: Industrial production index (2015=100, seasonally and calendar adjusted), harmonized index of consumer prices (2015=100, all items), CISS index of systemic financial stress, logarithm of euro system balance sheet in millions of euros, EONIA-MRO spread and real equity prices (euro - stoxx 50 index divided by harmonized prices).

In the extended model, the following proxies were included: Interest rate on loans to non-financial sector/firms, logarithm of total ECB non-energy commodity prices (ECB commodity price index Euro denominated), total share price index (2015=100), final government

[15] The Unconstrained Optimization by Quadratic Approximation (UOBYQA) is a numerical algorithm by Powell (2002). The purpose of UOBYQA is to minimize a function of many variables by a trust region method that forms quadratic models by interpolation. In terms of approach, the algorithm situates a quadratic, C_a by interpolation of the objective function (n+1) (n+2)/2 and then minimizes, C_a within a trust region. A trust region is a subset of the objective function which is approximated using a model function.

consumption expenditure (2015=100)[16] and lending spreads (weighted spreads between mortgage interest rate for new loans to non-financial corporations and the swap rate). For robustness checks, the paper added euro area term spread (difference between 10-year yield and MRO), euro area government 10-year yield and VSTOXX index (Implied volatility of Euro STOXX 50 index). The VAR model was specified with an optimal lag =1[17] as indicated by the Swartz Bayesian Information Criterion (SBIC), the shock is 1 SD in size, and it was imposed in the first 2 months. The table 3 & table 4 below provides some descriptive statistics and correlation matrix for the baseline scenario. The descriptive statistics revealed that on average the IP and prices were 99.23 percent and 97.43 percent respectively. The correlation matrix indicates a positive correlation coefficient of 0.37 percent for IP and prices. The euro system balance sheet also shows a positive correlation coefficient with IP at 0.22 percent and prices at 0.9 percent. The baseline model is specified in equation 16 as follows:

$$Y_t = (\text{IP, HICP, CISS, Euro system balance sheet, EONIA} - \text{MRO spread, Equity prices})' \qquad (16)$$

Table 3: Descriptive statistics

Variables	Mean	Std.Dev	Min	Max
IP	99.2	4.8	86.7	110.3
HICP	97.43	3.89	89.67	104.09
CISS	0.27	0.16	0.06	0.63
Euro-system balance sheet	884247.1	355900.8	280272	1579116
EONIA-MRO spread	-0.08	1.17	-0.8	4.24
Equity prices	3.08	0.5	2.01	4.23

Note: The table provides a descriptive statistic of the baseline variables with regards their mean, standard deviation (Std. Dev), minimum values (min) and maximum values (max).

[16] This series was interpolated from quarterly to monthly using cubic spline interpolation.
[17] Findings were consistent when the model was specified with different lag order.

Table 4:Correlation matrix

Variables	IP	HICP	CISS	Euro-system balance sheet	EONIA-MRO spread	Equity prices
IP	1	0.37	-0.29	0.22	0.53	0.75
HICP	0.37	1	-0.65	0.90	-0.36	0.39
CISS	-0.29	-0.65	1	-0.42	0.08	-0.70
Euro-system balance sheet	0.22	0.9	-0.42	1	-0.55	0.12
EONIA-MRO spread	0.53	-0.36	0.08	-0.55	1	0.45
Equity prices	0.75	0.39	-0.70	0.12	0.45	1

Source: Author's calculation. All figures are rounded to 2 decimal places.

2.7 Empirical Results

2.7.1 Effects of Balance Sheet Shock in the Euro area (Baseline Model)

After estimating the BVAR model with the penalty function method, the balance sheet shock was extracted. The median and the 68 percent error bands (blue colour) were calculated and plotted in figure 5. The horizontal axis describes the series at monthly frequencies whilst the vertical axis measures the balance sheet shock. The choice of variables in the baseline model (see figure 6) follows Elbourne, Ji, & Duijndam (2018). By controlling for interbank market lending conditions, equity prices and financial uncertainty, IRF results suggest that a 1 SD shock to the UMP led to an expansion in the euro system balance sheet. This development is expected to increase investment spending and aggregate demand which puts upward pressure on IP and prices. These findings are consistent with the "humped shape"[18] description given in

[18] The peak response of IP is higher than prices.

the literature (see for instance Boeckx, Dossche, & Peersman 2017; Wieladek & Garcia Pascaul 2016; Burriel & Galesi 2016; Gambacorta, Hofmann, & Peersman 2014). The FEVD results confirmed the IRFs that is, in forecast period of 1 year, the inflationary UMP shock accounted for fluctuations of 10.36 percent and 5.71 percent respectively in IP and prices (see figure 7). The implication is that ECB's loose monetary policy has pronounced effect on economic activity than it had on inflation.

Figure 5: Euro system balance sheet shock

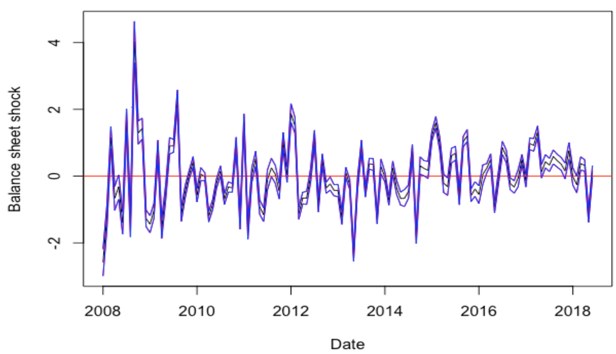
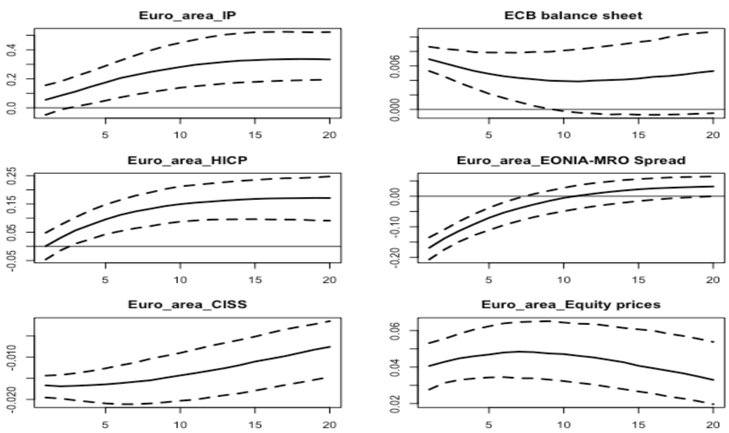
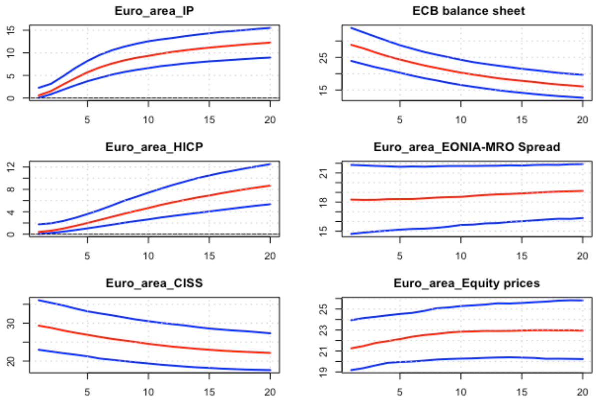


Figure 6: Baseline impulse responses



Note: The vertical -axis represents the response of the dependent variables to an UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 7: Baseline forecast error variance decomposition

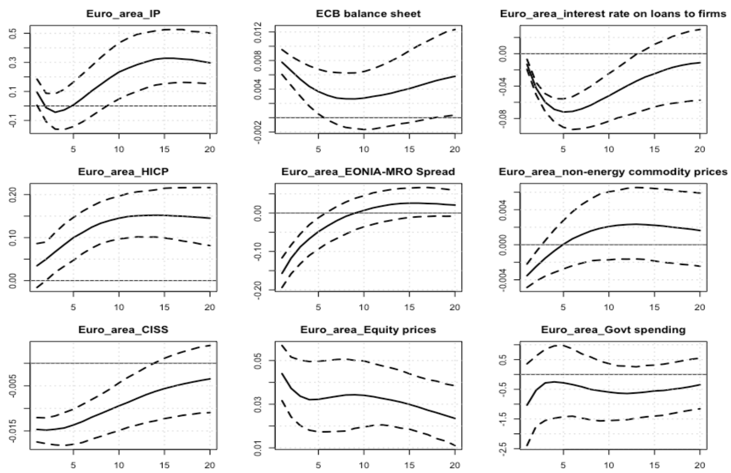


Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the euro system balance sheet.

2.7.2 Channels of Transmission of the Balance Sheet Shock in the Euro Area

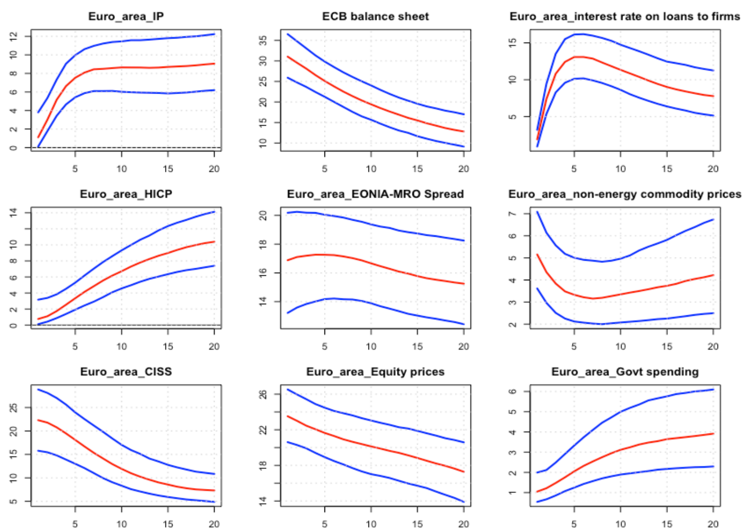
This section examined the channels through which an inflationary UMP shock affects the real economy at aggregate euro area. Results shown in figure 8 indicates that the balance sheet expansion which led to a fall in systemic stress (CISS) had a positive impact on economic activity and prices at aggregate euro area. As expected, the reduction in cost of lending to firms triggered investment spending which translates into increased aggregate demand, production and price inflation in the aggregate euro area (bank lending channel). Alternatively, since equity prices forms part of financial wealth, the hike in asset prices has provided households with additional wealth income which they could use to increase expenditure on consumption leading to increases in aggregate demand, economic activity and inflation (asset price channel). Although the expansive UMP shock induced a lower interest rate environment, it did not fuel an increase in the fiscal deficit through higher government spending. As a result, private sector investment was not crowded out and output was also not negatively affected in the euro area. The FEVD in figure 9 below showed that in a forecast period of 1 year, the UMP shock explained variability of 11.12 percent in IP and 8.60 percent in prices. Consistent with IRFs results, the balance sheet shock has accounted for higher variability in IP as compared to prices.

Figure 8: Channels of transmission in the aggregate euro area



Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 9: Forecast error variance decomposition for aggregate euro area

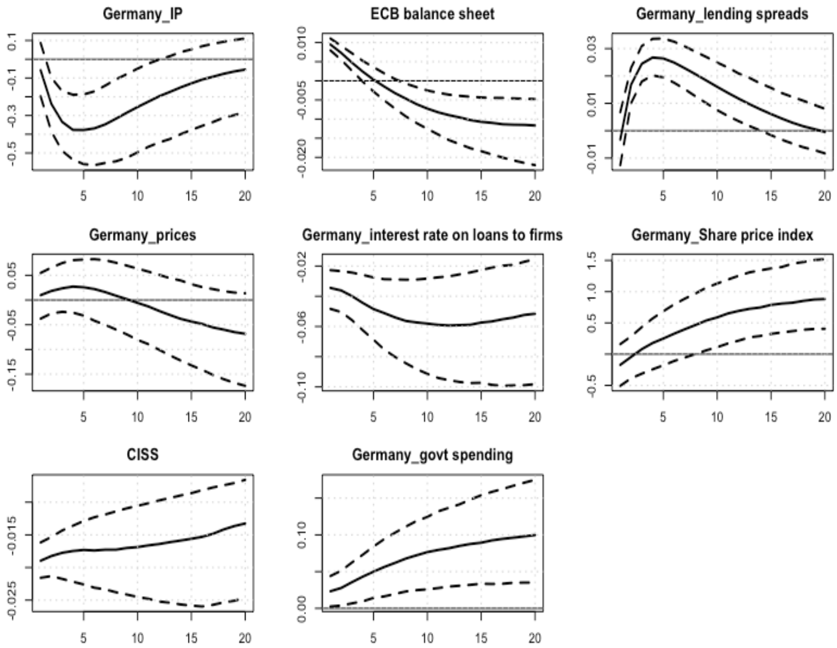


Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the euro system balance sheet.

2.7.3 Channels of Transmission of Balance Sheet Shock in the Core Countries

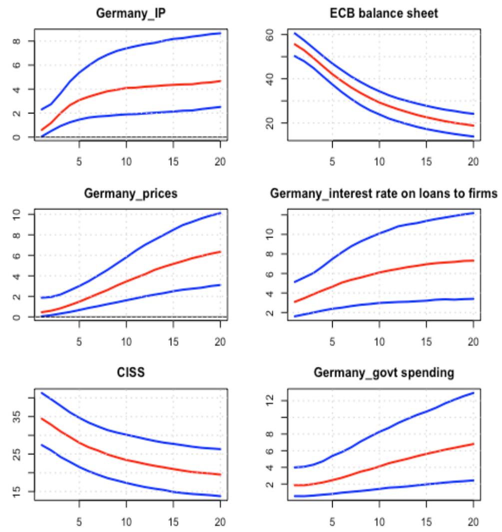
This section examined the pass-through of ECB's expansionary balance sheet policies in Germany, Austria and Netherlands. For Germany, the reduction in the cost of lending to firms which should stimulate loan growth and investment spending did not have the intended positive impact on output. Albeit the impact on prices was positive, it was not statistically significant. The increase in the fiscal deficit through the hike in government spending may have triggered the upward pressure on lending spreads leading to the crowding out of private sector investment thereby reducing production in Germany (see figure 10). It is also evident that the increase in asset prices due to the expansive UMP shock was not pronounced to influence IP and prices via higher consumption expenditure. In a forecast horizon of 1 year (see figure 11), the UMP innovation accounted for variability of 4.83 percent in IP and 3.10 percent in prices in Germany. As shown in figure 12 for Austria, both IP and prices responded positively to the inflationary UMP shock. It is expected that these real effects were induced by the asset price inflation (wealth effect) and the lower lending cost to firms which translates into higher investment expenditure leading to increases in aggregate demand and production. It is also obvious that increase in government spending which should put an upward pressure on lending spreads did not crowd out private investment hence output was not negatively affected in Austria. In terms of percentage of fluctuations, the UMP shock accounts for variability of 2.78 percent in IP and 3.22 percent in prices (see figure 13). For the Netherlands, whereas price response was positive and statistically significant, the response of IP was negative in the first 12 months before rebounding to positive territory over the medium term. Albeit, lending spreads fell temporarily, it later increased but the impact was muted. Per the IRF results, asset price inflation and the lower cost of lending to firms are the dominant channels for the UMP shock transmission in Netherlands over the medium term (see figure 14). In a forecast horizon of 1year, the UMP shock has accounted for 8.85 (see figure 15).

Figure 10: Channels of transmission for Germany



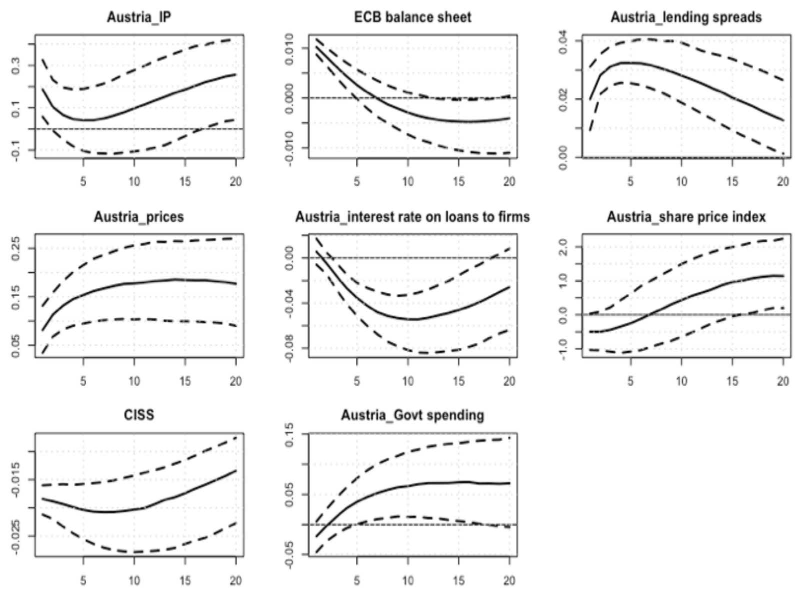
Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 11: Forecast error variance decomposition for Germany



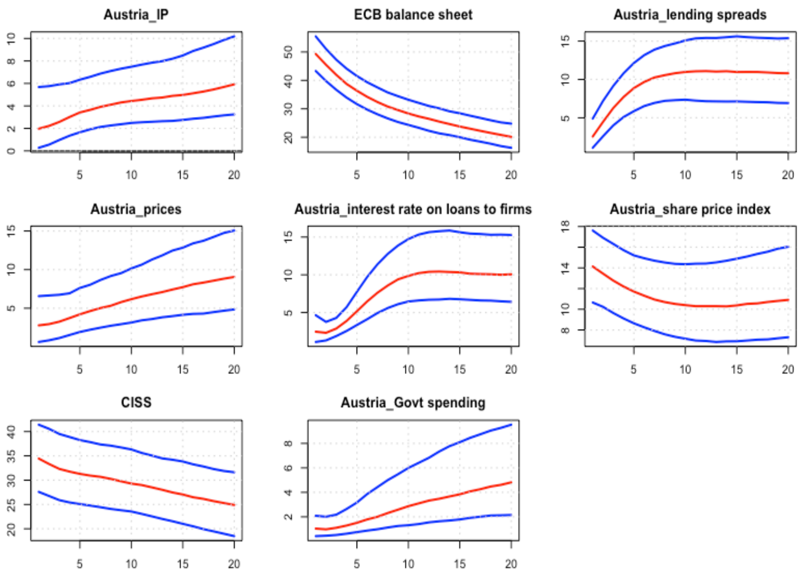
Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion shock in the Euro system balance sheet.

Figure 12: Channels of transmission for Austria



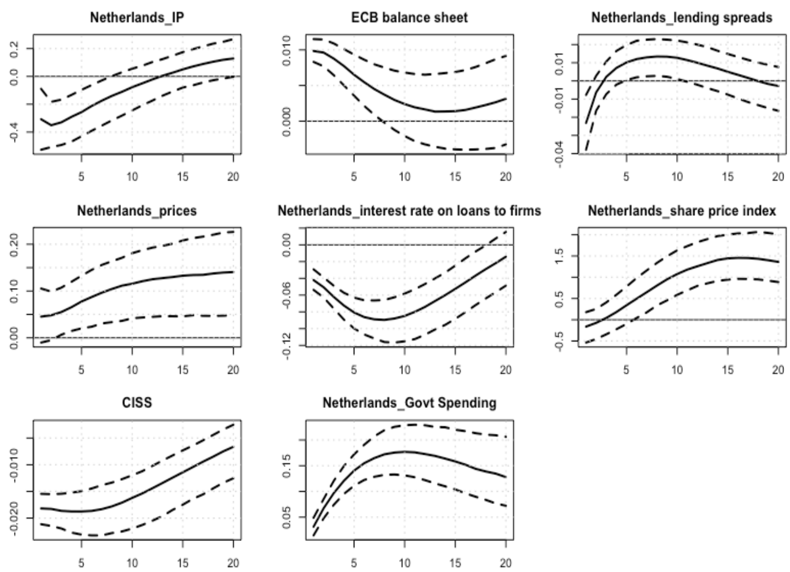
Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 13: Forecast error variance decomposition for Austria



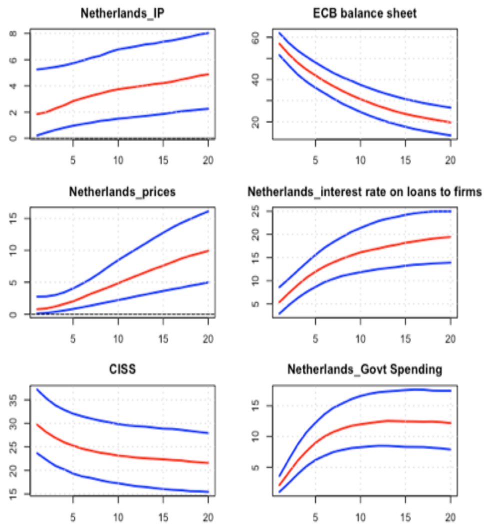
Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the Euro system balance sheet.

Figure 14: Channels of transmission for Netherlands



Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 15: Forecast error variance decomposition for Netherlands

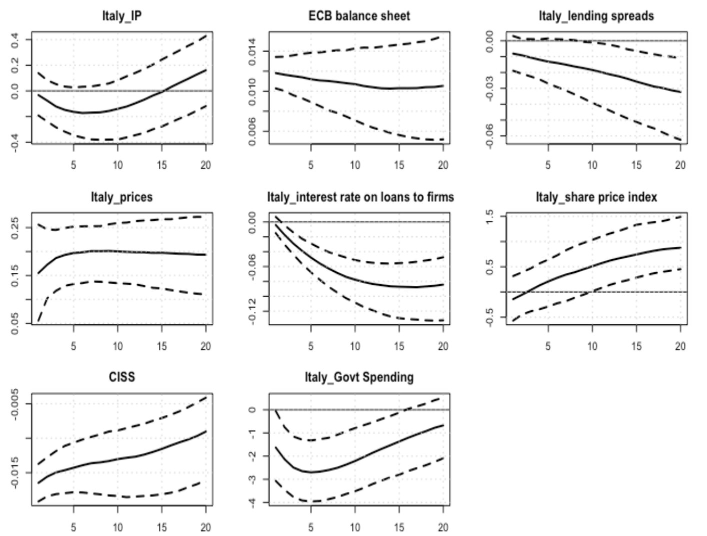


Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the Euro system balance sheet.

2.7.4 Channels of Transmission of Balance Sheet Shock in the Peripheries

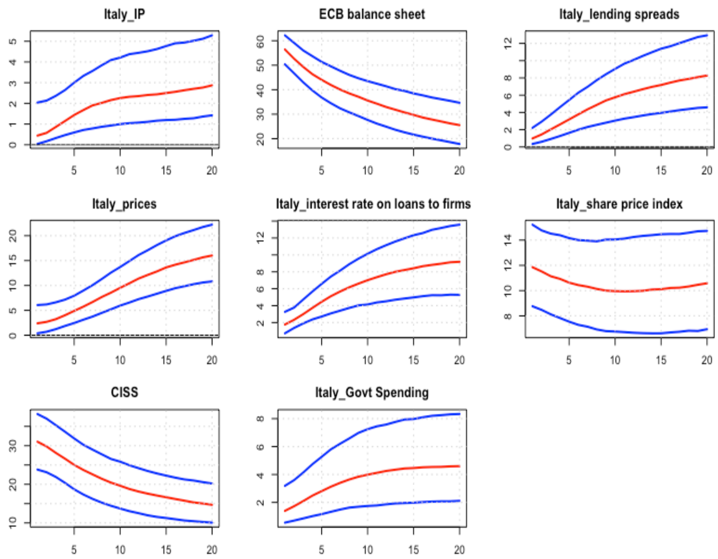
The thesis of this section is to evaluate the impact of the inflationary UMP shock on the real economies of Italy, Spain and Portugal. As shown in figure 16 whereas price response to the UMP shock was positive and persistent in Italy, IP was negative but started increasing only after 15 months. The fall in lending spreads which led to the lower cost of lending to firms spurred investment spending, aggregate demand and production. The growth in asset prices could have positively affected aggregate demand and production via the wealth effect on consumption. In a forecast period of I year, the UMP impulse accounted for fluctuations of 3.80 percent in IP and 6.24 percent in prices (see figure 17). For Spain, figure 18 showed that whilst price response was positive and persistent, IP was negative in the first 5 months before increasing over the medium term. These positive macroeconomic outcomes over the medium terms could be attributed to asset price inflation via the wealth effect on consumption, lower lending spreads which translates into lower cost of lending to firms which eventually spurred production. In terms of variability, 4.56 percent fluctuation in IP and 6.16 percent in prices is attributed to the UMP shock (see figure 19). Lastly, as shown in figure 20, production and prices in Portugal increased following the expansionary UMP shock. The fall in lending spreads which might have tiggered a reduction in cost of lending to firms may have accounted for the positive impact of the expansionary balance sheet on economic activity and price inflation. In addition, the hike in asset prices is expected to positively affect consumption through the wealth effect leading to increases in investment spending, aggregate demand and production in Portugal. The increase in the fiscal deficit via increased government spending was not pronounced to crowd out private investment. The FEVD showed that, the balance sheet shock accounted for fluctuations of 4.06 percent in IP and 6.95 percent in prices in Portugal (see figure 21).

Figure 16: Channels of transmission for Italy



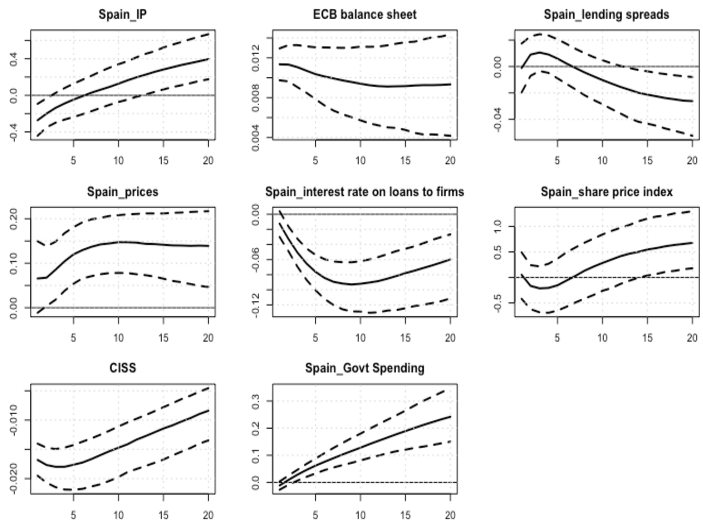
Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 17: Forecast error variance decomposition for Italy



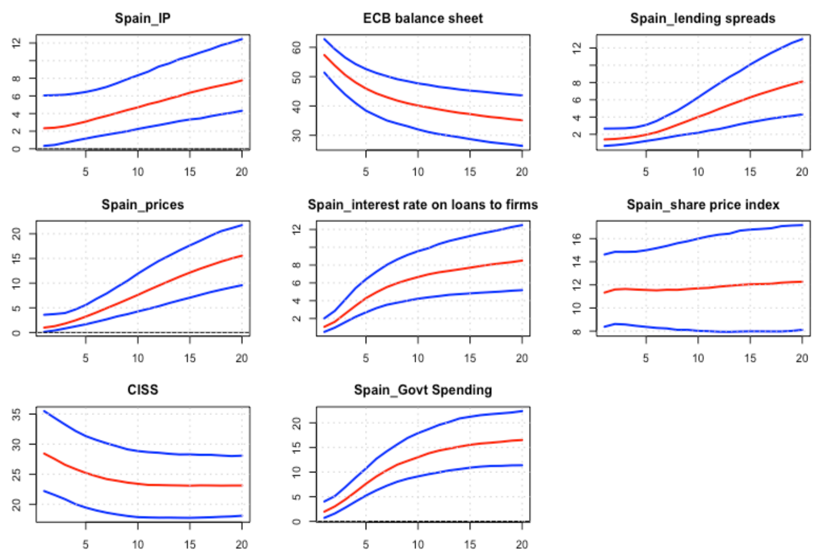
Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the euro system balance sheet.

Figure 18 : Channels of transmission for Spain



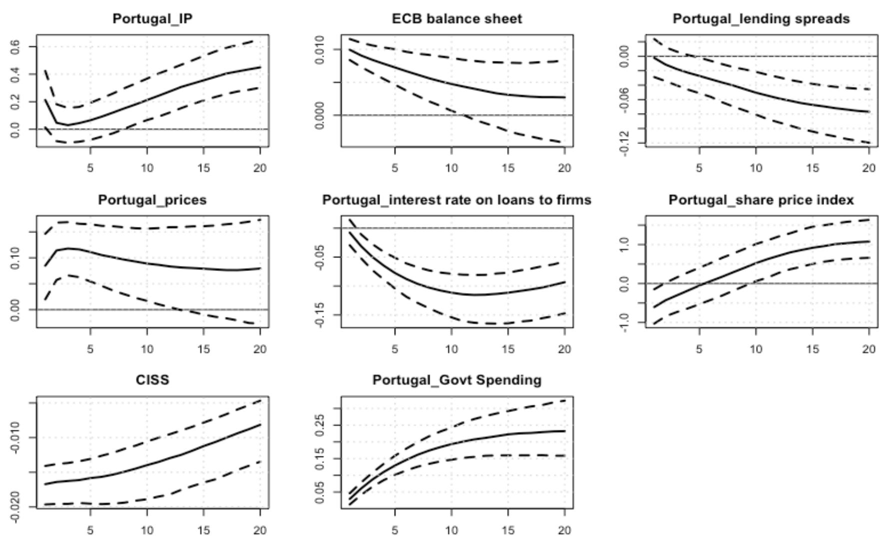
Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 19:Forecast error variance decomposition for Spain



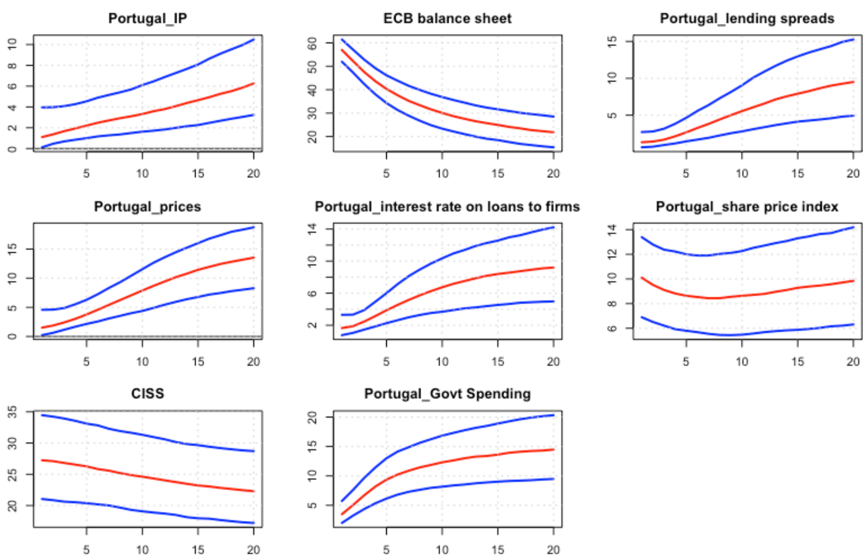
Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the euro system balance sheet.

Figure 20: Channels of transmission for Portugal



Note: The vertical -axis represents the response of the dependent variables to a UMP shock, whilst the horizontal-axis shows the months. The IRFs were based on 1-SD expansion shock to the euro system balance sheet. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 21: Forecast error variance decomposition for Portugal



Note: The FEVD showed percentage variation in the other variables when there is a 1-SD expansion in the euro system balance sheet.

2.8 Robustness Checks

This part of the paper conducted three different modifications to the baseline model. The first robustness check replaced the euro system balance sheet with euro area 10-year yield. Results as shown in figure 22 below is consistent with the benchmark results. The IRFs showed that a fall in euro area long term yield reduced systemic stress and lending conditions which put an upward pressure on asset prices at the aggregate euro area. This development eventually increased investment spending, aggregate demand and production. In the second robustness check, the euro system balance sheet and CISS were respectively replaced with euro area term spread and VSTOXX index. Results shown indicates that an expansionary shock to UMP led to a fall in euro area term spread which reduced financial stress and lending conditions thereby stimulating growth in asset prices and production (see figure 23). In the third and final robustness check, the Uhlig (2005) penalty function approach was replaced with the Rubio-Ramirez, Waggoner, & Zha (2010) rejection algorithm (RWZ). The RWZ algorithm is based on a QR decomposition where the draw for the impulse vector is from the standard normal distribution. The steps to execute the algorithm is described as follows: Let (Γ, θ) = unrestricted structural parameters.

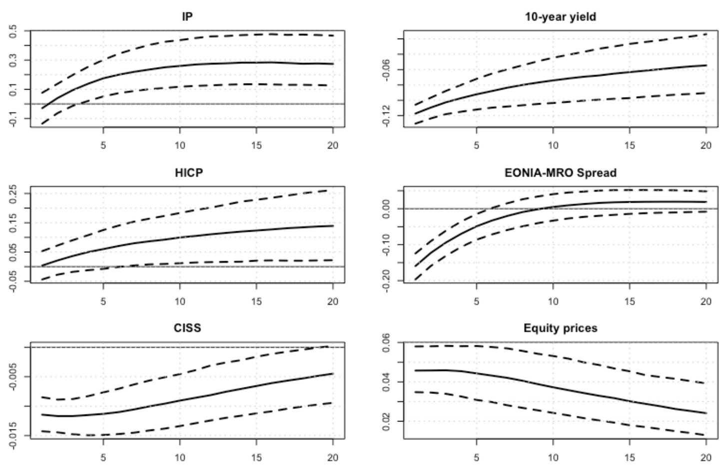
Step 1: Draw a matrix say, $\tilde{F}$ which is considered an independent standard normal.

Let $\tilde{F}$ = $\tilde{Q}$ $\tilde{R}$ be the QR decomposition of $\tilde{F}$ with a positive diagonal $\tilde{R}$.

Step 2: Let G= $\tilde{Q}$ and generate IRFs from ΓP and B= $\theta\,\Gamma^{-1}$.

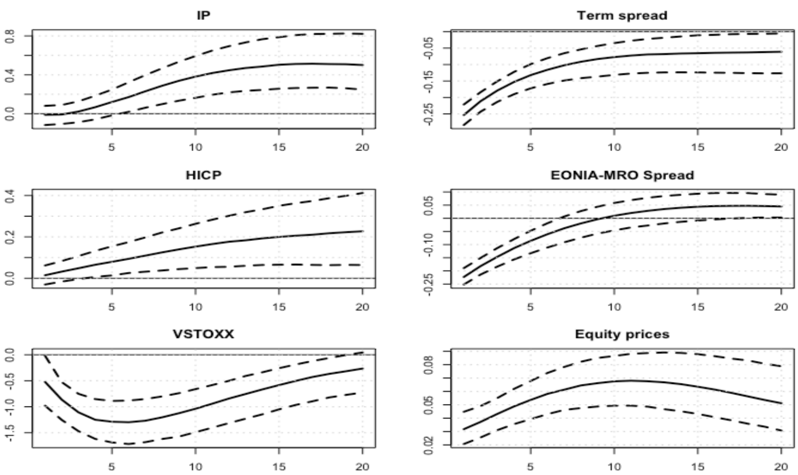
Step 3: Following Rubio-Ramirez, Waggoner, & Zha (2010) if the IRFs do not satisfy the sign restrictions after a maximum of 100,000 iterations, the algorithm moves to step1 to take another sub-daw from the orthogonal matrix $\tilde{Q}$. The IRFs showed that an expansive balance sheet shock led to a positive impact on IP and prices, but the impact is muted (see figure 24).

Figure 22:Impulse response for 10-year yield shock



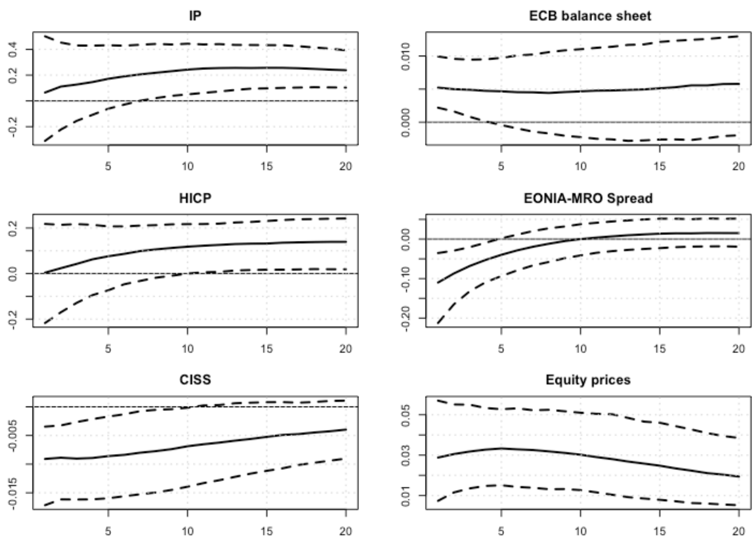
Note: The vertical -axis represents the response of the dependent variables to euro area 10-year yield shock whilst the horizontal-axis shows the months. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 23: Impulse response for term spread shock



Note: The vertical -axis represents the response of the dependent variables to euro area term spread shock whilst the horizontal-axis shows the months. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band.

Figure 24: Impulse response for balance sheet shock

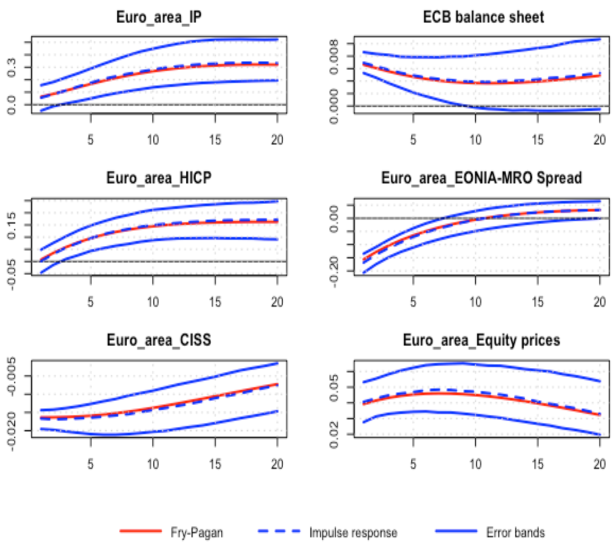


Note: The vertical -axis represents the response of the dependent variables to euro area balance sheet shock whilst the horizontal-axis shows the months. The solid line represents the response at each horizon whereas the dashed line depicts the 68% error band. IRFs are based on Rubio-Ramirez, Waggoner, & Zha (2010) rejection method.

2.9 Diagnostic Analysis

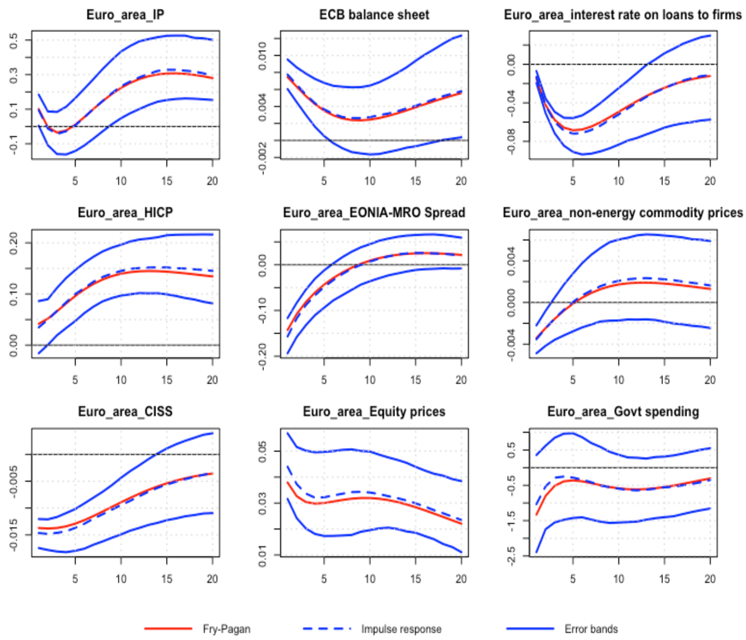
Apart from robustness analysis, a diagnostic analysis was conducted using the median target (MT) approach of Fry & Pagan (2011). The basic premise of the MT is to ascertain whether the IRFs come from a single model or not. The idea of the MT approach is to minimize the sum of squared standardized intervals between the sign constrained IRFs of the model understudy and the IRFs of the MT. If there exist a similarity between the sign restricted IRFs of the understudied model and the MT IRFs, then the IRFs did come from a single model. Diagnostic results are shown below in (figure 25 , figure 26 , figure 27, figure 28 , figure 29, figure 30, figure 31 and figure 32). The diagnostic plots indicate that the intervals between the IRFs of MT and the IRFs of the penalty function is minimum or largely similar. That is, the IRFs produced by the penalty function method did come from a single model and that the model's inferences are accurate.

Figure 25: Median Target Responses (Baseline Model)



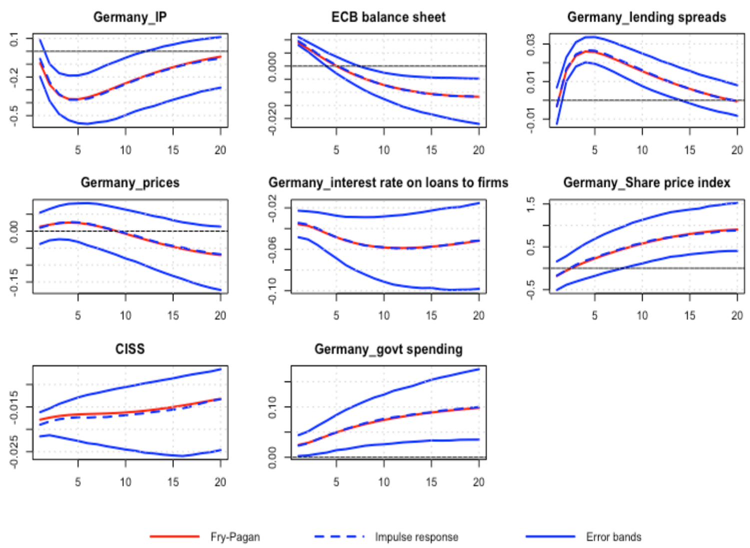
Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band.

Figure 26: Median Target Responses (Channels of transmission in the euro Area)



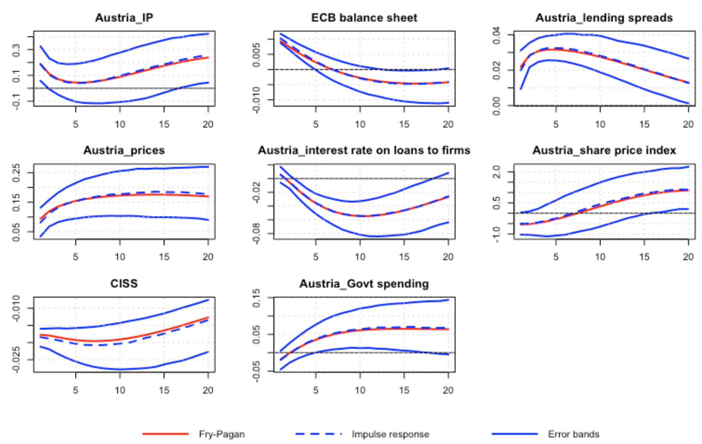
Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

Figure 27:Median Target Responses (Channels of transmission in Germany)



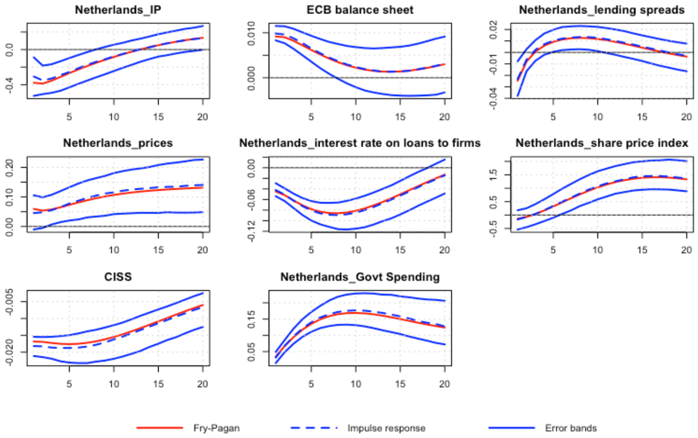
Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

Figure 28: Median Target Responses (Channels of transmission in Austria)



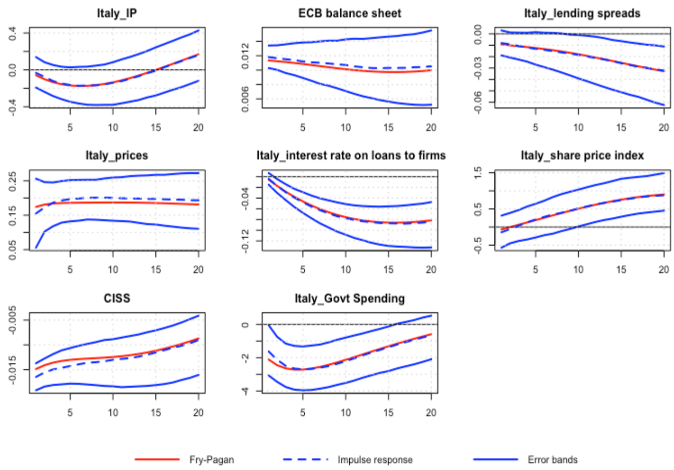
Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

Figure 29: Median Target Responses (Channels of transmission in Netherlands)



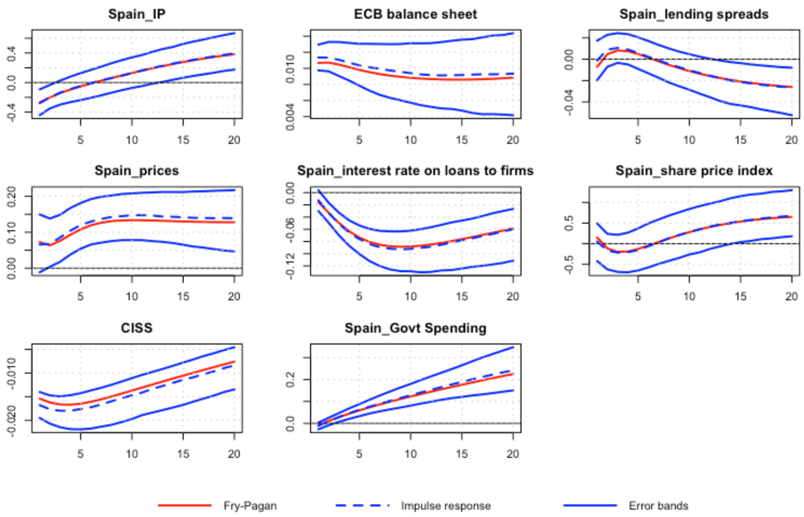
Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

Figure 30: Median Target Responses (Channels of transmission in Italy)



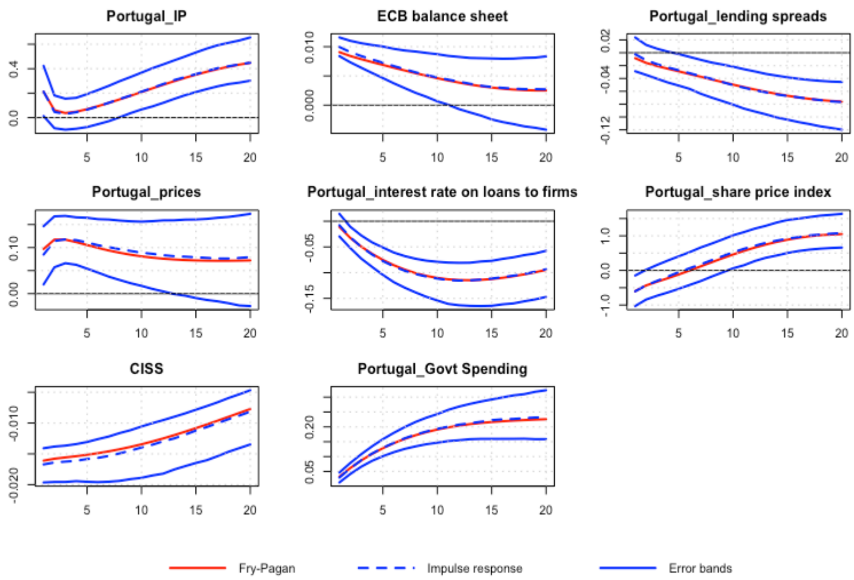
Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

Figure 31: Median Target Responses (Channels of transmission in Spain)



Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

Figure 32:Median Target Responses (Channels of transmission in Portugal)



Note: The red solid line represents the responses from the MT method, whilst the dashed blue line denotes the IRFs from the penalty function. The thick blue line is the 68% error band. The dashed blue lines and the red lines did not diverge from each other, implying that the IRFs do come from a single model.

2.10 Closing Remarks

The premise of the paper is to examine the macroeconomic effects and the channels of transmission of ECB's balance sheet expansion in the aggregate euro area as well as in the core and peripheries. This is achieved by employing a Bayesian vector Autoregressive model (BVAR) identified using sign restriction with the penalty function as in Uhlig (2005). Using an optimal lag of 1, the posteriror draws of the BVAR model was estimated with a total of 10,000 Markov Chain Monte Carlo (MCMC) iterations with 1000 burn-ins.

Findings showed that an increase in the euro system balance sheet which culminated into a reduction in the cost of lending triggered an increase in investment spending which translates into hikes in economic activity and prices inflation at the aggregate euro area. A known channel that is, the wealth effect postulates that asset price hikes which increases financial wealth for households stimulate consumption expenditure leading to higher investment spending and production.

Given the structural diversities in the core and peripheries, findings showed that the impact of the inflationary balance sheet shock on economic activity and price inflation was heterogenous. Generally, the channels of transmission were invariant to what was found at the aggregate euro area level. Further evidence suggests that since cost of lending fell following the expansive balance sheet shock, a fiscal deficit might have emerged through increases in government spending leading to crowding out of private investment. However, this paper argues that for the fiscal expansion to crowd out private investment depends on the economic situation of the country. That is, at full employment, increasing the deficit via government spending will lead to a competition with private sector for the available scarce funds leading to the crowding out of investment which eventually reduces output. In brief, the positive impact of the fiscal stimulus on production will be negated by the crowing out of investment. On the other hand, when the country is below full employment where there is a glut of resources available for investment spending, government will not be competing with the private sector for the available resources. Consequently, the fiscal expansion will achieve the desired outcome on production.

Chapter 3

Effects of Monetary and Macroprudential Policies in Central and Eastern Europe

3.1 Introduction

The aftermath of the financial crisis of 2007/08 has shown that achieving price and financial stability has become a daunting task for policy makers. In this regard, there has been a clarion call for monetary policy (MP) to complement macroprudential policy (MAPP) to ensure price and financial stability. To make a case for a complementary use of both polices, Shin (2015) posits that albeit, monetary policy and macroprudential policy could respectively have price stability and financial stability objectives, both polices have the tendency to affect the price and the supply of credit. From a policy perspective, Woodford (2012) argued that when forecast of financial stability is not injurious to the objectives of price stability, central banks should endeavour to include threats to financial stability in their policy directives.

In this regard, the general premise of this study is to evaluate the combined impact of MP and MAPP innovations on the macroeconomy of Central and Eastern Europe (CEE)[19]. The paper's motivation stemmed from these two reasons. Firstly, the clamour for a policy mix between MP and MAPP for macroeconomic stability. Secondly, the consensus that the euro area and CEE were linked through trade and finance (see, for instance Potjagailo 2017; Hajek & Horvath 2016; Cevik, Dibooglu, & Kutan, 2016; Allen, Jackowicz, & Kowalewski, 2013; Horvath & Rusnak 2009; Mackowiak 2006).

Hitherto, there is a growing strand of literature that evaluated the efficacy of MAPP and MP on financial and macroeconomic variables. Notable amongst such studies are as follows. Alam et al. (2019) examined the effectiveness of macroprudential policies on a new database of 134 countries. They found that loan targeted macroprudential instruments had significant impact on household credit and a reduction in consumption. Akinci & Olmstead-Rumsey (2018) employed a dynamic panel model to assess the efficiency of MAPP in reducing credit growth and house price increases. They found that a contractionary MAPP led to a reduction in bank credit growth which further reduced credit for house purchases leading to a deceleration in house prices. More so, they showed that MAPP which are targeted to curb house price growth was most effective. Fahr & Fell (2017) employed a New Keynesian model to examine some policy trade-offs. They found that whilst MAPP were effective in ensuring financial system resilience (financial stability), MP is best suited for price stability objectives.

Kim & Mehrotra (2017) examined the effects of MAPP and MP in the Asia Pacific region via a structural panel vector autoregressive model. They found that a tightening of MAPP and MP

[19] Based on data availability, the CEE countries used in this study are Czech Republic, Hungary and Poland. At the time of writing this paper, there is no known study which examined jointly the effects of MAPP and MP shocks for CEE.

led to a fall in real output, prices and total credit in the Asia Pacific region. Using a database of capital flow measures and MAPP, Bruno, Shim, & Shin (2017) comparatively assessed the efficacy of MAPP in selected Asia-Pacific economies. Their findings showed that a contractionary MP is most effective in achieving its desired result. Alpanda & Zubairy (2017) used a dynamic stochastic general-equilibrium model (DSGE) with housing and household debt, and compared the effectiveness of MP, housing-related fiscal policy, and MAPP in reducing household indebtedness. They found that the tightening in deductions on interest payments on mortgages and regulatory loan to value ratio are effective in reducing household debt. Boar, Gambacorta, Lombardo, & Da Silva (2017) examined the effects of MAPP on long run performance of an economy. Their study showed that countries that often implement macroprudential measures, ceteris paribus, experience stronger and less volatile GDP growth. Rubio & Yao (2017) also employed a DSGE model with housing and collateral constraints to assess the effects of MAPP in a low interest rate environment. They found that since low interest rates can increase risk taking and financial volatility, MAPP should come handy in containing excessive lending. They further argued for a complementary usage of MAPP and MP in periods when the latter is constrained at zero. Using a Structural VAR model, Bachmann & Rueth, (2017) examined the macroeconomic effects of a change in the loan to value ratio in the United States. They found a 25-basis point tightening of the loan to value ratio led to a fall in GDP by 0.1 percent. In terms of monetary policy response, their study showed that the FED reduced its policy rate as an endogenous response to the tightening in the loan to value ratio. In other studies, Aikman, Bush, & Taylor (2016) examined the impact of macroprudential and monetary policy in the United Kingdom from the 1950s to the 1980s. Their analysis estimated impulse responses via local projection approach. They found credit controls and macroprudential measures were potent to restrain the credit cycles. Additionally, the muted credit growth led to a fall in industrial output, but the impact on prices is lethargic. Sanchez &

Röhn (2016) used a quantile regression to evaluate the effects of various policy settings on economic growth in a panel of OECD countries. They found a greater use of MAPP leads to less extreme positive shocks to growth. They conclude that, countries with stronger bank supervision and a robust capital markets experience a reduced negative shock to growth. In a panel study, Kuttner & Shim (2016) examined the efficacy of non-interest rate polices on the stability of house prices and credit for house purchases. Their main findings showed that when the panel was estimated with mean group and event study methods, house credit was significantly affected by maximum debt service to income ratio. Conversely, when the conventional panel methods are employed, housing credit growth was significantly affected by all the macroprudential measures, that is maximum debt income to service ratio, loan to value ratio, limits on exposure to housing sector and housing related tax measures. Using a VAR augmented by qualitative variables (Qual VAR), Tillmann (2015) found a tightening of the MAPP reduces appreciation in house prices and reduces credit growth. Conversely, in bad times when the steady state interest rate is low, MAPP could complement MP for economic stability. Using an IMF survey analysis, Cerutti, Claessens, & Laeven (2015) examined the usage of MAPP on 119 economies from 2000-2013. They found that whereas emerging economies often use foreign exchange related MAPP, advanced economies instead prefer the usage of borrower-based ones. They also posit that, albeit these polices restrains growth of credit to households and constrains the financial cycle, they seem to be less effective during periods of a bust. Using a narrative approach, Monnet (2014) assessed the effects of money and credit controls during France's golden age (1948-1973). Findings points to strong effects on output and prices. Based on panel regressions, Claessens, Ghosh, & Mihet (2013) studied how dynamics in banks' balance sheet responds to MAPP. Findings showed that caps on loan to income ratio, debt service to income ratio as well as limits on foreign exchange lending and growth in credit are potent in reducing asset price growth. Furthermore, Schularick & Taylor

(2012), Jorda, Schularick, & Taylor (2013) found that muting excessive credit growth via MAPP reduces the negative output tail risk from costly financial crisis and excess growth in credit. Dell'Ariccia, et al. (2012) indicated that, MAPP can limit the credit booms and reduce the cost associated with credit booms. In a study by Vandenbussche et al (2012), they examined the impact of a set of macroprudential instruments on house prices in Central, Eastern and South-eastern Europe. They found that only some of the instruments had an impact on house price inflation. Wong, Fong, Li, & Choi (2011) examined the pros and cons of loan to value ratio in Hongkong. They found that, albeit loan to value ratio can be used to curb systemic risk, it also has the tendency to impose higher liquidity constraints on home buyers. Reinhart & Rogoff (2009) found that periods of prolonged plummeting in asset markets can be a precursor for severe financial crisis. Borio & Lowe (2002) showed that there is a probability of a banking crisis when there are excessive hikes in asset prices and credit growth.

To contribute to the existing literature, this study follows Kim & Mehrotra (2017) and Vandenbussche et al (2012). But this paper differs from its predecessors in several ways. Firstly, by controlling for euro system balance sheet and CEE level covariates, the study employed a fixed effects panel vector autoregressive model (PVAR) to assess the impact of MP and MAPP on macroeconomic stability in CEE. Secondly, because the borrower-based MAPP instruments are targeted at housing credit and house prices, the study extends the analysis to include residential property prices (PP) in CEE. Thirdly, previous studies where a dummy-type MAPP instrument[20] is used, this study employed the average limit on loan to value ratio (LTV) as in Alam et al. (2019). Given that the usage of these policy instruments could generate unintended consequences for other sub-sectors of the economy, the empirical analysis extends the PVAR model to assess the domestic spill over effects of MP and MAPP shocks on the industrial

[20] The dummy-type macroprudential policy from IMF's integrated macroprudential database (iMaPP) assigns value of 1 to macroprudential tightening and 0 to macroprudential loosening.

sector[21] in CEE. Following the PVAR literature, the usage of the fixed effect estimator is to capture the asymmetric response of the CEE economies to the MP and MAPP shocks. However, because the fixed effects may be correlated with the lags of the dependent variables, it tends to produce bias estimates in a dynamic panel. As a result, forward mean differencing or Helmert transformation is used to eliminate the fixed effects and the model's coefficients are estimated with general method of moments (GMM) (see for instance Love & Zucchino 2006 ; Boubtane, Coulibaly, & Rault 2013). In terms of identifying assumptions, the shocks of the model are identified via the Cholesky identification scheme where the variables in the PVAR system are ordered recursively. For instance, the euro system balance sheet is considered the most exogenous variable hence it was ordered prior to all other variables in the VAR system. At the CEE level, the study assumes that the three macroeconomic indicators that is, real GDP (RGDP), credit to GDP gap (credit_GDP) and consumer price index (CPI) are assumed to be contemporaneously exogenous to the two policy instruments, that is the policy interest rate (MPR) and LTV. This identification approach allows the monetary and macroprudential authorities to respond with their policy tools after examining dynamics in the macroeconomy. This identification scheme is consistent with Christiano, Eichenbaum, & Evans (1999) in the monetary VAR literature. The final part of the study focuses on using a machine learning algorithm known as random forest (RF) to predict the macroeconomic variables for CEE. To verify the consistency of the results, a robustness analysis was conducted by way of different orderings and modifications to the baseline model.

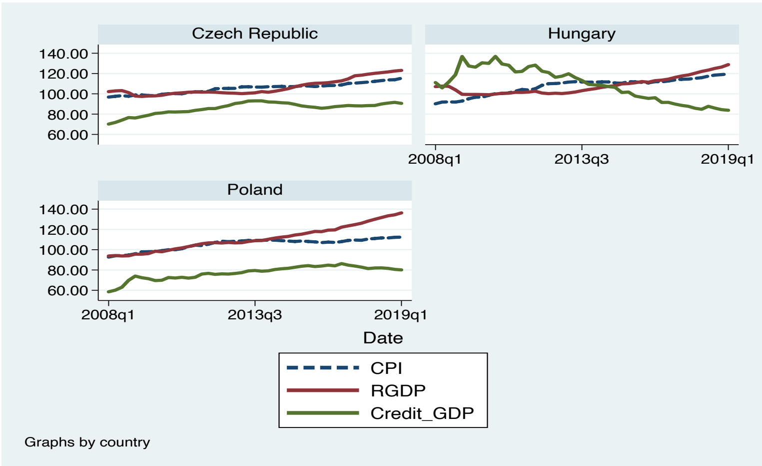
The paper's main findings are summarized as follows. Firstly, an expansive shock to MAPP fuelled increases in LTV which translates into an upsurge in credit to GDP gap in CEE. This finding corroborates Akinci & Olmstead-Rumsey (2018), Kim & Mehrotra (2017), Tillmann

[21] The industrial sector as used in this study refers to manufacturing, mining and quarry sectors. The choice of these two sub sectors of industry was based on economic intuition and some discretion.

(2015), Vandenbusshe et al. (2012) and many others. Surprisingly, the deluge in credit attributed to the expansive LTV shock did not stimulate PP, RGDP, prices and industrial production in CEE. This contradicts Bachmann & Rueth, (2017) and other studies in the literature. Consistent with mainstream wisdom, a contractionary MP shock which culminated into high borrowing cost led to a reduction in lending for house purchases (reduced mortgage lending) thereby decelerating PP. This development further fuelled a reduction in investment spending which negatively affected aggregate demand, economic activity and price inflation in CEE. Alternative to impulse response analysis (IRFs), the forecast error variance decomposition (FEVD) was used to explain fluctuations in the macroeconomic indicators that are attributed to MP and MAPP shocks. Results indicates that in the fifth quarter, the MP shock explained 6 percent variation in RGDP whereas the MAPP shock accounts for 8 percent. Innovations to MP explained 1 percent variability in CPI whilst the MAPP shock accounted for 2 percent. Also, 17 percent and 9 percent variation in credit_GDP is respectively attributed to MP and MAPP shocks. Finally, a RF algorithm was used to predict the macroeconomic variables of CEE. Using a data split of 70 percent for the train/in sample data and 30 percent for the test/ out of sample data, a total of 500 trees were grown with 2 feature variables randomly sampled at each split. Findings showed that amongst all the variables, as expected production in mining and quarry is the most important predictor of RGDP in CEE. In the credit_GDP gap equation, MPR is the most important predictor. In the price equation, the euro system balance sheet is the most important variable to predict CPI in CEE. Lastly, the baseline model was subjected to various robustness checks. Findings are generally consistent with the baseline results. Although the identifying assumptions are contentious, the IRFs results were consistent with the baseline model.

The figure 33 shows a panel data line plot of the macroeconomic indicators used in analyzing the CEE. The vertical axes show the index for the various macroeconomic indicators whereas the horizontal axes show the date at quarterly frequency. As expected, real GDP and CPI has been moving closely together over the span of the data.

Figure 33: Dynamics in CEE Macroeconomic Variables



Source: Plotted from Eurostat data

The remainder of the paper is as follows. Section 3.2. presents the panel VAR methodology. The random forest algorithm and the variable importance technique is explained in Section 3.3. Section 3.4 identified and estimated the PVAR model. Section 3.5 described the data used for the estimation. Section 3.6 provides the empirical results. Section 3.7 shows robustness checks and Section 4 provides the closing remarks.

3.2 Panel VAR Methodology

This empirical technique combines the traditional VAR approach, which considers all variables as endogenous, with the panel data approach which allows for unobserved cross-sectional heterogeneity. A fixed effects PVAR is presented in equation 1 as follows.

$$Y_{it} = z_i + A_1 Y_{it-1} + \ldots + A_p Y_{it-p} + BX_{t-q} + u_{it} \quad (1)$$

Where, $i \in \{1, 2\ldots, N\}$ & $t \in \{1,2\ldots,T_i\}$

$Y_{i,t}$ is a matrix of dependent variables for each country i at time t. X_{t-q} is a vector of exogenous covariates, u_{it} and z_i respectively refers to a vector of idiosyncratic disturbance terms and individual fixed effects, A and B are parameters to be estimated, p and q respectively refers to the optimal lags for the endogenous and exogenous variables. The error term u_{it} is assumed to have a zero mean and constant variance. The intent of introducing the individual fixed effects, z_i is to account for heterogeneity in the cross sections i. However, the literature documents that, in a dynamic panel model, the lags of dependent variables (regressors) are correlated with the fixed effects which leads to bias parameter estimates. To remedy this difficulty, the literature documents a plethora of measures to remove the fixed effects. A known approach is to eliminate the fixed effects via mean differencing. However, this approach leads to inconsistent parameter estimates (see for instance Nickell 1981). Referenced to Anderson & Hsiao (1982), the fixed effects can also be purged via first differencing where deviations are taken between current observations and previous observations and then the lagged deviations are used as instruments. However, in the situation where the panel is unbalanced, this approach has the tendency to enlarge gaps in the panel. An improvement on first difference transformation is the forward mean differencing put forth by Arellano & Bover (1995). This approach subtracts the mean of all future observations. Albeit only recent values are not included in the estimation, the estimation is considered efficient since it minimizes data loss nonetheless[22]. For the sake of this paper, the fixed effects are removed by forward mean differencing or the Helmert procedure as in Love & Zucchino (2006). Because the lagged deviations are orthogonal, they are considered as good instruments and the model's parameters are estimated with general method of moments (see for instance Boubtane, Coulibaly, & Rault

[22] Since past values are not included in the forward orthogonal deviation, they are considered as valid instruments.

2013). The transformation of the variables in forward means is specified in equation 2 as follows:

$$c^*_{i,t} = (c_{i,t} - \overline{c_{i,t}})\sqrt{\frac{T_{it}}{(T_{it}+1)}} \qquad (2)$$

Where T_{it} is the number of future observations for country i at time t and $\overline{c_{i,t}}$ is the average of future observations for country i at time t.

3.3 Random Forest Algorithm

The RF as popularized by Breiman (2001) is a tree-based ensemble method where all trees depend on a collection of random variables. The forest is grown from aggregating trees which forms an ensemble. The premise of the RF algorithm is to find a prediction function f (k) to predict Y. This is done by calculating the conditional expectation in equation 3 below.

$$f(k) = E(Y \mid K = k) \qquad (3)$$

Generally, ensemble methods collate the base learners, that is h1 (k), h2 (k), ..., hJ (k) which are combined into the ensemble predictor in equation 4 below.

$$f(k) = \frac{1}{J}\sum_{j=1}^{J} h_j(k) \qquad (4)$$

In the RF method, the jth base learner is a regression tree which we denote hj (K, Θj), where Θj is a collection of random variables. In RFs, the trees are based on binary recursive partitioning trees. They partition the predictor space in a sequence of binary splits on individual variables which form the branches of the tree. The root node in the tree is made up of the entire predictor space. The terminal nodes or leaves are nodes that are not partitioned, and they end up forming the final partition of the predictor space. Each nonterminal node is split into two descendant nodes, one to the left and one to the right. This is done according to the value of one of the predictor variables based on a splitting criterion known as a split point. Observations of the predictor variables smaller than the split point goes to the left and the rest to the right. The split of a tree is chosen by considering every possible split on every predictor variable and then selecting the best according to some splitting criterion. If the response values at the nodes are $y1, y2, y3,,yn$ then a common splitting criterion is the mean squared residual (MSE) at the node as shown in equation 5.

$$Q = \frac{1}{n}\sum_{i=1}^{N}(y_i - \bar{y})^2 \quad (5)$$

Where $\bar{y}$ is the average predicted value at the node. The splitting criterion provides a goodness of fit measure with low values showing good fit and large values showing poor fit. A possible split creates two descendant nodes, one on the left and one on the right. If we denote the splitting criterion for the possible descendants by Q_L and Q_R along with their respective sample sizes n_L and n_R, then the split is chosen to minimize

$$Q_{split} = n_L Q_L + n_R Q_R \quad (6)$$

Finding the best possible split means sorting the values of the predictor variable and then considering every distinct pair of values. Once the best possible split is found the data is partitioned into the two descendants' nodes which are in turn split in the same way as the original node. This procedure is recursive and stops when a stopping criterion is met. This can for example be that a specified number of unsplit nodes should remain. The unsplit nodes remaining when the stopping criterion is met are the terminal nodes. A predicted value for the response variable is then obtained as the average value from the terminal nodes for all observations.

3.3.1 Variable Importance (VI)

The variable importance (VI) determines which predictors are the most important to include in the estimation. For example, to measure the importance of variable k, first the observation on the variable is passed down the tree and the predictions are computed. Then the values of w are randomly permuted in the out-of-bag data while keeping all other predictors fixed. Thereafter, the modified out-of-bag data will be passed down the tree and a new set of predictions are computed. Using the real set and the one based on the permutations, the difference in the mean squared error (MSE) of the predictions from the two sets is obtained. The higher this number is, the more important the variable is deemed to be for the response.

3.4 Panel VAR Model Identification and Estimation

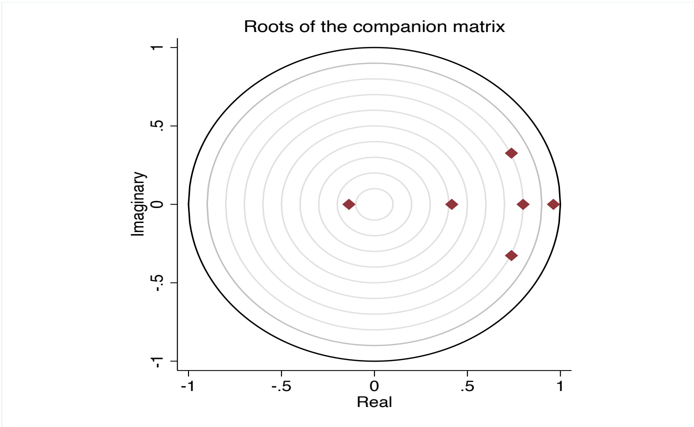
To engage the services of impulse response functions (IRFs) and FEVD, the innovations must be orthogonal, that is diagonal variance covariance matrix. The identification of the PVAR model relied on the Cholesky decomposition of the variance covariance matrix which assumes a recursive structure. Following Christiano, Eichenbaum, & Evans (1999) in the monetary VAR literature, the most exogenous variables are ordered first. That is, contemporaneously, variables ordered first are not affected by shocks emanating from variables ordered after it. In this study, the ordering is as follows. Firstly, the three macroeconomic variables $y_{it} =$ [$RGDP_{It}$, $Credit\_GDP_{It}$, CPI_{it}] are assumed to be contemporaneously exogenous to the two policy instruments $y_{it} =$ [LTV_{It}, MPR_{it}]. This identification approach allows the monetary and the macroprudential authorities to employ their policy levers after observing developments in the three macroeconomic indicators. Because the euro area relates to CEE through finance and trade, the study includes an exogenous variable, x_t =[ECB balance sheet] to control for euro area monetary policy (see forinstance Cevik, Dibooglu, & Kutan, 2016; Cevik, Dibooglu, & Kutan, 2016). To verify the consistency of the results,a robustness analysis was conducted by way of different orderings and modifications to the baseline model. Although the identifying assumptions are contentious, the IRFs results were consistent with the baseline model. To evaluate the impact of the MP and MAPP shocks on the macroeconomy of CEE, the benchmark PVAR is specified in equation 7 below.

$$Y_{it} = [ECB\_BS_t^{euro\ area}, RGDP_{it}^{cee}, Credit\_GDP_{it}^{cee}, CPI_{it}^{cee}, LTV_{it}^{cee}, MPR_{it}^{cee}] \quad (7)$$

To generate the IRFs and FEVD, the GMM PVAR[23] model is estimated with 3 lags based on the Andrews & Lu (2001) moment and model selection criteria (MMSC) which uses Hansen (1982) J statistic for over-identifying restrictions. The MMSC is akin to the conventional model selection criteria such as the Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC) and Schwartz Bayesian Information Criterion (SBIC). The confidence intervals for the IRFs were computed by Monte Carlo simulation with 500 repetitions. The shock is one standard deviation (1-SD) in size. Although the study did not conduct a unit root test to check the stationarity in the data series[24], the study relies on the VAR stability condition, that is a VAR is stable if all the moduli of the companion matrix are less than one (see forinstance Lutkepohl 2005 ; Hamilton 1994). The figure 34 shows that the benchmark PVAR model is stable since the eigen values were in the unit root circle.

[23] Since the PVAR was estimated with GMM, the 3 lags of the dependent variables were used as instruments during the estimation.
[24] The relatively short time span of the data also constrains a meaningful unit root analysis.

Figure 34: PVAR Stability



Note: All the eigenvalues lie inside the unit circle. PVAR satisfies stability condition

3.5 Data Issues

Quarterly data for the period 2008q1 to 2019q1 was used for the analysis. Datasets that are not available in quarterly series were interpolated using the Denton method[25]. The table 5 shows the description for the datasets used in the study. The descriptive statistics in table 6 for main macroeconomic targets varibles shows that on the average RGDP index in CEE is 108 with a minimum of 93.8 and a maximum of 136.3. The credit_GDP on average stood at 90.7 with a minimum of 58.5 as a percentage of GDP to a maximum of 136.9 as a percentage of GDP. The lowest CPI inflation in CEE is 90.1 up to a maximum of 119.6. On average CPI stood at 106.1. The table 7 presents the correlation matrix.

[25] The Denton method interpolates a low-frequency series by way of an associated high-frequency indicator series by imposing the constraints that the interpolated series obeys the low-frequency totals.

Table 5: Data Description

Variable	Description	Transformation	Source
ECB_BS	Millions of euros	Logarithm	ECB Statistical Data Warehouse
RGDP	Seasonal and calender adjusted (2010=100)	Logarithm	Eurostat
Credit_GDP	Credit to non-financial sector as a percentage of gross domestic product		Bank for International Settlements
CPI	All items (2010=100)		Eurostat
Man_Sector	Volume of production (2010=100)		Eurostat
M&Q_Sector	Volume of production (2010=100)		Eurostat
PP	Index of residential property prices (2010=100)	Logarithm	Bank for International Settlements
LTV	Average limit on loan to value ratio		integrated Macroprudential Policy Database
MPR	Central bank monetary policy rate		International Finance Statistics

Note: Following Alam et al (2019), the LTV variable summarizes the regulatory limit in each country and month. It considers those for real estate mortgage loans which may also include commercial real estate loans. If the country does not present LTV limit, the value is set to 100.

ECB_BS = Euro system balance sheet, PP = real residential property prices, Man_Sector = manufacturing sector, M&Q_Sector = Mining and Quarry sector.

Table 6: Descriptive Statistics

Variables	Mean	Std.Dev	Min	Max
ECB_BS	4604216	1708116	1974544	7713275
RGDP	108.5	9.8	93.8	136.3
Credit_GDP	90.7	17.1	58.5	136.9
CPI	106.1	6.4	90.1	119.6
Man_Sector	93.3	13.1	69.3	123.4
M&Q_Sector	107.9	9.7	88.7	130.3
PP	99.5	13.0	80.5	147.2
LTV	85.5	19.0	55	105
MPR	2.6	2.39	0.05	10

Source: Author's calculation. The Std.Dev = standard deviation, Min = Minimum values, Max = Maximum values. All other variables are described as before. For the sake of robustness analysis, a dummy-type indicator for MAPP (LTV_dummy) which assumes a value of 1 for a tightening and 0 for otherwise will be used. However, since this is a binary variable, it was not included in the descriptive statistics with the continuous variables.

Table 7: Pairwise Correlation Coefficients

	ECB_BS	RGDP	Credit_GDP	CPI	Man_Sector	M&Q_Sector	PP	LTV	MPR
ECB_BS	1								
RGDP	0.84	1							
Credit_GDP	-0.08	-0.15	1						
CPI	0.83	0.70	-0.01	1					
Man_Sector	0.85	0.94	-0.16	0.76	1				
M&Q_Sector	0.70	0.92	-0.06	0.68	0.94	1			
PP	0.30	0.32	-0.05	0.04	0.32	0.11	1		
LTV	-0.48	-0.42	-0.47	-0.63	-0.41	-0.47	-0.12	1	
MPR	-0.48	-0.41	0.47	-0.55	-0.56	-0.40	-0.07	-0.01	1

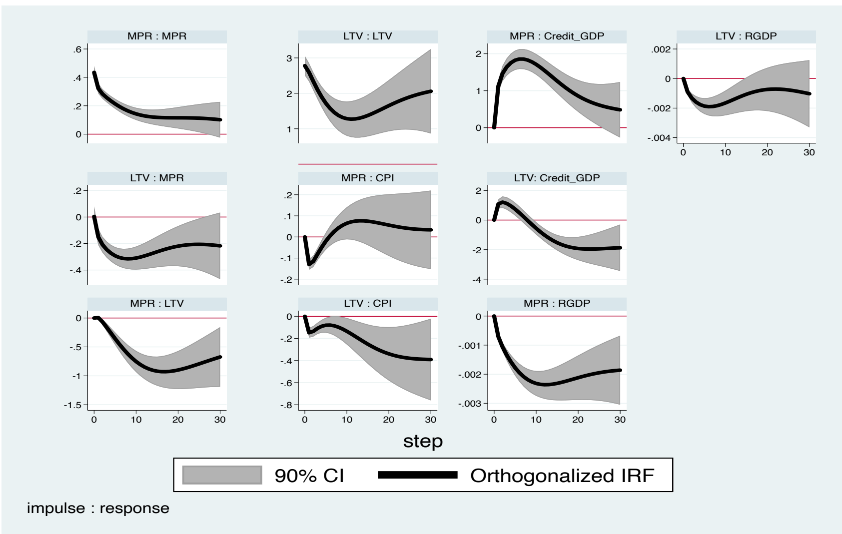
Source: Author’s calculation from data

3.6 Results

3.6.1 IRFs and FEVD for the Benchmark Model

Controlling for euro system balance sheet and other CEE level variables, the empircal analysis commences with an estimation of a benchmark model for the CEE. The choice of variables was partly based on Alam et al (2019) and Kim & Mehrotra (2017). Firstly, as shown in figure 35 the LTV increased in response to a one standard deviation (1 SD) expansive shock to MAPP. This translated into an upsurge in credit to GDP gap, but the impact fell over the medium term. This finding corroborates Akinci & Olmstead-Rumsey (2018), Kim & Mehrotra (2017), Tillmann (2015), Vandenbussche et al. (2012) and many others. Surprisingly, the expansion in credit did not accelerate house prices in CEE. This part of the result disproves earlier studies as the credit expansion did not accelerate CEE house prices. On the other hand, a contractionary shock to MP (increase in MPR) fuelled a fall in investment expenditure which depressed aggregate demand leading to a fall in economic activity and price inflation in CEE. This finding corroborates the mainstream economic wisdom on MP transmission. Alternatively, the FEVD (see table 8) is used to explain fluctuations in the macroeconomic indicators that are attributed to MP and MAPP shocks. Results indicates that in the fifth quarter, the MP shock explained 6 percent variation in RGDP whereas the MAPP shock accounts for fluctuations of 8 percent. Innovations to MP explained 1 percent variability in CPI whilst the MAPP shock accounted for 2 percent. Also, 17 percent and 9 percent variation in credit_GDP is respectively attributed to MP and MAPP impulse.

Figure 35: Response for the Benchmark Model



Note: The vertical axes measure the response of the dependent variables to MP and MAPP shocks whereas the horizontal axes measure the quarterly horizon. The solid black line represents the orthogonal IRFs whilst the grey area shows the 90 percent confidence band which was generated with 500 Monte Carlo replications.

Table 8: Variance Decomposition for the Baseline Model

Variables	MP Shock	MAPP Shock
RGDP	0.06	0.08
Credit_GDP	0.17	0.09
CPI	0.01	0.02

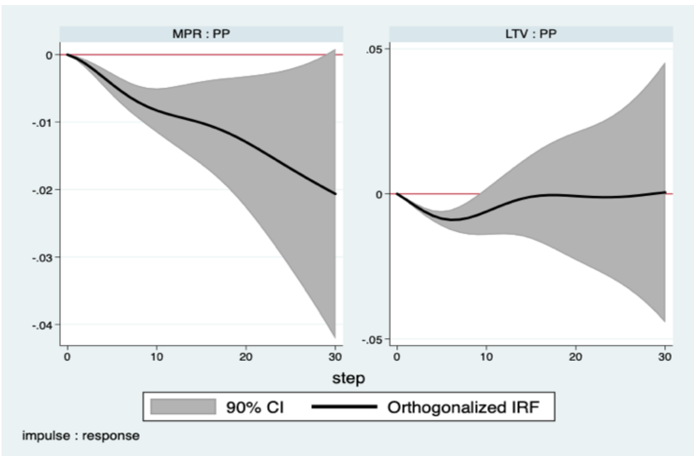
Note: The table shows the effect of MP and MAPP shock on the macroeconomic indicators in the fifth quarter. The MPR represents the MP shock whilst the LTV represents the MAPP shock.

3.6.2 IRFs and FEVD for the Extended Model

The analysis in the section is put into three parts. Given that the borrower based macroprudential instruments are targeted at housing credit and house prices, the first part of the empirical analysis evaluates the response of PP to MP and MAPP innovation in CEE. The second part examined the domestic spill over effects of the MP and MAPP shock on the industrial sector in CEE. In order to have a parsimonious model, the variables will be added to the PVAR model one at a time. The final part employed a machine learning algorithm to predict the macroeconomic indicators in CEE. Graphical evidence in figure 36 showed that when the policy rate interest rate was tightened, cost of mortgages increased which eventually culminated into a fall in demand for residential housing which depressed PP. On the other hand, although credit to GDP increased following an expansive shock to MAPP, bank lending for house purchase surprisingly decreased leading to a fall in PP in CEE. This disproves Tillmann (2015), Vandenbussche et al. (2012) among others. As an altenative to the IRFs, the structural analysis was conducted via FEVD. Results in table 9 showed that in the fifth quarter, whilst the MP shock explained 3 percent fluctuation in PP, the MAPP shock accounted for 21 percent variability.

The analysis continued by evaluating the domestic spill overs of MP and MAPP innovations on the Man_Sector and M&Q_sectors in CEE. The figure 37 indicates that the monetary tightening which decreased investment spending and aggregate demand had a negative impact on production in Man_Sector in CEE[26]. The MAPP expansion which triggered a hike in credit growth did not stimulate production in Man_Sector in CEE. The FEVD showed that a shock to MP accounted for 8 percent fluctuations in production in Man_Sector whilst the MAPP shock explained 6 percent variability (see table 10). Results shown in figure 38 indicates that a policy rate hike had a negative impact on production in M&Q_sector but the impact is muted. The MAPP shock on the other hand led to a fall in production in M&Q_sectors but the impact was also not significant. Evidence presented in table 11 indictaes that MP impulse explained 8 percent variation in production in M&Q_sectors whilst the MAPP shock accounts for 7 percent fluctuation.

Figure 36:Impulse Response for Property Prices



Note: The vertical axes measure the response of property prices to MP and MAPP shocks whereas the horizontal axes measure the quarterly horizon. The solid black line represents the orthogonal IRFs whilst the grey area shows the 90 percent confidence band which was generated with 500 Monte Carlo replications.

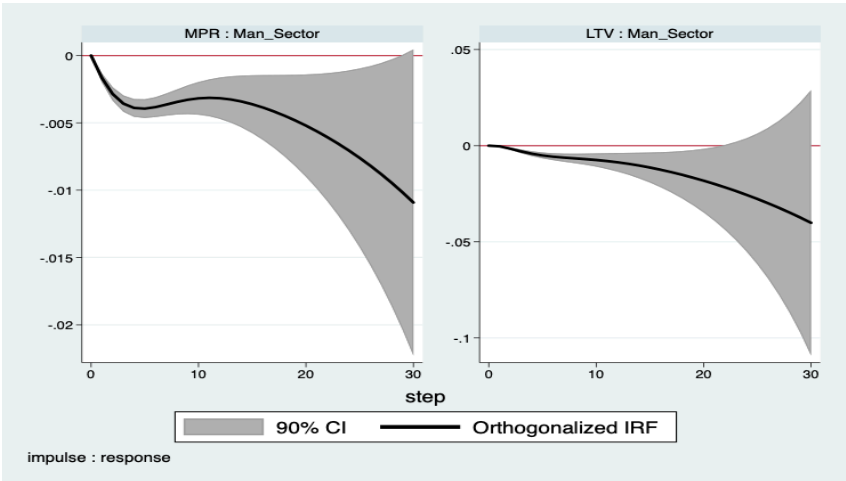
[26] Given that RGDP fell to the interest rate tightening, this result was expected.

Table 9: Variance Decomposition for Property Prices

variable	MP Shock	MAPP Shock
PP	0.03	0.21

Note: The table shows the effect of MP and MAPP shock on property prices in the fifth quarter. The MPR represents the MP shock whilst the LTV represents the MAPP shock, PP = residential property prices.

Figure 37: Impulse Response for Production in Manufacturing



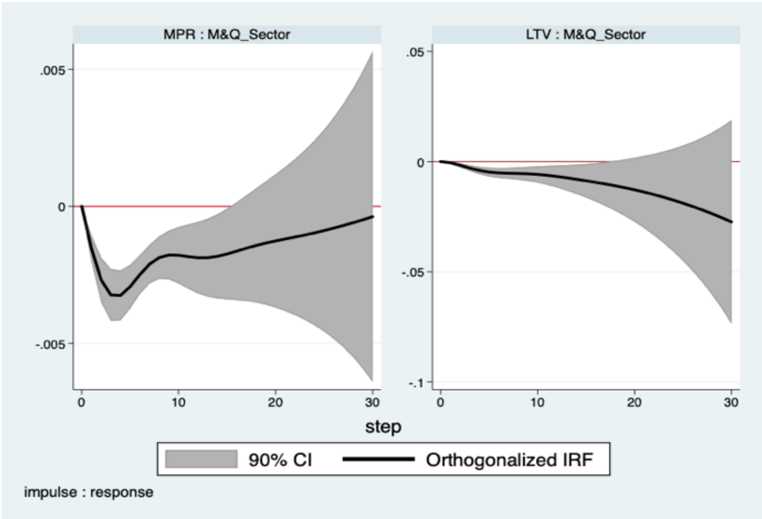
Note: The vertical axes measure the response of production in manufacturing to MP and MAPP shocks whereas the horizontal axes measure the quarterly horizon. The solid black line represents the orthogonal IRFs whilst the grey area shows the 90 percent confidence band which was generated with 500 Monte Carlo replications.

Table 10: Variance Decomposition for Production in Manufacturing

Variable	**MP Shock**	**MAPP Shock**
Man_Sector	0.08	0.06

Note: The table shows the effect of MP and MAPP shock on manufacturing sector in the fifth quarter. The MPR represents the MP shock whilst the LTV represents the MAPP shock.

Figure 38: Impulse Response for Production in Mining and Quarry



Note: The vertical axes measure the response of production in mining and quarry to MP and MPP shocks whereas the horizontal axes measure the quarterly horizon.

Table 11: Variance Decomposition for Production in Mining and Quarry

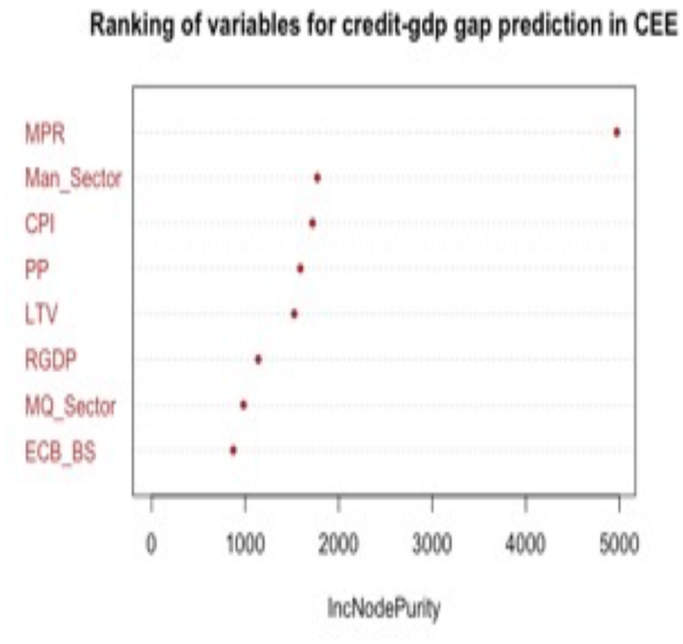
Variable	MP Shock	MAPP Shock
M&Q_Sector	0.08	0.07

Note: The table shows the effect of MP and MAPP shock on mining and quarry in the fifth quarter. The MPR represents the MP shock whilst the LTV represents the MAPP shock

3.6.3 Predicting the Macroeconomy of CEE via Random Forest

The empirical analysis was taken to the territories of prediction where machine learning methods are employed. The idea of the RF algorithm is to find a prediction function that will predict the response variables that is, the macroeconomic indicators. Using a dot chart, the study uses RF to rank feature variables that are important in predicting the three macroeconomic indicators in CEE. Findings are presented as follows. The dot chart in figure 39 indicates that the MPR is the most important predictor of credit_GDP in CEE. In terms of feature variable usage, the LTV had the highest usage, that is 1294 times by the RF in the credit_GDP equation (see table 12). In figure 40, production in M&Q_sector is the most important variable to predict RGDP in CEE. Findings in table 13 suggest that in the RGDP equation, CPI had the highest usage of 1440 in the RF. Evidence presented in figure 41 suggest that in the price equation, ECB_BS is the most important feature variable to predict CPI in CEE. The MPR and production in M&Q_sector had the usage of 1228 in the CPI equation (see table 14).

Figure 39: Dot Chart for Credit to GDP Equation



Source: Author’s calculation

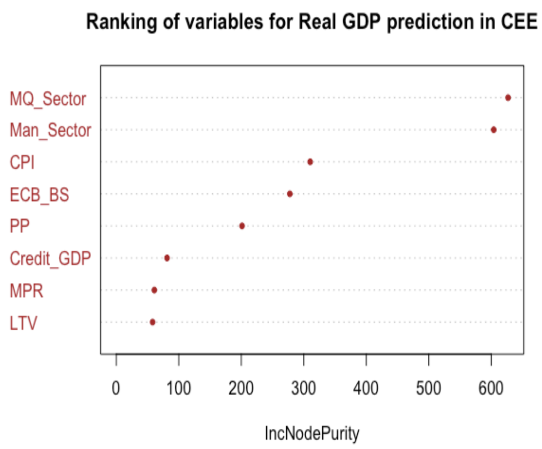
Table 12: Usage of Feature Variables in the Credit_GDP Equation

Variables	Frequency
MPR	1094

Man_Sector	1062
LTV	1294
CPI	956
PP	1191
M&Q_Sector	1199
RGDP	556
ECB_BS	1128

Note: The table shows the number of times the feature variables were used in the random forest in predicting credit_GDP in CEE.

Figure 40: Dot chart for the Real GDP Equation



Source: Author's calculation

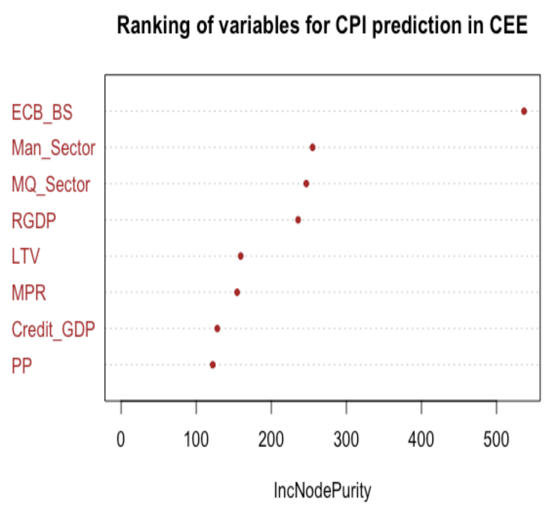
Table 13: Usage of Feature Variables in the RGDP Equation

Variables	Frequency
M&Q_Sector	1198
Man_Sector	1009
ECB_BS	1095

CPI	1440
PP	1157
MPR	1400
LTV	390
Credit_GDP	761

Note: The table shows the number of times the feature variables were used in the random forest in predicting RGDP in CEE.

Figure 41: Dot chart for the Consumer Prices Equation



Source: Author's calculation

Table 14: Usage of Feature Variables in the CPI Equation

Variables	Frequency
ECB_BS	1186
Man_Sector	1085

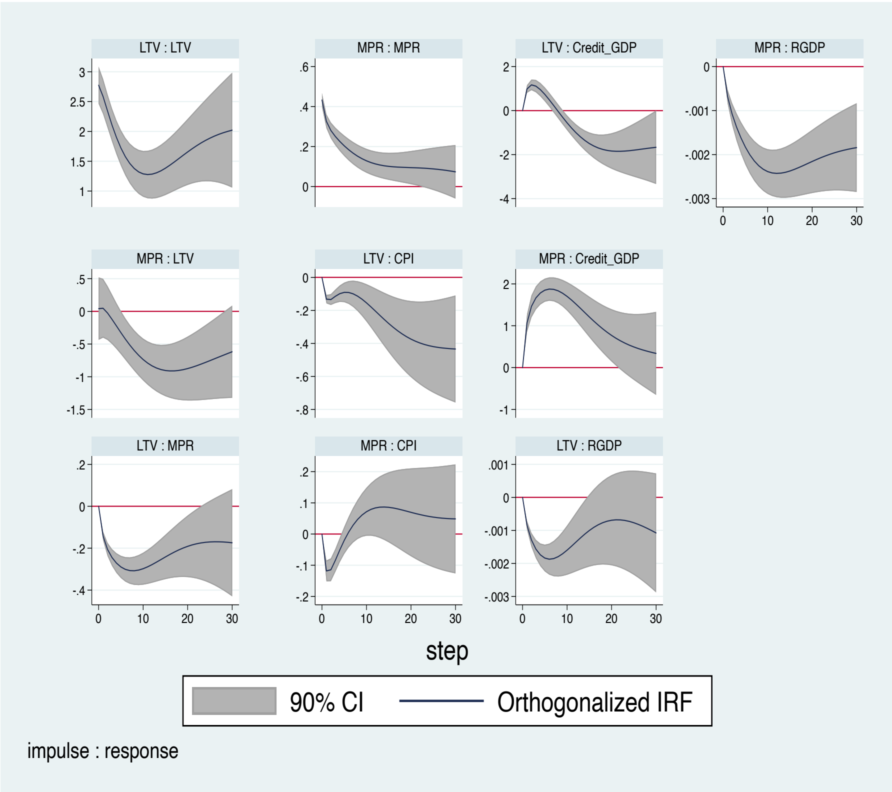
RGDP	1092
M&Q_Sector	1228
MPR	1228
LTV	1097
Credit_GDP	585
PP	995

Note: The table shows the number of times the feature variables were used in the random forest in predicting CPI in CEE.

3.7 Robustness Analysis

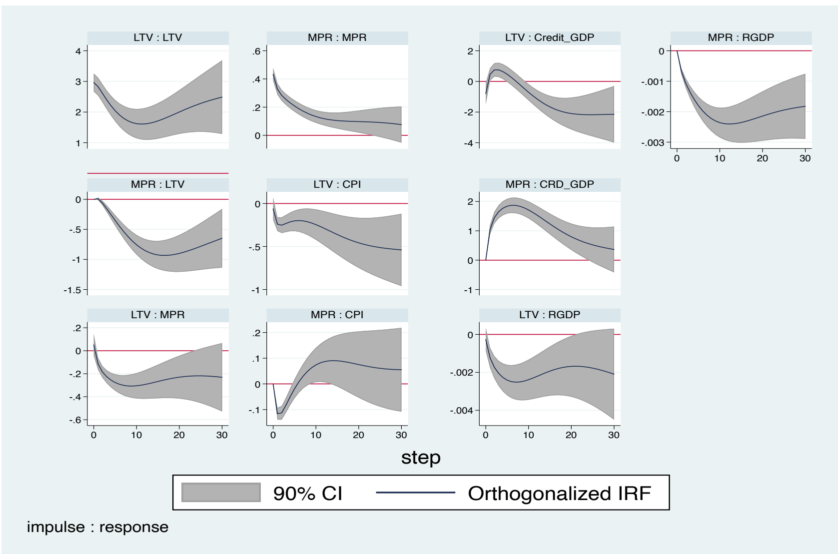
To ensure that results from IRFs are invariant to various specifications of the baseline model, the paper conducts several robustness analyses. In the first robustness check, the MPR is assumed to be exogenous to the LTV hence it was ordered prior to the LTV. The figure 42 corroborates the baseline model that is, the contractionary MP shock led to an increase in MPR whereas an expansionary MAPP fuelled an upward pressure on LTV. The policy rate hike (high lending cost) reduced investment expenditure which triggered a fall in RGDP and prices in CEE. The increase in LTV expectedly increase credit to GDP in CEE. In the second robustness exercise in figure 43, the LTV is assumed to the exogenous to all other variables in the PVAR system, hence it was order prior to all other variables. That is shocks to LTV affects itself and all other variables order after it. Findings are generally consistent with the benchmark model. The final robustness exercise employed a dummy-type macroprudential policy tool in place of the average limit on LTV. This dummy-type index takes a value of 1 if it’s a macroprudential tightening and 0 if otherwise. Findings as shown in figure 44 is also consistent with the baseline model.

Figure 42: Impulse Response to MP and MAPP Shock (Robustness Check 1)



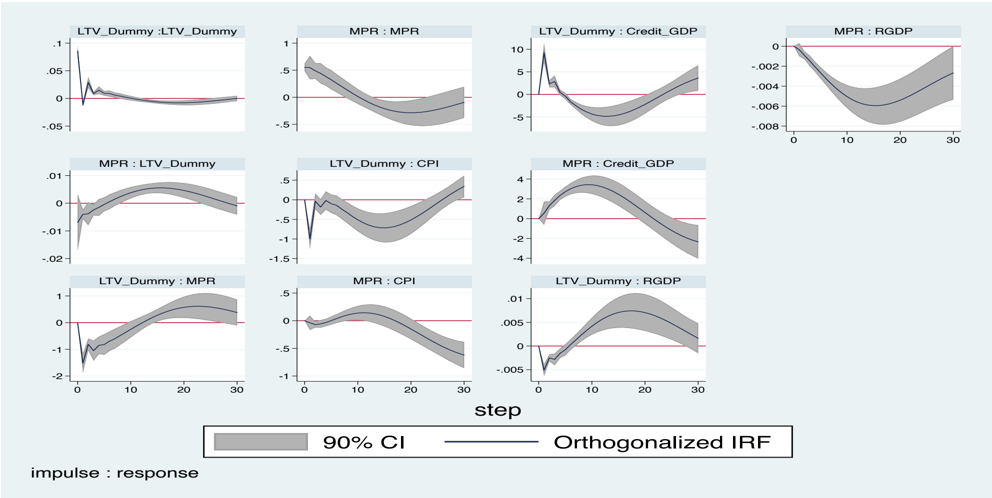
Note: The vertical axes measure the response of the dependent variables to MP and MAPP shocks whereas the horizontal axes measure the quarterly horizon. The solid black line represents the orthogonal IRFs whilst the grey area shows the 90 percent confidence band which was generated with 500 Monte Carlo replications.

Figure 43: Impulse Response to MP and MAPP Shock (Robustness Check 2)



Note: The vertical axes measure the response of the dependent variables to MP and MPP shocks whereas the horizontal axes measure the quarterly horizon. The solid black line represents the orthogonal IRFs whilst the grey area shows the confidence band which was generated with 500 Monte Carlo replications.

Figure 44: Impulse Response to MP and MAPP Shock (Robustness Check 3)



Note: The vertical axes measure the response of the dependent variables to MP and MPP shocks whereas the horizontal axes measure the quarterly horizon. The solid black line represents the orthogonal IRFs whilst the grey area shows the confidence band which was generated with 500 Monte Carlo replications.

LTV_Dummy = dummy-type indicators for loan to value ratio

4. Concluding Remarks

The study used data from 2008q1 to 2019q1 to evaluate the effect of monetary policy (MP) and macroprudential policy (MAPP) on the macroeconomy of Central and Eastern Europe (CEE). Because the paper's aim is to examine the impact of two policy instruments, the study includes prospective macroeconomic targets for the policy tools. The policy instruments used in this study are the policy interest rate (MPR) and average limit on loan to value ratio (LTV). In terms of macroeconomic indicators, the consumer price index (CPI) and real output (real GDP) represents the target indicators for MP whilst credit to GDP gap will be the indicator for

MAPP. The main empirical analysis was conducted as follows. The study firstly examined the combined impact of MP and MPP impulses on residential property prices (PP) in CEE via a dynamic panel vector autoregressive model (PVAR). Given that the implementation of the policy directives could have unintended consequences for other sectors of the economy, the PVAR model was extended to evaluate the domestic spill over effects of MP and MAPP shocks to the industrial sector in CEE. The final part used random forest to predict the macroeconomic variables in CEE.

The main findings are summarised as follows. The monetary contraction which increased the MPR translates into a fall in investment spending and aggregate demand leading to a downward pressure on RGDP, prices and industrial production in CEE. The interest rate hike which triggered higher mortgage interest rates led to a fall in demand for residential housing which eventually decelerates property prices in CEE. On the other hand, an expansive shock to MAPP increased the LTV leading to a positive impact on credit to GDP gap in CEE. Surprisingly, the upward pressure on credit reduced property prices, RGDP, prices and industrial production in CEE.

Lastly, random forest's feature variable selection method was used to predict the macroeconomic indicators in CEE. Results indicate that the most important predictor of credit to GDP gap in CEE is the MPR. In the RGDP equation, the most important predictor is production in the mining and quarry sector. The euro system balance sheet variable ranked highest in predicting CPI in CEE.

Future areas of research should consider the distributional effects of these two policy levers on household income and wealth as well as employment groups in the euro area.

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