Università degli Studi di Cagliari

PhD in Economics and Business Sciences
Cycle XXX

Three essays on the effects of unconventional monetary policy

Scientific Disciplinary Sector:
SECS-P/01

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Final exam. Academic Year 2016 – 2017
Thesis defence: March 2018 Session

UNIVERSITÀ DEGLI STUDI DI CAGLIARI

PH.D. THESIS

Three essays on the effects of unconventional monetary policy

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Acknowledgements

There are many people I would like to thank for their help and support during my three PhD years.

First of all, my research supervisor prof. Paolo Mattana, without whom this thesis would literally not even exist. He has been always available for suggestions, help and encouragement that have been fundamental for the realisation of this thesis and for both my academic and human growth.

Besides him, I cannot forget to thank all the professors and researchers of the department of Economics in Cagliari.

A special mention goes for my colleagues both in Cagliari and at the University of Essex, where I spent an amazing year as a visiting student that I will keep forever in my heart. Among them, I want to thank Tiziana Medda, Stefania Marica, Davide Eltrudis, Alejandra Vásquez, Vahid Ghasemi and Shynar Shaikh for their contribution that goes well beyond the academic sphere.

A thought goes of course to my family: my parents, my sisters Rossella and Alice and also my grandparents, two of whom passed away during the PhD.

Finally, I am very grateful to Elton Beqiraj for his huge help on the development of the last chapter.

Contents

Introduction

We propose three essays on the evaluation of the recent measures undertaken by many central banks that go under the name of unconventional monetary policy. In particular, we focus on Large Scale Asset Purchases (LSAP), often referred also as Quantitative easing (QE), texploring the so called portfolio rebalance channel of transmission, that exploits the imperfect substitutability of financial assets and affects the economy through the longer term interest rates.

The thesis is structured in three chapters. The first chapter presents a review of the main works that try to assess the effects of unconventional policies both from an empirical and a theoretical point of view. In particular, in the first part we describe the main contributions to the literature that make use of the VAR methodology, emphasizing the different approaches used and the results obtained, classified by geographical area. In the second part of the chapter we turn our attention to theoretical models and describe the main DSGE built in the literature that include the possibility for the central bank to affect the economy by means of purchases of securities, beside or instead of conducting monetary policy in a traditional way controlling the policy rates.

In the second chapter, we assess the effects of Large Scale Asset Purchases (LSAP) on the real economy in the euro area by estimating a Structural Vector Autoregression (SVAR) model. We use a recent panel technique developed by Pedroni (2014) that allows us to take into account heterogeneity among members, disentangling shocks that are specific to each member from shocks that are "common" to all members. Our data sample consists of monthly observations for 18 countries for the period from January 2010 to March 2017. Given the difficulty to find an appropriate measure to proxy the central bank's interventions, we follow Kapetanios et al. (2012) and use the change in the long term rates on sovereign bonds. The structural shocks are identified by means of sign restrictions.

In the third chapter, we develop a DSGE model with a banking sector and recursive preferences. We base our work on the framework of Ellison and Tischbirek (2014) that allows for a "preferred habitat" channel and for central bank purchases of assets with different maturities. We explore the demand side of the transmission mechanism by introducing recursive preferences à la Epstein-Zin. Disentangling the parameter that governs the intertemporal elasticity of substitution from the one that rules risk aversion, we are able to show how the responses of the real variables to a purchase of long term bonds by the central bank vary as the two parameter change.

Chapter 1

The effects of Quantitative Easing: a survey of the recent literature

1.1 Introduction

After the Great Recession, many economies have faced a prolonged period of low inflation and output growth. Central banks have quickly responded by lowering the key policy rate, until it reached the so called Zero Lower Bound. The necessity of a further monetary stimulus has forced authorities to look for alternative measures to undertake. These are usually referred as "unconventional" monetary policy measures, in contrast to the "conventional" policy consisting in the traditional manipulation of the official interest rates, and include the purchase of large quantities of assets (Quantitative Easing and Credit Easing) and different types of communications and announcements in order to affect expectations about economic fundamentals and the future conduct of monetary policy (Forward Guidance).

The first central bank to undertake Large Scale Asset Purchases (henceforth, LSAP) was the Bank of Japan in the early 2000s, followed, after the financial crisis, by many others, included the Federal Reserve, the Bank of England and the European Central Bank.[1]

All these types of interventions are believed to affect the economy in a number a ways through several channels. Broadly, three channels of transmission have been identified: a *portfolio rebalancing channel*, that exploits imperfect substitutability of

[1] We refer to Fawley and Neely (2013) for a detailed description of the measures undertaken in those countries.

assets and allows the authorities to ease credit access, a *signalling channel*, that works through the "signals" that the central bank transmits to the economy about future monetary policy and economic conditions, and a *liquidity channel*, generated by the liquidity injected in the system by the monetary authority.

A growing part of literature has tried to evaluate the effects of those policies. Most of this literature has focused on the effects on financial markets[2], while fewer papers have concentrated on the effects on the real economy, given the difficulties of finding appropriate methodologies and measures and the lack of sufficiently large series of data, since economic data usually have quarterly or monthly frequency.

The aim of this chapter is therefore to provide an overview of the different works in the literature that try to evaluate the effects of unconventional monetary policy on the real economy. We structure the paper in two parts: in the first, we focus on the empirical literature that relies on the Vector Autoregression (VAR) methodology, while in the second part we concentrate on the theoretical literature and, in particular, on models of the DSGE (Dynamic Stochastic General Equilibrium) family.[3]

1.2 Empirical literature

Most of the empirical literature on the evaluation of the effects of LSAP on the real economy relies on the VAR methodology, an instrument that is often used also in order to assess the effects of conventional monetary policy. Typically, a VAR is a system of equations in which all the variables are treated as endogenous and, in each equation, every variable is regressed on its own lags and the lags of the other variables. Formally:

$$Y_t A = a + Y_{t-1} B_1 + ... + Y_{t-p} B_p + \mu_t \tag{1.1}$$

[2]We refer to Joyce et al. (2012) and Bhattarai and Neely (2016) for a review of the literature on the impact of unconventional policy on financial markets.

[3]A third, less followed, way, pointed out by Kimura and Nakajima (2013), consists in estimating the impact of LSAP on financial variables and then "plug" the results into macroeconomic models to measure the impact on real variables. We do not cover those works in this survey.

where the suffix t denotes time, a is a vector of constants, Y is a vector of variables, $B_1, ..., B_p$ and A are matrices of coefficients and μ is a vector of error terms. The expression in equation (1.1) is referred as reduced form of a VAR, in contrast to the so called structural form, in which the error terms are orthogonal to each other. The structural form is obtained from the estimated reduced form premultipliying the system in equation (1.1) by the matrix of contemporaneous correlations A^{-1}, obtaining:

$$Y_t = aA^{-1} + Y_{t-1}B_1A^{-1} + ... + Y_{t-p}B_pA^{-1} + \mu_tA^{-1} \tag{1.2}$$

and:

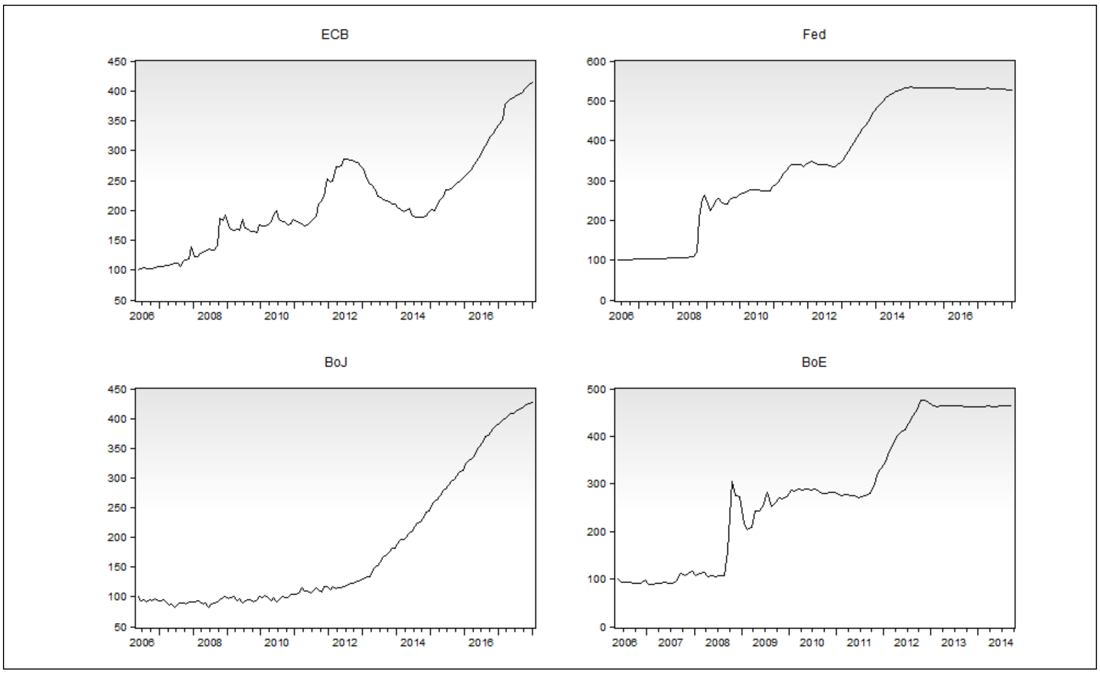
$$Y_t = b + Y_{t-1}F_1 + ... + Y_{t-p}F_p + \epsilon_t \tag{1.3}$$

Where $F_1 = B_1A^{-1}$, $F_p = B_pA^{-1}$, $BB = aA^{-1}$ and $\epsilon_t = \mu_tA^{-1}$. Typically, the problem in retrieving the structural form of the system is given by the estimation (identification) of the matrix A^{-1}. This is usually done by imposing a set of restrictions driven by the economic theory on the A matrix, and allows to retrieve the responses of each variable to the identified shocks in the model.

VARs have been commonly used for evaluating conventional monetary policy. A minimal example can be set by including three variables in the specification: output, prices and the nominal interest rate controlled by the central bank. This allows to directly interpret the three shocks in the model as an aggregate demand shock, a cost-push shock and a monetary policy shock, making it possible to evaluate the effects of the latter on the real variables in the system.

Unlike the conventional case, where the policy variable is the official interest rate directly controlled by the central bank, the choice of the variable that can quantify the economic stimulus provided by unconventional measures is less straightforward. Because of the short history of those measures, and because of the typically low frequency of macroeconomic data, there are not many works that shed light on the real effects of LSAP. In this section, we provide an overview of the main pieces of literature on the topic. We focus on four countries (euro area, US, UK and Japan) that have made a large use of unconventional measures in the recent

FIGURE 1.1: Central banks' total assets



Sources: ECB, Federal Reserve, Bank of Japan and Bank of England.

years, as figure 1.1, that shows the expansion of their central banks' balance sheet after 2007, testifies. We present a brief description of the different measures undertaken by the central banks, emphasising both the different approaches followed and the results obtained.

1.2.1 Euro area

The ECB started to undertake unconventional policy measures in 2009, with the Covered Bond Purchase Programme (CBPP), aimed at supporting those banks hit by the financial crisis with the purchase of €60 billion assets. A second round of purchases, often referred as CBPP2 and accounting for €40 billion, was implemented in 2011. A third programme, announced in 2010 under the name of Securities Markets Programme (SMS), consisted in the purchase of public and private securities. Moreover, starting from 2011, the ECB carried out two programmes of Longer Term Refinancing Operations (LTRO), aimed at providing liquidity to commercial banks through direct lending operations.

All these unconventional facilities were mosty directed to inject liquidity in the financial system and encourage lending, while QE in strict sense started only in

September 2014, with the Asset Purchase Programme (APP), consisting of four sub-programmes for a total of €60 billion[4] of monthly purchases: a Corporate Sector Purchase Programme (CSPP), an Asset-Backed Securities Purchase Programme (ABSPP), a Public Sector Purchase Programme (PSPP, from March 2015) and a third round of the already mentioned Covered Bond Purchase Programme (CBPP3).

In the literature, there are not many works that tried to evaluate the effects of those measures on the real economy. The majority of them concentrate on the first round of unconventional measures taken by the ECB. For instance, Lenza et al. (2010), in an early work, use a Bayesian VAR (B-VAR) model to evaluate the non-standard liquidity provision measures taken by the ECB in 2009 and 2010. They estimate a large model with 32 variables using the spread between money market rates and the policy rate as measure of policy and find a relevant role for those policy actions in tackling the effects of the financial crisis, but only with a lag.

Peersman (2011) uses the monetary base as a measure of unconventional policy. He estimates a VAR for the euro area using monthly data for the period between 1999 and 2009 and including bank credit and interest rate on credit as variables, since the ECB unconventional measures undertaken during the period considered included mainly direct lending operations to the banking system. By means of a mixture of sign and zero restrictions, three shocks are identified: a credit supply shock, a conventional policy shock and an unconventional policy shock. The sign restrictions are imposed for the third and fourth month for the credit shock and for the first five months for the other two. The author finds that output and prices respond to the unconventional shock, measured by an increase in the monetary base of about 2 percent, only after one year and remain significant for more than 24 months. In the robustness analysis, several other ECB balance sheet items are used to account for unconventional policy, such as bank reserves, assets used for liquidity provision operations and the total size of the central bank's balance sheet.

The second round of QE has been instead analysed by Gambetti and Musso (2017), who estimate a time varying parameter VAR (TVP-VAR) for the period between 2009 and 2016. The QE variable is represented by the securities purchased for

[4]The monthly amount of purchases was recalibrated to €80 billion assets in April 2016.

monetary policy purposes by the ECB, but also the long term government bond yields are included in the model. The identification of the shocks is obtained by means of sign and magnitude restrictions, imposed for the first four quarters. This is done because of the nature of the programmes of the ECB, that announced the monthly purchase of €60 billion assets in March 2015, making such purchases not fully unexpected and, hence, not treatable as exogenous shocks in a SVAR environment. The set of restrictions imposed allows the authors to identify one specific shock that coincide with the initial asset purchase announcement in March 2015. A significant impact, lasting more than five years, is found on inflation, while output responds less, with a duration of about two years. A positive effect is found, even if the quantification is considered very uncertain because of the impact of the financial crisis.

1.2.2 United States

The Federal Reserve has implemented so far three programmes of asset purchases, commonly referred as QE1, QE2 and QE3. The QE1 programme was implemented between 2008 and 2009 and intended to support the housing credit market through the purchase of a total amount of about $2 trillion assets, mainly mortgage-backed securities (MBS), government-sponsored enterprise (GSE) and Treasury securities. QE1 was generally considered more effective in influencing the real economy than the second programme, QE2, implemented between 2010 and 2011, and targeting a general lowering of longer term interest rates and a rise in in the inflation with the purchase of further $600 billion Treasuries. After changing the composition of its portfolio with the maturity extension programme (MEP), through which the Fed sold short term Treasuries and bought longer term securities instead, a third round of purchases (QE3) was implemented in September 2012, consisting in the purchase of $85 billion in Treasuries and MBS.

Among the papers that have tried to evaluate the effects of those policies on the real economy, Baumsteier and Benati (2012) use a TVP-VAR to evaluate the effects of a compression in the spread between the long term government bond yields and the policy rate, induced by QE. The analysis is performed for both US and UK, employing quarterly data for a large sample that goes from from 1954 to 2011. A set of zero and sign restrictions is used to identify the shocks, such that a negative shock to the long term yields has no effects on the short term rate but a positive effect on the real variables. A strong positive effect on both output and inflation is found, while, by means of a counterfactual analysis, the authors conclude that without unconventional policy both the US and the UK economy would have faced a high risk of deflation in 2009.

Chung et al. (2011) use several types of models for evaluating QE in the US, among which simulated macroeconomic models of the DSGE and the FRB/US type, a GARCH bivariate model and a TVP-VAR. A significant role for unconventional policy is found, with an increase of about 3 percent of GDP growth, 1 percent of inflation and 1.5 percent of employment.

Kimura and Nakajima (2016) estimate a TVP-VAR for the period from 1982 to 2012, allowing for a shift between a conventional and an unconventional policy regime, being the latter the period between 2001 and 2006. Their baseline specification includes five variables: inflation, a measure of output gap, bank reserves, short term and long term interest rates, while the identification of the shocks is achieved by means of a set of zero restrictions for each regime.

1.2.3 United Kingdom

Three round of purchases have been carried out by the Bank of England as well. The first started in March 2009, with the purchase of £200 billion assets, the second in October 2011 (£125 billion) and the third in July 2012 (£50 billion). Most of the assets bought were gilts and, to a lesser extent, commercial paper and corporate bonds.

We mention, among the related empirical works, Kapetanios et al. (2012), who use the term spread between the long term and the short term government bond yields, under the idea that QE reduced the spread of about 100 basis points (Joyce et al., 2011). They conduct a counterfactual analysis based on three different models: a B-VAR, a Markow-switching VAR and a TVP-VAR. The models are estimated using different samples and data frequencies. Zero restrictions and sign restrictions are used in order to identify four shocks: a demand shock, a supply shock, a conventional policy shock and a yield spread shock. In response to a 100 basis points shock to the yield spread, the authors estimate an average effect that ranges from 1.4 and 3.6 percent for the output and from 1.2 and 2.6 percent for the inflation, with considerable differences in the magnitude and the timing effects in the three models considered.

Baumsteier and Benati (2012), as already mentioned, find a positive impact on output and prices for both the US and the UK. Bridges and Thomas (2012) estimate the impact of QE on the money supply and then set up a SVAR with eight variables (broad money, deposit rates, short term rates, long term rates, equity prices, exchange rate, GDP and CPI inflation) for the period between 1964 to 2007. A set of zero restrictions is imposed to identify the shocks, and a positive impact is found on both inflation (about 1 percent) and output (about 2 percent).

1.2.4 Japan

The Bank of Japan (BoJ) was the first central bank to undertake unconventional monetary policy measurees, starting its Quantitative Easing Policy (QEP) in 2001. The programme aimed at boosting the current account balances held by financial institutions at the BoJ and at providing liquidity to banks by means of the purchase of Japanese government bonds (JGB) and other financial assets.The amount of monthly purchases was set to ¥400 billion per month and then increased to ¥1.2 trillion in October 2002, until the end of the programme in 2006. From March 2006, also asset backet securities were included in the purchases, in order to support that specific market. The effects of this first round of QE are quite debated in the literature, since inflation remained low during the period considered but a positive effect on the real economy has been considered by several authors.

After the financial crisis, the BoJ started a second round of interventions to support the financial system, intended to inject liquidity in the economy and facilitate lending. [5] In October 2010, the BoJ started a new programme of asset purchases, called Quantitative and Qualitative easing (QQE), in order to achieve an inflation level of 2 percent by increasing the monetary base at a pace of ¥60 trillion per year,

[5] See Hausken and Ncube (2013) for a summary of the post 2008 interventions.

later recalibrated up to ¥80 trillion and enhanced with the introduction of negative interest rates.

Among the papers, we mention Schenkelberg and Watzka (2011) who estimate a four-variable SVAR for the period 1995-2010, including both long term interest rates and reserves. After identifying the shocks by sign restrictions, a positive effect on output is found, while inflation does not seem to respond significantly.

Tachibana (2015) uses bank reserves as well as a measure of QE. He includes the term spread in the model and assumes that the QE shock, identified by a combination of sign, magnitude and zero restrictions, has a negative impact on the spread, unlike many other papers that leave the response of the long term rates unrestricted. A positive but not long lasting response of both output and inflation is found, but output responds immediately while inflation only with a lag.

1.2.5 Panel level analyses

Gambacorta et al. (2014) estimate a SVAR over a panel of eight countries[6] for the period from January 2008 to June 2011. In order to avoid biased or inconsistent estimates, they use the mean group estimator developed by Pesaran and Smith (1999), that estimates the equations separately for each unit and considers the average of the results, instead of pooling the data and estimating common coefficients for all countries. The authors use, as a proxy for unconventional policy, the total assets in the central bank balance sheet and add, as a financial variable, the stock market volatility index (VIX) of each country. This approach has the drawback of not distinguishing among different types of asset purchases, including private assets, public assets and also simple open market operations. This is the reason why the authors do not include a conventional monetary policy instrument, considering the purchase of assets as the only instrument used by the central bank and supposing that the official interest rate is stuck at the zero lower bound. The inclusion of a financial index is common in the literature in order to take into account responses of the economy to financial shocks. The identification of the shocks is achieved by means of sign restrictions imposed on the IRFs in the first

[6] Euro Area, Canada, Japan, Norway, Sweden, Switzerland, UK and USA.

two months. In response to a shock to the central bank assets of about 3 percent, they find a large effect on output (peak of 10 percent) [7], that lasts about 18 months, and a weaker response of inflation (peak of 4 percent), significant for 12 months. Another major contribution to the literature is given by Bhattarai et al. (2015), who estimate the spillover effects of QE on a panel of emerging economies.[8] The analysis is divided in two stages: in the first, a B-VAR is estimated for the US using a sample from 2008 and 2014, employing the amount of securities held outright by the Fed in its balance sheet to proxy for unconventional policy, and including both long term and short term government bond yields as well as a measure of financial stability. The identification of the shocks is achieved by means of short run restrictions. In the second stage, a panel SVAR is estimated for the above mentioned emerging countries. The authors find that a QE shock has a positive effects on output, inflation and stock prices and a negative impact on long term rates.

1.3 Theoretical literature

In order to evaluate the positive and normative implications of different monetary policy strategies, both academicians and central bankers have relied for years mainly on macroeconomic models that abstract from the presence of a financial sector and that were totally unable to predict and to fight the 2007 financial crisis. The recent events highlighted the necessity of changing the way those models are thought in two ways: considering financial imperfections and their impact on the real economy, and considering the alternative "unconventional" measures undertaken recently by many central banks. The two issues are strictly related as, in order to make unconventional policy measures not neutral to the real economy, financial frictions are often included as well. For this reason, we briefly describe the main ways used in the literature to include financial frictions in DSGE models and then concentrate specifically on those models that consider a role for unconventional policy. In particular, we follow Bhattarai and Neely (2016) in

[7] As a measure of output the authors compute an interpolation of the GDP series with industrial production and retail sale.

[8] Brazil, Chile, Colombia, India, Indonesia, Malaysia, Mexico, Peru, South Africa, South Korea, Taiwan, Thailand, and Turkey.

identifying three ways of including unconventional policy in DSGE models: models that incorporate financial frictions, models that consider the existence of a "preferred habitat" channel and models that expolit the so called "signalling channel" of transmission.

1.3.1 Financial frictions in DSGE models

Even though the idea, due to the Modigliani-Miller (1958) theorem, that its financial structure is not relevant to the economy, macroeconomic models that include a role for credit and financial sector have a long history that dates back to the seminal paper of Bernanke and Gertler (1989). In fact, it is well known that financial markets and credit flows are pro-cyclical and credit tightening counter-cyclical.
In order to include financial imperfections into macroeconomic models, three broad approaches have been used in the literature: the "financial accelerator" mechanism, the "collateral constraint" approach and the inclusion in the models of a financial sector. All the three approaches modify the classical New Keynesian framework introducing some kind of heterogeneity between agents, that makes them willing to interact borrowing and lending money, and some kind of asymmetric information between them. Ex-ante information asymmetries typically generate agency costs that are modelled in the financial accelerator approach and generate an "external finance premium", while ex-post asymmetries are typically modelled in collateral constraint frameworks where an adverse selection problem arises. We will see each of the three approaches more in detail in order to underline the main features and the most important models developed in the literature.
1. *The financial accelerator.* The most common mechanism according to which the effects of macroeconomic shocks are amplified by financial imperfections is referred as the financial accelerator, whose first formulation is due to Bernanke and Gertler (1989). Their model introduces into an overlapping generations framework capital producers that fund their activity through financial contracts. Capital is then used by firms to produce goods that are consumed by households. The financial friction occurs because lenders face a cost [9] to monitor the investment projects taken by the borrowers. Since borrowers finance their projects both with their own wealth and

[9] This "costly state verification" problem is due to Townsend (1979).

debt, a difference between the cost of raising funds externally and internally arises. This is referred in literature as "external finance premium" and it is given by the fact that externally raised funds have to be remunerated more because of the cost in which lenders occur and because of the uncertainty in the outcome of the projects, increased by the fact that borrowers tend to undertake riskier projects when they fund them with a higher amount of external funds. Because of the positive correlation between the borrower net worth and the real activity, a negative shock to output makes net worth fall and hence the premium rise. This causes borrowing to be more difficult, amplifying the fall in investments and production as well, and hence causing a further recession in the following period so that the mechanism keeps on going even for the following generations. In other words, an important result of the model is the persistence of the effects of a shock.

Strictly related to the Bernanke and Gertler (1989) work is the model of Carlstrom and Fuerst (1997), who abandon the overlapping generation framework and extend the results to the case of infinitely lived agents. In particular, they assume that capital producing agents (entrepreneurs) fund their investment I both with debt D and their net worth N, according to the relation $D = I - N$, such that the amount they have to repay the lenders at the end of the period is $(1 + r)(I - N)$. The return of their project is affected by a shock ω, so that the final net profit of the project is $\omega q - (1 + r)(I - N)$. Since ω is not observable to the lenders even after its realization, they have to pay a monitoring cost to know its value. If the shock is not too big (under a certain threshold $\bar{\omega}$) they are able to complete their project and pay back the lenders. Above the threshold $\bar{\omega}$, the entrepreneur goes bankrupt and is able to repay only an amount ω_i to the lenders (netted of the monitoring cost). In this model the financial accelerator mechanism still works: a negative shock decreases entrepreneurs' net worth and hence investment, the level of capital and therefore output and, again, net worth in the following period, activating the mechanism again and causing persistence in the effects of the shock.

The model often taken as a benchmark of the financial accelerator approch is by Bernanke, Gertler and Gilchrist (1999), that works not differently from the above models, but introducing several innovations into the framework among which price stickiness and heterogeneity among borrowers. Moreover, they add increasing marginal costs in the capital production that create an amplification effect in the propagation of financial shocks.

2. *The collateral constraint approach.* The approach taken by Kyiotaki and Moore (1997) differs from the above models because frictions are given not by agency costs but by collateral constraints borrowers have to face. In other words, it is not the external premium that makes borrowers want to borrow more or less but it is their creditworthiness that matters. In a world where contracts are incomplete, lenders can secure their loans only by means of collaterals, that is assets that are transferred to the lender in case of bankruptcy. If loans need to be fully collateralised, a shock that hits the collateral market produces effects not only on the net worth of firms but also on their capability of raising money through debt. In their model there exist two kinds of agents: "farmers" and "gatherers", where the former borrow money from the latter using land, which is a production input as well, as a collateral. A negative shock to the price of the land produces therefore an amplified effect: it reduces farmers' net worth and it reduces demand for assets that subsequently further shrinks net worth.

Among the extensions of the Kyiotaki and Moore (1997) model, it can be mentioned Iacoviello (2005), who considers the case in which the collateral is not the land but housing and introduces nominal contracts instead of real contracts, and Kocherlakota (2000), who makes the hypothesis that negative and positive shocks do not have symmetric effects on the production choices of firms, an idea lately examined also by Mendoza (2010) and Jermann and Quadrini (2012).

3. *Including financial sectors into the models.* Another branch of DSGE models with financial frictions is the one that includes financial intermediaries inside the models. In fact, the previous models focused more on the demand side of credit market, and imperfections were given by incompleteness of contracts, but no specific role was designed for banks and financial entities. Before the crisis the only paper moving in that direction was by Christiano, Motto, and Rostagno (2003), whose intent was to evaluate different monetary policy hypothesis during the Great Depression. The model was built under a agency cost framework like in Bernanke, Gertler and Gilchrist (1999), but with a financial sector that borrows deposits from households and lends money to firms. Goodfriend and McCallum

(2007) build a model with financial intermediaries and different types of interest rates. Banks choose their optimal amount of loans, given their collateral and their monitoring costs, in a similar way to what non-financial firms do. In a similar fashion, Curdia and Woodford (2009) build a model with a banking sector and two kinds of consumers (borrowers and lenders), where the intermediation of the banking system and the intermediation cost they face causes a spread between the rate at which they lend and the rate at which they borrow. The idea is therefore similar to the verification cost models seen earlier, but in this case it is the important role the banking sector plays that causes the friction. In a following extension of their model, Curdia and Woodford (2010) demonstrate monetary policy should not simply consider short term interest rate, modifying the standard Taylor rule such that it tracks also the credit spread, obtaining a remarkable improvement in efficiency.

Among other contributions to the literature that includes a banking sector in DSGE models, we can mention Gerali et al. (2010), who abandon the idea of perfect competition among banks and hypothesise banks have some power in setting interest rates.

A new strand of literature tries to include the interbank market into the models. Among them there are the works by Dib (2010), Hilberg and Hollmayr (2011) and De Walque et al. (2010). What they do is to divide banks in several categories (for instance Dib (2010) distinguishes commercial banks from investment banks) and model them such that they interact with the central bank.

Inside this macrocategory it is included a branch of the literature more strictly related to the recent monetary policy developments, that tries to cope with the unconventional policy measures taken recently by central banks and the zero lower bound issue, that we analyse in the next section.

1.3.2 Unconventional policy in DSGE models

We identify three main methods of introducing unconventional monetary policy into DSGE models. The most followed way is the inclusion of financial frictions, that generate a spread between the interest rates in the economy (usually between the lending rate and the deposit rate) and in which the central bank intervenes injecting money into the economy through some type of credit policy. The second method we describe exploits the inclusion of a so called "preferred habitat" channel, in which agents have preferences over different maturities but with a certain degree of substitutability, that allows the central bank to affect the real economy purchasing assets, usually in the form of long term bonds. The last method exploits expectations: when the central bank conducts unconventional monetary policy, it affects the agents' expectations about future policy and the future development of inflation and output.

Models with financial frictions

Curdia and Woodford (2009) build a DSGE model with a banking sector and several types of financial imperfections, adding the possibility for the central bank balance sheet to have a role in monetary policy. In particular, financial intermediaries collect deposits d_t from households that remunerate at nominal rate i_t^d, and lend to non financial firms loans L_t at nominal rate i_t^b. Also, they determine the amount of reserves m_t the central bank holds, on which they pay a nominal interest i_t^m. In order to generate a spread between the rates, they include two kinds of frictions: the first is due to an exogenous cost of originating loans, while the second is due to the presence of "bad loans", that the borrower does not repay, and the assumption that the intermediary is not able to predict which loans are good and which are bad. Formally, banks choose the amount of deposits according to the relation

$$(1 + i_t^d)d_t = (1 + i_t^b)L_t + (1 + i_t^m)m_t \tag{1.4}$$

Because of the frictions above mentioned, they do not use all the deposits for producing loans or reserves. Some of them are used to compensate the fraction of bad loans $\chi_t(L)$, that is supposed to be known by the bank, and the cost of producing loans, which is given by a function $\Xi_t(L_t, m_t)$. Bank profits Π_t, namely the remaining part of deposits, are distributed as dividends. Profits are then given by

$$\Pi_t = d_t - m_t - L_t - \chi_t(L_t) - \Xi_t(L_t, m_t) \tag{1.5}$$

Profits maximization yields two FOCs that define the spreads between the rates

$$\frac{i_t^b - i_t^d}{1 + i_t^d} = \frac{\partial \Xi_t(L_t, m_t)}{\partial L_t} + \frac{\partial \chi_t(L_t)}{\partial L_t} \tag{1.6}$$

$$\frac{i_t^d - i_t^m}{1 + i_t^d} = -\frac{\partial \Xi_t(L_t, m_t)}{\partial m_t} \tag{1.7}$$

In this context, the central bank chooses the amount of reserves to hold and the rate of interest it pays on them. Then, it lends to the private sector at the same rate i_t^b charged by intermediaries, so that the interest rate is not a central bank's choice variable. In a nutshell, three types of monetary policy actions are allowed in the model: (i) a "conventional" interest rate policy, consisting in setting the policy rate i_t^d, which is also the rate that remunerates government bonds and deposits, according to a standard Taylor rule; (ii) a "reserve supply" policy, in which the central bank chooses the amount of reserves and the relative rate of interest; (iii) a "credit policy", consisting in directly lending funds to the private sector. The authors conclude that the most effective action in normal times is the standard interest rate policy, while the reserve supply policy is considered ineffective under certain conditions. A role for credit policy is found when credit frictions exist in the economy.

The possibility of augmenting the standard Taylor rule for conventional policy with a measure of financial stability, namely a credit spread, or a measure of private credit, is considered using the same framework by Curdia and Woodford (2010), even if the focus of their work is more on the response to financial disturbances than on unconventional policy.

Gertler and Karadi (2011) build a model in which the central bank conducts unconventional policy by directly lending to non financial firms a fraction of the total loans in the economy. In particular, they assume that firms fund their investments in capital through loans they get both from intermediaries and the central bank, so that the following relation holds

$$Q_t K_{t+1} = Q_t S_t \tag{1.8}$$

where K_{t+1} is the amount of capital firms buy from capital producers at price Q_t and S_t is the total amount of loans in the economy, in the form of claims issued by both intermediaries and the central bank at price Q_t. These assumptions allow the authors to simulate a financial crisis, by introducing a stochastic shock to the efficiency of capital, that affects both intermediaries' net worth and firms' capital. When such a shock hits the economy, the central bank chooses to directly lend to firms more. The fraction of loans intermediated by the central bank $S_g t$ is given by

$$Q_t S_g t = \psi_t Q_t S_t \tag{1.9}$$

where the fraction of total loans ψ is determined according to the following Taylor-type rule

$$\psi_t = \bar{\psi} + \nu E_t[(\log R^k_{t+1} - \log R_{t+1}) - (\log \bar{R}^k - \log \bar{R})] \tag{1.10}$$

where $(\log R^k_{t+1} - \log R_{t+1})$ represents the log-spread between the rate of return of loans and the rate of return of deposits, ν is a parameter that determines how sensitive the response of the central bank is to variations in the spread, and variables with a bar denote steady state values.

The authors include in the model a financial friction in the form of a balance sheet constraint that intermediaries face. In particular, in order to avoid that banks can expand their balance sheet indefinitely, it is assumed that, each period, intermediaries can abscond with a fraction λ of their total assets. Households are able to make banks go bankrupt and recover a part of those assets, so that they will keep lending deposits to banks only when the following incentive constraint is satisfied

$$V_{jt} \geq \lambda Q_t S_{jt} \tag{1.11}$$

where V_{jt} denotes the expected terminal wealth of bank j.

The authors find evidence in favor of the effectiveness of a credit policy when the economy is constrained by a zero lower bound in contrasting the effects of a financial crisis.

Gertler and Kiyotaki (2010) build a model with the same frictions and the same credit policy as in Gertler and Karadi (2011), but adding an interbank market and liquidity risk à la Kiyotaki and Moore (2008). The authors assume that there exists a continuum of islands but not every island has investment opportunities in each period. The random probability π_n of having such investment opportunity in each island determines the possibility for the banks of that island of obtaining new capital. Since banks are able to lend only to firms on the same island, they will use the interbank market to borrow to islands with no investment opportunities. The financial friction à la Gertler and Karadi (2011) mentioned above is reinforced by the fact the banks are constrained in obtaining funds not only from households but also from other banks. This is done assuming that banks can divert, of the total assets $Q_t S_t$, only a fraction of interbank borrowing b_t depending on a parameter ω. In formulas, the following relation holds

$$V_{jt} \geq \lambda(Q_t S_t - \omega b_t) \tag{1.12}$$

When $\omega = 1$, the interbank market is frictionless, as other banks can fully recover the assets when a bank goes bankrupt. Conversely, when $\omega = 0$, the interbank market and the deposit market have the same degree of efficiency.

The authors are able to analyse different types of credit policies in their framework. First, they assume that the central bank lends to the private sector at the same rate of bank loans, financing the operations through government debt, remunerated at the same rate of deposits. The second type of policy explored by the authors is the "discount window lending", in which the central bank lends in the interbank market with a comparative advantage with respect to households and other banks in recovering the funds it lends. The third type of policy is represented by equity injections, that are carried out by the central bank at a per unit cost τ. The banks' balance sheet is therefore:

$$Q_t S_t = n_t + b_t + d_t + n_g t \tag{1.13}$$

Where the left hand side represents assets and the right hand side liabilities, namely deposits d_t, borrowings from the interbank market b_t, and equity privately and publicly owned n_t and $n_g t$. After simulating a financial crisis as in Gertler and Karadi (2011), a relevant role for credit policies is found in mitigating its negative effects on output and inflation.

A further extension of the Gertler and Karadi (2011) framework is developed by Foerster (2013), who uses a Markow switching model to evaluate an "exit strategy" from unconventional policies and finds that the best strategy to avoid a deep recession is a gradual exit. A role for expectations about the exit strategy is also found, with a smaller effect in the case of gradual exit strategy.

Models with a preferred habitat or a signalling channel

Vayanos and Vila (2009) and, later, Ellison and Tischbirek (2014), build a model with a "preferred habitat" channel, in which banks collect deposits from households and invest them in both short and long term government bonds. The preferred habitat channel arises because households have preferences about maturities that are incorporated in the "deposit device" bank sell to them. When the central bank conducts unconventional policy, households modify their intertemporal consumption decisions. Since savings tend to yield less, they tend to consume more, causing a boost in economic activity.

Similar preferred habitat models were developed by Curdia, Ferrero and Chen (2012) and Hamilton and Wu (2012).

Beau et al. (2012) build, upon the Iacoviello (2005) framework, an estimated DSGE model for both the euro area and the US. They consider the interactions between monetary policy and macroprudential policy by identifying several regimes, in which the central bank conducts monetary policy taking into account credit variables or directly lends funds to intermediaries.

Bhattarai, Eggertsson, and Gafarov (2015) follow a different approach and abstract from the presence of financial frictions focusing on the "signalling channel" of unconventional policy, that works through expectations about the future official short term interest rate. In their model, the central bank is able to expand its balance sheet size and commit to keep the rates low in the future.

1.4 Conclusions

The recent monetary policy developments in many countries have highlighted the need of evaluating the new measures undertaken by central banks. In this survey of the literature, we indentified two main methods for evaluating unconventional policy: VAR models and DSGE models. We listed the main papers that employ the VAR methodology, classified geographically, with a particular focus on the main methodological issues in the choice of the variables and the identification of the structural shocks. We then turned to DSGE models, trying to give a flavor of the main mechanisms exploited to reproduce the central bank measures and the way they affect the economy in macroeconomic models. We identified several classes of models, broadly following the channel of monetary transmission they consider.

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Chapter 2

The effects of Quantitative Easing in the euro area: A panel SVAR approach

2.1 Introduction

After the global financial crisis, many economies have faced a prolonged period of low economic fundamentals. In particular, in the Euro area, inflation has been considerably below target since 2012, being even close to zero or negative for almost two years and returning above 1 percent only recently. In response to these facts, many central banks drastically cut their policy rates until they reached the zero lower bound (ZLB), denying authorities their main instrument of traditional policy. Among them, the European Central Bank (ECB) gradually cut the benchmark interest rate from 5 percent in 2007 until reaching zero in March 2016.[1]
In order to provide a further stimulus to the economy, many central banks started to engage different interventions, commonly referred as unconventional policy measures, such as liquidity provision and direct lending operations, large scale asset purchases (Quantitative Easing and Credit Easing) and new forms of communications designed to affect expectations about inflation and future monetary policy (Forward Guidance). In particular, the ECB started to undertake non-standard policy measures in 2008 with several direct lending operations that go under the name of Longer Term Refinancing Operations (LTROs) and Targeted

[1]We show the dynamic of inflation and the the official interest rate cuts in Figure 2.1.

Longer Term Refinancing Operations (TLTROs) and several asset purchase programmes. [2]

However, these measures, even if unconventional, are not commonly classified as Quantitative Easing. The implementation of the actual QE dates back to September 2014, with the announcement of the Asset Purchase Programme (APP), consisting in the monthly purchase of €60 billion of private and public securities.[3]

There have been identified several transmission channels through which QE affects the real economy. We focus on the so called *portfolio rebalance channel*, that exploits the imperfect substitutability of financial assets of different maturity. Imperfect substitutability implies that, when the central bank buys a financial asset, the supply of that asset falls, its price increases and its rate of return declines. This makes investors willing to invest in assets that are close substitutes, whose demand rises, making their yields fall as well. This means that the purchase of assets of the central bank does not affect only the market of the purchased assets, but also sectors that are not directly involved in the programme. In other words, the yield curve of a large number of financial assets shifts down, making access to credit easier. Other transmission channels are the *signalling channel*, through which the central bank commits to keep the interest rates low in the future, because otherwise it would face huge losses on the bought assets, and the *liquidity channel*, resulting from the amount of liquidity injected in the economic system.

In this work, we want to analyse the effects of QE measures in the euro area. We do this by means of the Structural Vector Autoregression (SVAR) methodology, estimated on a panel of 18 euro area countries. We follow Kapetanios et al. (2012) in focusing on the *portfolio rebalance channel*, since it operates through the longer term interest rates[4] in the economy, making it easier to find a variable that can proxy the central bank's interventions. We impose sign restrictions for the structuralisation of the shocks and use a recent technique developed by Pedroni (2013) in order to

[2] Covered Bond Purchase Programme (CBPP1 and CBPP2), and Securities Markets Programme (SMP).

[3] The APP includes four programmes: the Corporate Sector Purchase Programme (CSPP), the Asset-Backed Securities Purchase Programme (ABSPP), the Covered Bond Purchase Programme (CBPP3) and, from March 2015, the Public Sector Purchase Programme (PSPP). The total amount of monthly purchases was raised to €80 billion in April 2016.

[4] Note that the programme that more directly affects the longer term rates, namely the programme of purchase of public sector securities PSPP, accounts for about the 85 percent of purchases of the ECB.

account for panel effects. It has to be kept in mind that the use of the long term rates as a monetary variable does not allow to interpret the shocks as "full" QE shocks. In fact, there might be other events that can influence the long term rates in the economy. However, since the recent variations in those yields is commonly attributed to the unconventional policies undertaken by the monetary authorities, we reasonably assume that a large part of those shocks reflects the central bank's interventions.

The chapter is structured as follows. In Section 2.2 we brievly review the literature on the topic, Section 2.3 illustrates the empirical methodology we use in our analysis, Section 2.4 describes our data, Section 2.5 presents the results, Section 2.6 is dedicated to some robustness analysis and Section 2.7 concludes.

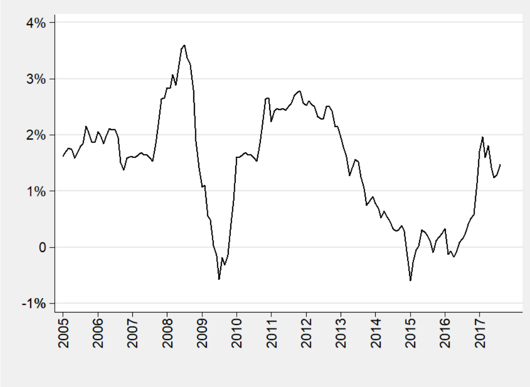
2.2 Literature review

In the literature, most of the work on the analysis of the effects of large scale asset purchases (LSAP) has focused on how it affects asset prices and financial markets, while, especially for the euro area, only a relatively small strand of literature has tried to quantify its impact on the real economy. This has been done both from a theoretical point of view, by means of general equilibrium models of the DSGE (Dynamic Stochastic General Equilibrium) type, and empirically, making use of instruments such as Vector Autoregressive (VAR) models.

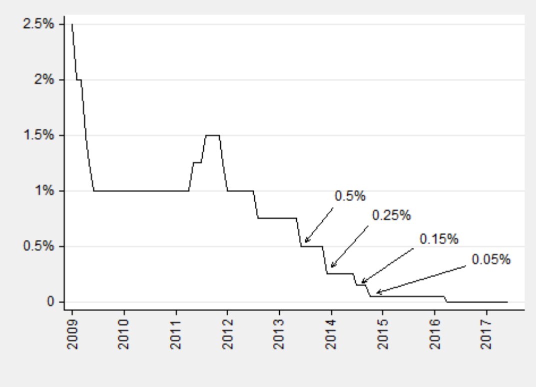
VAR models have been widely used in order to evaluate the effectiveness of both conventional and unconventional monetary policy on the real economy. As for the unconventional policy, many authors have focused on the Japanese case, since the Bank of Japan was the first central bank to implement QE policies in the early 2000s, and on the US case. Less attention have been paid to the European case, mainly because the ECB started the QE in strict sense only recently.

The two major problems in using the VAR approach for evaluating monetary policy are the choice of the variables that can proxy unconventional policy measures and the identification of the shocks. As a measure of QE, several measures have been adopted. For instance, Gambacorta, Hofmann and Peersman (2014), that focus on a panel analysis on 8 advanced economies, use the amount of

FIGURE 2.1: Annualized CPI inflation in the Euro Area (a) and the ECB Main Refinancing Operations (MRO) rate (b). Source: ECB.



(A)



(B)

total assets in the Central Bank's balance sheet, Bhattarai et al. (2015) use the securities held outright by the Federal Reserve and Peersman (2011) uses the monetary base in the Euro area, even if their analysis is not addressed to the QE in the strict sense of the term, but to other unconventional measures taken by the ECB, such as the above mentioned LTROs programmes.

The second issue, namely the identification of unconventional shocks in a structural VAR context, has been initially faced with recursive identification schemes à la Cholesky or with specific non-lower triangular zero restrictions schemes. This approach is particularly frequent for the Japanese case. For example, Iwata and Wu (2006) use a Cholesky identification scheme, while Kimura and Nakajima (2016) use a regime switching VAR where either the conventional or the unconventional policy shock is restricted to be zero according to the regime in which the economy is. However, as shown by Bhattarai et al. (2015), the recursive identification scheme does not seem to be appropriate, since it generates a positive response of the long term interest rates to the QE shock. Moreover, identification by zero restrictions typically causes the so called "price puzzle", in which a positive monetary shock leads to a decrease of prices instead of an increase.

For these reasons, a new approach, that relies on restricting the sign of some impulse responses instead of the matrix of the contemporaneous correlations, has taken place in recent times. This has been pioneered by Faust (1998) and further developed by Canova and De Nicolo (2002), Uhlig (2005) and Moutford and Uhlig

(2009), and has been used in most of the recent monetary policy analysis papers.[5]
A further issue arises when analysing the effects of QE in the euro area because the asset purchases are not unexpected as they should be in a structural VAR context. In fact, the ECB announced, in March 2015, the monthly purchase of €60 billion (on average) of securities. Gambetti and Musso (2017) bypass this problem by considering the total amount of purchases not fully expected, since it varies of about €10-15 billion from month to month, and imposing magnitude restrictions to identify the shocks.
The closest work to ours is Kapetanios et al. (2012), who explore the QE effects on the real economy through the portfolio rebalance channel in the UK, exploiting the idea that the transmission of QE occurs through the long term interest rates, since several studies have proven that QE policies have produced in the UK a fall in the long term rates of about 100 basis points. The same happened in the Euro area, even if a quantification of the impact is less straightforward because of the nature of the ECB announcements. De Santis (2016) estimates the reduction in the 10-year euro area sovereign bond yields caused by the QE in 63 basis points, in October 2015. In Figure 2.3 we show the evolution of an euro area 10-year bond yield benchmark, that proves the recent fall in the long term rates in the euro area.

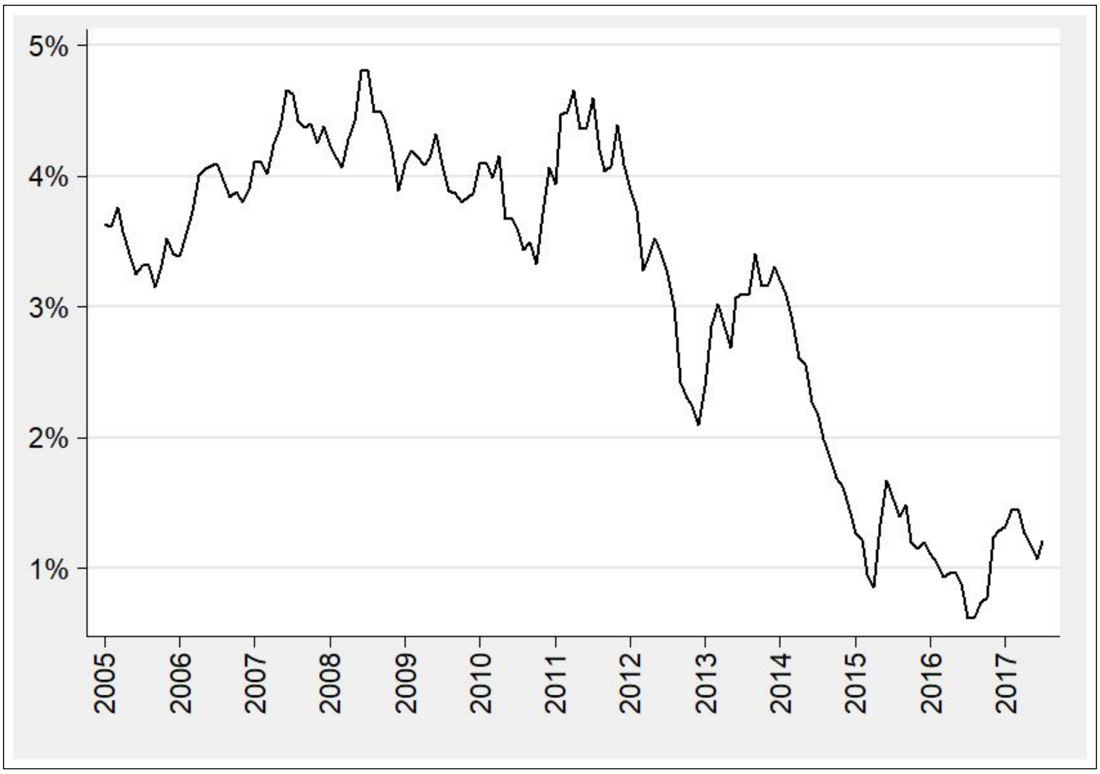
Our approach is slightly different. We consider the effects of a shock to the long term interest rates, not necessarily induced by QE, on the real economy, keeping in mind that, especially from 2015 on, most of the yields fall has been caused by the unconventional policies implemented by the ECB. Moreover, we conduct a panel analysis on 18 euro area countries, using a recent technique developed by Pedroni (2013), that decomposes the structural shocks in idiosyncratic and common shocks, in order to take into account heterogeneity among members.

2.3 The empirical model

We conduct our investigation using the structural VAR methodology. In order to take into account heterogeneity in our panel, we use the Pedroni (2013) approach

[5] We refer to Kilian (2011) for a detailed description of the different identification methods used in the literature.

FIGURE 2.2: Euro area 10-year government benchmark bond yields.



Source: ECB.

that allows us to take into account differences among countries, not only by considering heterogeneity in the fixed effects, but also in the dynamics of the model. The method separates those shocks that are "common" to more countries, by means of the estimation of loading factors, from shocks that are specific to single members ("idiosyncratic" shocks).

To this end, the Pedroni (2013) technique involves two main steps: (i) the estimation of country specific structural VARs with standard methods and a "time effects" VAR to recover the part of information common to all countries by means of the estimation of specific loading factors; (ii) the use of the estimated loading factors to disentangle idiosyncratic from common errors and responses.

More formally, let us suppose that we have a vector of m endogenous variables, namely $Y_{i,t}$, where the subscript i indicates the member, while the subscript t denotes time. In our baseline specification, we have four variables: the industrial production growth, CPI inflation, the main national stock market index and the

10-year government bond yields.[6] Moreover, let us define $\bar{Y}_t = \frac{\sum_{i=1}^{N} Y_{i,t}}{N}$ the vector of "time effect" variables, where N is the number of members in the panel. In the baseline specification, each country specific VAR has the following reduced form representation

$$Y_{i,t} = B_1 Y_{t-1,i} + B_2 Y_{t-1,i} + ... + B_k Y_{t-k,i} + \epsilon_{i,t} \tag{2.1}$$

where B_1, B_2,..., B_k are matrices of coefficients and ϵ is an error term vector. The VARs are specified including two lags[7], while we do not include a constant, as the data were demeaned before the estimation.

The next step is defining an identification strategy that allows us to retrieve the structural errors μ_t starting from the estimated reduced form errors ϵ_t. As standard in the VAR literature, the relationship between the non-orthogononal reduced form errors and the structural orthogonal errors is:

$$\epsilon_t = A^{-1}\mu_t \tag{2.2}$$

In order to estimate the matrix of coefficients A, our identification strategy consists in imposing a number of sign restrictions[8] on the impulse responses of the variables. In a nutshell, defining the matrix of covariances between the errors ϵ_t as $\sum_\epsilon$ and the Cholesky decomposition of it P, we can write $\sum_\epsilon = PP^{-1}$. If we pick up a random orthonormal matrix S such that $\sum_\epsilon = PP^{-1} = PSS^{-1}P^{-1} = DD^{-1}$, we can achieve the identification by drawing a sufficient number of random S matrices, discarding the ones that do not obey a series of a priori theory-based sign restrictions on the relative impulse response function. After finding a sufficient number of accepted draws, we compute the median of the impulse responses.

The set of restrictions we impose are summarised in Table 2.1. We identify three shocks: the first two are a standard demand shock and a standard supply shock, the third is a shock to the long term yields (henceforth, yields shock) that we suppose induced by QE policies. We design the first two shocks as standard in the literature:

[6] Unlike the standard monetary policy VARs, we do not include the short term interest rate in our baseline specification since it has been close to the ZLB over the period considered. Moreover, the inclusion of the short term rate does not affect the main results of our analysis.

[7]The number of lags has been chosen in order to minimise the Akaike information criterion.

[8]See Faust (1998), Canova and De Nicolo (2002), Uhlig (2005) and Moutford and Uhlig (2009) for a detailed explanation of the methodology.

the demand shock has a positive immediate impact on output, inflation and stock prices, while the supply shock leads to higher inflation and lower output growth. As for the yields shock, we impose restrictions in the baseline specification only from the second quarter. We assume that a negative yields shock has a positive impact on both output and inflation, but we leave the response of stock prices free.[9]

After recovering with the above procedure the structural residuals $\mu_{i,t}$ and the

TABLE 2.1: Restrictions imposed for the identification of the shocks

	Demand shock	Supply shock	Yields shock
Output	≥ 0	≤ 0	≥ 0
Inflation	≥ 0	≥ 0	≥ 0
Stock Prices	≥ 0	?	?
Long term rates	?	?	≤ 0

Note: ? = left unconstrained

composite impulse responses for each single country VAR, we can compute the loading matrix Λ_i for every member i. Each loading matrix has dimension $m \times m$, with m number of variables in the model, and its components $\lambda_{i,j}$ can be computed using the relation $\lambda_{i,j} = \frac{E[\mu_{i,j}\bar{\mu}_j]}{E\bar{\mu}_j^2}$[10], for j that goes from 1 to m. We then decompose the composite structural shocks into idiosyncratic and common shocks, using the relation:

$$\mu_i = \Lambda_i \bar{\mu} + \tilde{\mu}_i \tag{2.3}$$

where $\bar{\mu}$ are the common shocks and $\tilde{\mu}_i$ are the idiosyncratic shocks.

Ultimately, we are able to disentangle idiosyncratic responses from common responses as well. If we denote as $A_i(L)$, $A_i(L)$ and $\tilde{A}_i(L)$ respectively the composite, common and idiosyncratic responses for the i-th member, we can perform the decomposition using the following relations:

$$A_i(L) = \bar{A}_i(L) + \tilde{A}_i(L) \tag{2.4}$$

$$\bar{A}_i(L) = A_i(L)\Lambda_i \tag{2.5}$$

$$\tilde{A}_i(L) = A_i(L)(I - \Lambda_i \Lambda_i^{'})^{1/2} \tag{2.6}$$

[9]We choose the timing of the restrictions in order to maximise the number of accepted draws. However, we tested that imposing restrictions on impact for the yields shock does not alter significantly our main findings.

[10]We dropped the time subscript from each variable for simplicity.

2.4 Data

Our balanced panel consists of monthly data from January 2010 to March 2017[11] for 18 Euro area countries.[12] We use the annualised industrial production growth as a measure of output growth, the annualized CPI inflation as a measure of prices, the 10-year sovereign bond yields as a measure of long term interest rates, and the main stock exchange index[13] of each country in the model as a measure of financial stability. The data have been collected from the ECB Statistical Data Warehouse, the IMF, Thomson Reuters and several national data sources. In order to avoid the problem of correlation between fixed effects and the regressors, we demeaned the data before the estimation. In Table 2.2 we report the descriptive statistics for the variables.

Before proceeding with the estimation, we explore the issue of the stationarity of the series. We do this for two reasons: first, non-stationarity could lead to the problem of "spurious" regression, invalidating our results. In that case, we could either check for cointegration or differentiate the series. However, we want to avoid the latter method as "differencing will throw information on any long-run relationships between the series away" (Brooks, 2014). The second issue we mention is related to the long run effect of the shocks, as we expect that a shock can have a permanent effect on a non-stationary series but only a temporary effect on a stationary series.

We test for stationarity in our series by means of the panel unit root test of Fisher (ADF and PP) and Im, Pesaran and Shin. We do not find evidence in favour of the presence of unit roots in the industrial production series, while for the other three series (CPI inflation, stock prices and long term yields) we cannot reject the null hypothesis of non stationarity. The outcomes of the tests are reported in Table 2.3.
The non stationarity of three of four series warns us on the possible presence of a long-run relation between the variables, hence, we need to check for cointegration.

[11] The choice of the sample is made in order to capture the period in which the ECB implemented unconventional policy measures. In the robustness analysis we restrict the sample from 2014 onwards to focus the attention on the PSPP programme, that is intended to influence long term rates more directly.

[12] Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Slovakia, Slovenia, Spain. We excluded the Estonia because of the lack of data on long term sovereign bond yields.

[13] The interest rate and the stock price data are considered in logarithms.

TABLE 2.2: Descriptive statistics

(A)

		Industrial production growth				CPI Inflation			
Country	Obs.	Mean	Max	Min.	Std. Dev.	Mean	Max	Min.	Std. Dev.
Austria	87	2.130	8.100	-2.800	2.579	1.777	3.550	0.450	0.835
Belgium	87	2.648	11.800	-4.400	4.436	1.727	3.650	-0.620	1.021
Cyprus	87	-2.609	30.400	-36.600	17.307	0.870	4.410	-2.490	2.011
Finland	87	0.131	9.500	-4.500	3.346	1.564	3.300	-0.680	1.157
France	87	0.707	6.500	-4.700	2.462	1.135	2.580	-0.390	0.819
Germany	87	3.194	14.400	-3.600	4.682	1.201	2.600	-0.400	0.824
Greece	86	-1.938	9.800	-11.800	4.842	0.771	5.390	-2.980	2.214
Ireland	87	8.561	64.600	-32.200	18.533	0.292	2.500	-2.500	1.074
Italy	87	0.148	9.800	-8.600	4.127	1.269	3.600	-0.500	1.234
Latvia	87	5.518	20.820	-7.900	6.645	0.933	4.450	-4.170	1.831
Lithuania	87	5.689	25.598	-18.198	7.647	1.390	4.590	-1.510	1.600
Luxembourg	87	0.799	19.900	-12.500	5.696	1.617	3.670	-1.140	1.328
Malta	87	0.747	26.480	-16.000	8.231	1.553	4.160	0.240	0.959
Netherlands	87	0.410	13.000	-8.000	4.207	1.273	3.190	-0.660	1.148
Portugal	87	-0.016	5.300	-12.100	3.472	1.247	3.800	-0.680	1.247
Slovakia	87	6.520	20.000	-16.900	4.726	1.202	4.420	-0.860	1.683
Slovenia	87	3.189	12.100	-5.800	4.181	1.155	3.550	-1.150	1.284
Spain	87	-0.290	5.400	-7.900	3.383	1.122	3.420	-1.450	1.481

(B)

		Stock prices (logs)				10-year sovereign bond yields (logs)			
Country	Obs.	Mean	Max	Min.	Std. Dev.	Mean	Max	Min.	Std. Dev.
Austria	87	4.586	4.816	4.327	0.108	0.013	0.027	0.001	0.007
Belgium	87	4.741	5.038	4.412	0.183	0.017	0.033	0.001	0.009
Cyprus	87	2.357	4.605	1.317	1.089	0.047	0.063	0.033	0.011
Finland	87	4.667	4.944	4.321	0.160	0.012	0.025	0.001	0.006
France	87	4.694	4.956	4.387	0.142	0.014	0.027	0.001	0.007
Germany	87	5.012	5.403	4.588	0.231	0.009	0.023	-0.002	0.006
Greece	86	3.687	4.605	2.947	0.384	0.104	0.249	0.049	0.047
Ireland	87	4.954	5.440	4.432	0.331	0.035	0.106	0.004	0.025
Italy	87	4.364	4.609	4.007	0.151	0.030	0.054	0.012	0.011
Latvia	87	4.942	5.477	4.599	0.214	0.033	0.120	0.001	0.027
Lithuania	87	5.011	5.323	4.605	0.186	0.028	0.069	0.003	0.014
Luxembourg	87	4.572	4.818	4.315	0.130	0.011	0.027	-0.001	0.007
Malta	87	5.170	5.560	4.605	0.203	0.024	0.037	0.006	0.009
Netherlands	87	4.793	5.100	4.479	0.161	0.012	0.026	0.000	0.007
Portugal	87	4.515	4.730	4.241	0.102	0.052	0.121	0.017	0.027
Slovakia	87	4.562	4.927	4.308	0.175	0.022	0.041	0.003	0.011
Slovenia	87	4.252	4.605	3.913	0.151	0.031	0.059	0.006	0.015
Spain	87	4.509	4.714	4.076	0.135	0.030	0.057	0.010	0.013

We do this using the panel Pedroni test, whose results are reported in Table 2.4. Since the null hypothesis is the absence of cointegration, we do not find evidence in

TABLE 2.3: Stationarity tests

	Fisher ADF test	Fisher PP test	Im, Pesaran and Shin test
	P-Value	P-Value	P-Value
Output	0.001	0.000	0.000
Inflation	0.737	0.827	0.380
Stock prices	0.899	0.62	0.9463
Long term rates	0.755	0.150	0.565

favor of the presence of cointegration in six of the seven tests performed.

TABLE 2.4: Cointegration tests

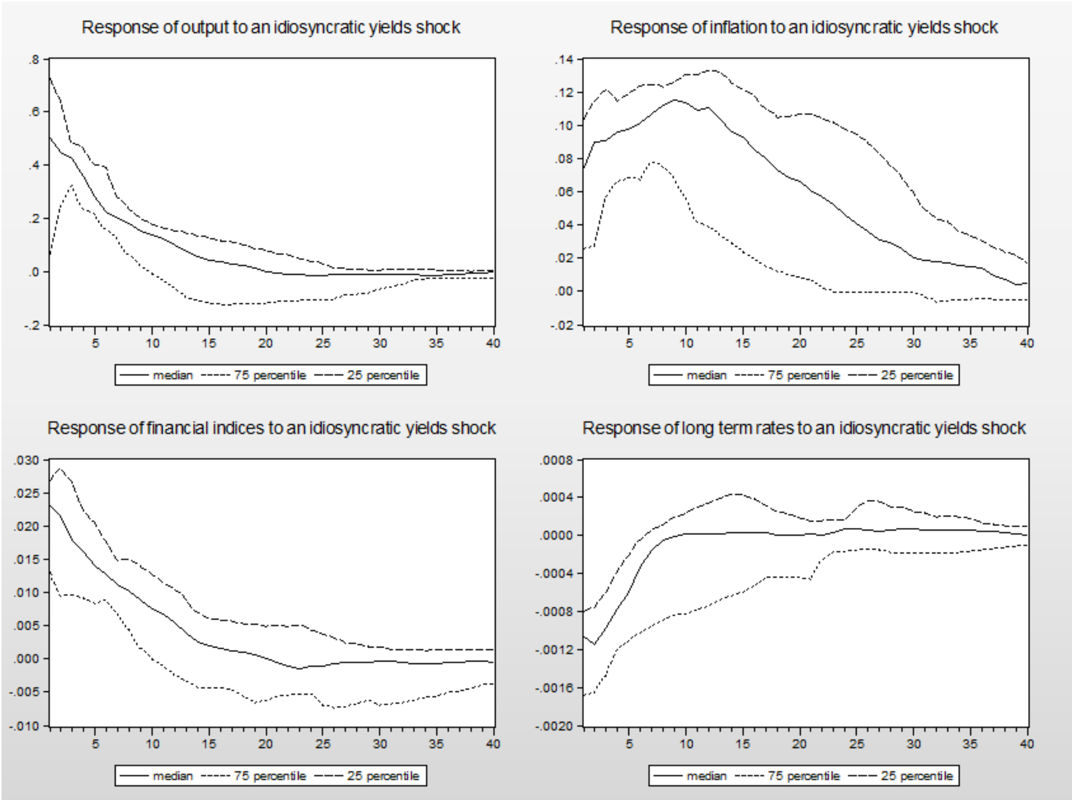
	Statistic	P-Value
Within dimension		
Panel v-Statistic	−1.890	0.970
Panel rho-Statistic	0.013	0.505
Panel PP-Statistic	0.006	0.502
Panel ADF-Statistic	1.745	0.959
Between dimension		
Group rho-Statistic	−1.230	0.109
Group PP-Statistic	−2.177	0.014
Group ADF-Statistic	0.483	0.686

2.5 Results

We generate with the above methodology both idiosyncratic and common responses of the variables to the identified shocks. In Figure 2.3, we show the idiosyncratic responses to a 1 percent negative shock to the long term yields. We report the median responses, the 25th and the 75th percent quantile of the countries in our sample. The results are in line with what suggested in the literature: a negative shock to the long term yields, that we can suppose induced by an asset purchase programme, has a positive effect on both inflation and output, but while the effect on the former is stronger and long lasting, the effect on the latter seem to be more a short-run phenomenon. In fact, the response of inflation remains significantly positive for more than two years, while output responds positively only for about 12 months. Financial markets, on which we did not impose any restrictions, respond positively as well for about one year.

Because of the nature of our analysis, it is not straightforward to compare the

FIGURE 2.3: Idiosyncratic impulse responses to a Yields shock

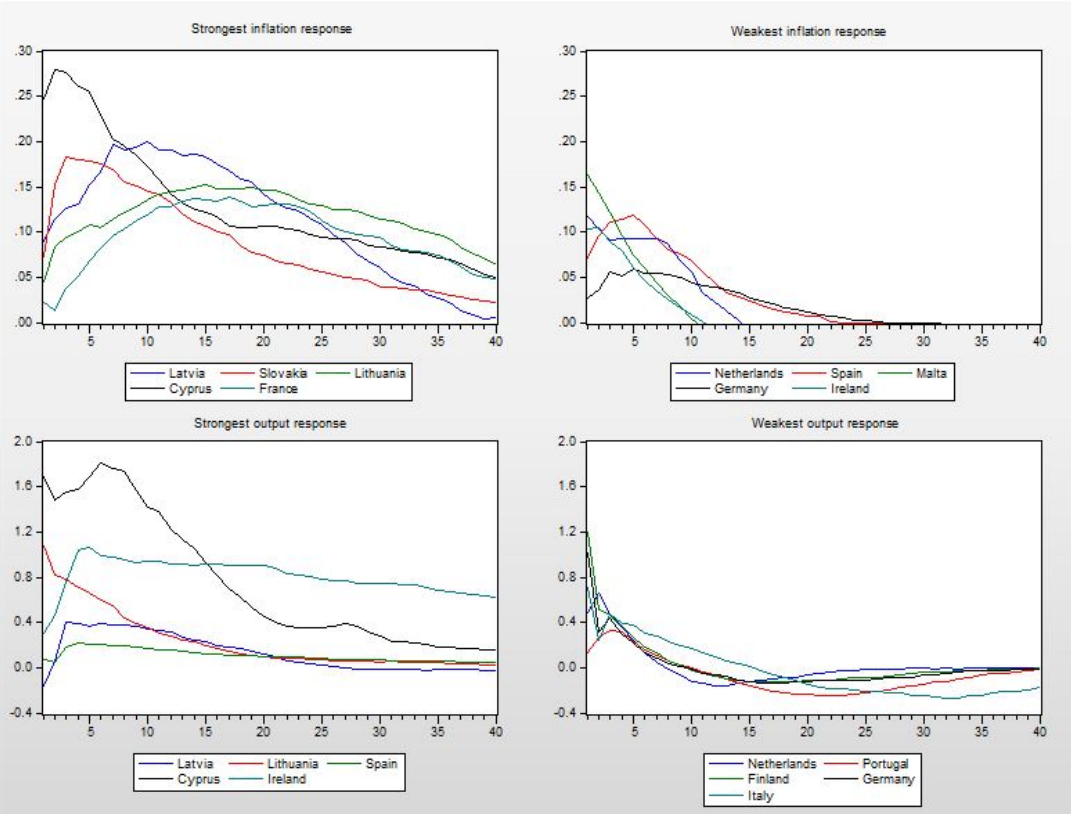


magnitude of our results with other works in the literature, since we are analyzing only a transmission channel of QE and because one can argue that there may be other factors that can cause a shock to the long term yields. The response of inflation peaks after about a year with a magnitude of 0.1 percentage points, a result not far from other estimates in the recent literature that range from 0.1 to 0.3 (see, for instance, Gambetti and Musso, 2017). Also the response of output, that has a peak on impact of 0.5 percentage points, is not easy to contextualize as results vary considerably in the literature. For instance, Gambetti and Musso (2017) find a maximum response of 0.16, while Andrade et al. (2016) and Wieladeck and Garcia Pascual (2016) find a much higher effect of about 1 percent.

We compare our results also to Kapetanios et al. (2012), since, even if they focus on the UK, their work is the most similar to ours in the approach, making the QE effects on the UK case and the European case more comparable. They obtain a response of output of 0.1 (considerably smaller than our 0.5) and a response of inflation only slightly less than our 0.1 (ranging from 0.05 to 0.08, depending on the different specifications).

In Figure 2.4, we show the individual idiosyncratic responses of the countries that

FIGURE 2.4: Idiosyncratic individual IRFs



responded more strongly or more weakly to the yields shock. In particular, on the left we show the countries with a stronger response of inflation (above) and output (below), while on the right the ones with a weaker response.[14] We see that Latvia, Lithuania and Cyprus are among the countries with a bigger response of both the variables. Slovakia and France have a strong inflation response, while both Ireland and Spain are among the countries with a bigger output response but also among the ones with a lower inflation response. Netherlands and Germany have a small response of both inflation and output, while Portugal, Finland and Italy are among the ones with a low output response.

We show also the responses of the variables to the other two shocks, namely the demand shock and the supply shock, in Figure 2.5, and the responses to the common shocks in Figure 2.6.

We end our analysis by showing in Figure 2.7 the forecast error variance decomposition (FEVD) of the variables, that shows how much of the variation of

[14]We kept the same scale in order to make the graphs more comparable.

FIGURE 2.5: idiosyncratic impulse responses to a demand shock (left) and a supply shock (right)

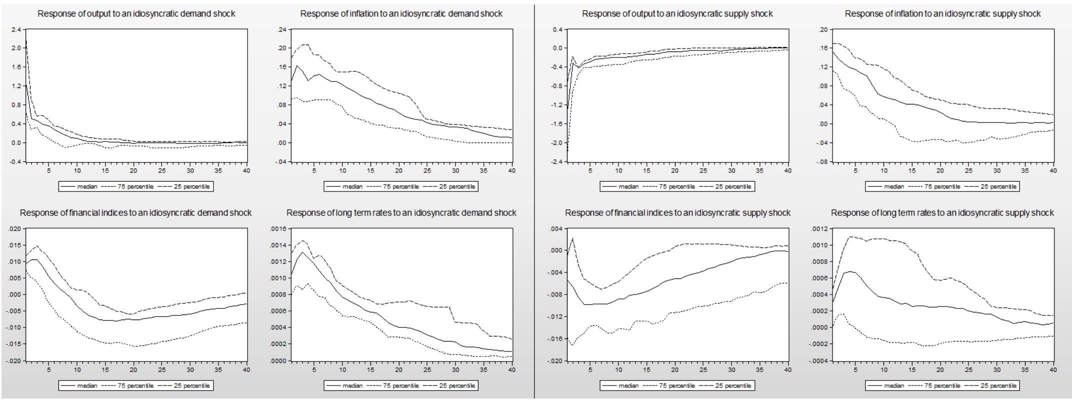
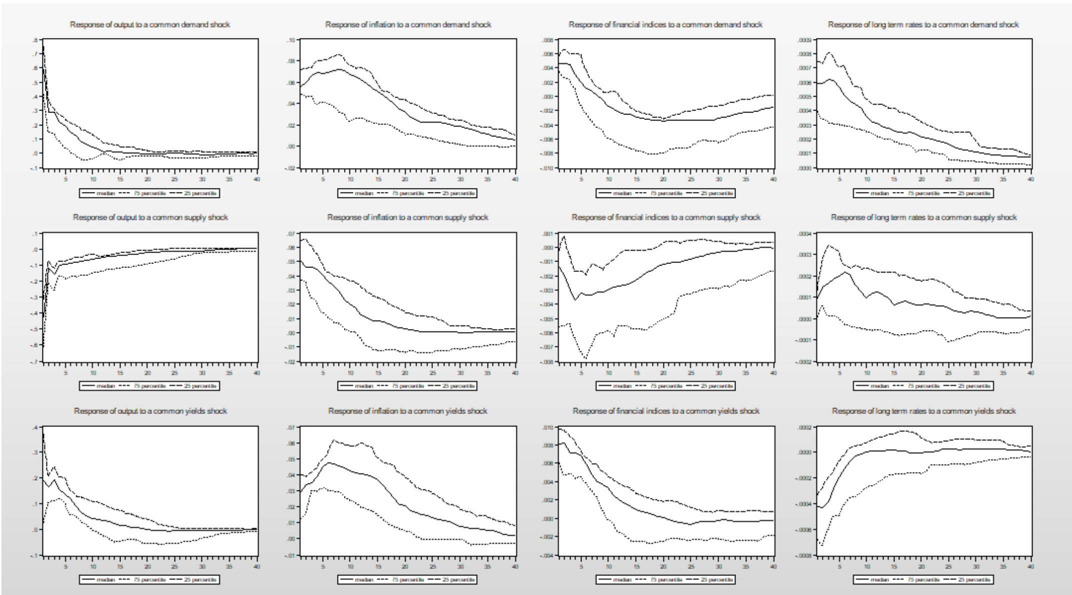


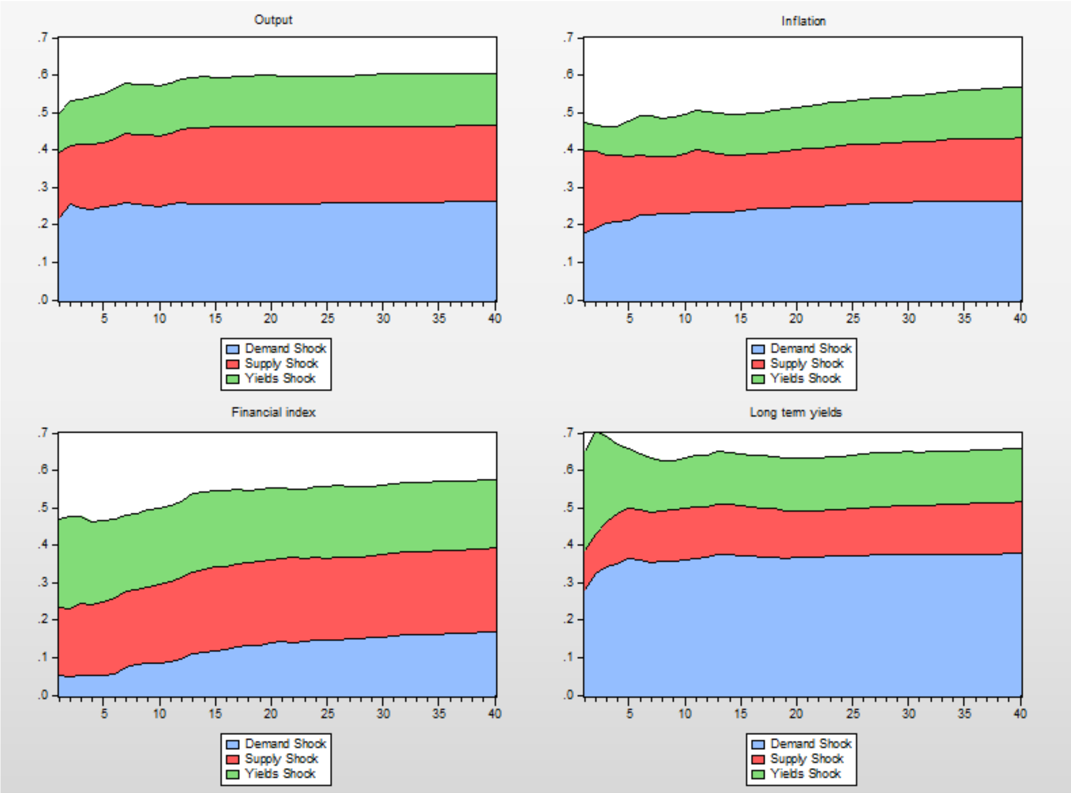
FIGURE 2.6: Common responses to a Yields shock



variables is explained by each shocks. Both variations of output and inflation are mostly due to the demand shock (about 20-25 percent), while the variation due to the yields shock ranges from about 10 percent to 13 percent and the supply shock from 15 and 20 percent. The yields shock has a relatively major impact in explaining the stock prices' variations compared to the other two shocks, while the variation in the long term yields is most largely explained by the demand shock. [15]

[15] Note that the sum of the shocks does not sum up to one both because we only identified three shocks in the model and because we computed them as an average over the 500 replications we performed when imposing the sign restrictions.

FIGURE 2.7: Forecast Error Variance Decomposition



2.6 Robustness

We discuss in this section the robustness of our results by presenting the IRFs to the QE shock when using a different measure of output and when considering a restricted sample covering only the period in which the ECB implemented the APP. As we will show, our results are robust to both changes.[16]

GDP measure In figure 2.8, we present the responses to a yield shock when using an alternative measure of output, namely a measure of GDP growth computed interpolating the quarterly real GDP using the monthly industrial production index as reference series.[17] We notice that the responses of output and inflation tend to be more hump shaped but the sign and the duration are very similar as before. What changes is the magnitude of the response of GDP, which peaks at 0.9 after six months and declines quite suddenly in the following semester, confirming the result previously obtained that the effect on output is more a short-term phenomenon. The other variables tend instead to have the same magnitude:

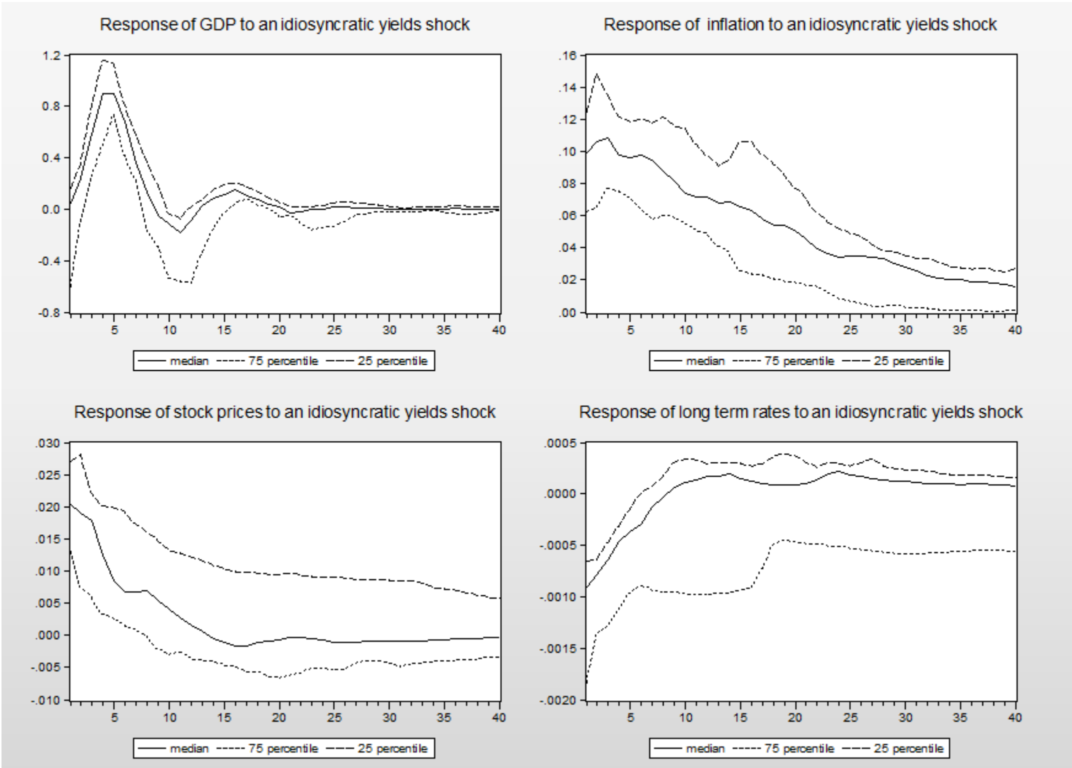
[16] Also, a different timing for for the yields shock restrictions has been implemented. We did not include it in this section as it does not alter significantly the results.

[17] The interpolation has been performed using the Denton method.

inflation peaks after a few months (instead than on impact) and declines for two years and stock prices respond positively for less than a year.

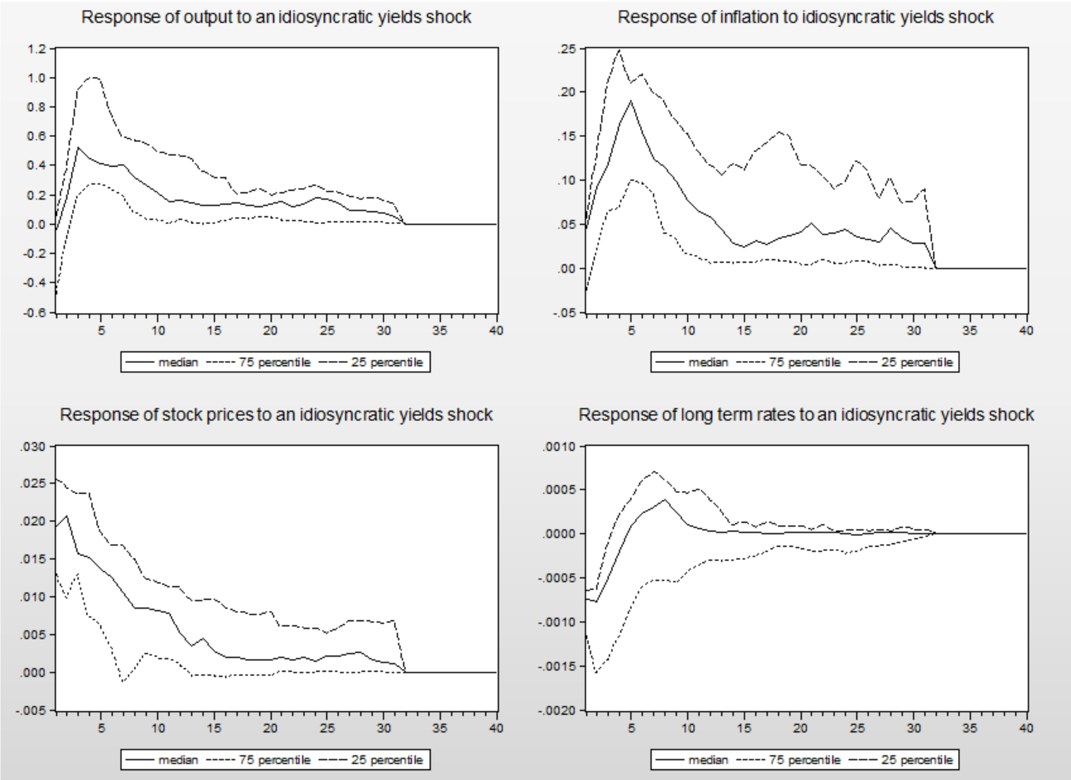
Shorter sample The second robustness check we try is to use a restricted sample

FIGURE 2.8: Idiosyncratic IRFs using a GDP measure



starting from September 2014, when the ECB announced the Asset Purchase Programme. This allows us to focus on the effects of the public sector purchase programme, which is the programme that more specifically targets long term interest rates. We show the IRFs in figure 2.9. The positive effect on output and inflation is confirmed, but the magnitude and the persistence are considerably different for the latter. In fact, the peak effect on inflation almost doubles the one when using the larger sample, but it lasts considerably less, remaining significant for less than a year. Also the effect on stock prices, even if similar in terms of magnitude, is less persistent and lasts about six months.

FIGURE 2.9: Idiosyncratic IRFs with the restricted sample



2.7 Conclusions

This paper examined the real effects of quantitative easing on the euro area economy, conducting a SVAR analysis for a panel of 18 countries. We explore the portfolio rebalance channel of transmission by proxying QE with the long term government bond yields, under the idea that the recent fall in those yields has been induced by the ECB interventions. We identify by sign restrictions three shocks: a supply shock, a demand shock and a long term yields shock. Panel aggregation is performed by means of a recent technique developed by Pedroni (2013), that allows to take into account heterogeneity among members.

We found a considerable positive impact of a negative shock to the long term yields on both output and inflation, with a stronger effect lasting more than two year on the latter and a weaker effect of only 12 months on the former. A positive effect on financial markets is also found. Moreover, we are able to show the countries in which the impact of the shock on inflation and output hase been stronger or weaker.

Of course, given the nature of the ECB programmes, that implemented QE in strict sense only from 2014 on, our results are still in evolution and present two main drawbacks related to the use the long term yields as a measure of QE: the possibility that other factors played a role in the change in the interest rates and the existence of other channels, other than the portfolio rebalance channel we consider, through which QE affected the economy. The natural solution to these problems would be to use a balance sheet measure that take into account the amount of purchases undertaken by the ECB. However, currently, this does not seem to be possible using the VAR instrument, both because of the nature of the ECB asset purchases, that consist in a fixed monthly amount that does not allow to treat the shocks as unexpected, and because of the lack of data at a country specific level, that denies the possibility of conducting a panel specific analysis.

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Chapter 3

Unconventional monetary policy in a DSGE model with recursive preferences

3.1 Introduction

The recent years have seen a major shift in the way central banks have conducted monetary policy. In fact, in order to combat the low, when not negative, inflation levels in many countries, most monetary authorities have repeatedly lowered their main instrument policy, the official nominal interest rate, until setting it close to zero or even negative. Hence, many central banks have had to find new ways of affecting the real economy, with a series of interventions commonly reffered as "unconventional" policy measures, such as direct lending to the financial system, the purchase of financial assets or announcements and communications with the purpose of affecting people's expectations about the economy and future monetary policy.

In the literature, evaluating the effectiveness of these policy have been a major challenge, that have been faced both from an empirical and a theoretical point of view. The latter has been done mainly with the use of models of the DSGE (Dynamic Stochastic General Equilibrium) type, introducing a financial system into otherwise standard new Keynesian models and trying to reproduce the mechanisms behind the large-scale asset purchases (henceforth, LSAPs) undertaken by monetary authorities. Since LSAPs work through several channels, there have been developed different ways of introducing them into DSGE models, analysing, in turn, a different aspect of the transmission mechanism. This reflects the fact that there exist different types of assets that can be purchased - and, therefore, different markets that can be affected - and different channels through which those purchases can influence the economy. For instance, the European Central Bank has carried out in the recent years four programmes of LSAPs[1] that involve four different kinds of assets. Each programme of asset purchases affects a different market and each market affects the real economy in a number of ways.

The main channel through which LSAPs work is believed to be the so called "Portfolio Rebalancing Channel", according to which financial assets are imperfect substitutes and purchases of assets in a market affect the yields of those assets, as investors tend to change the composition of their portfolio. When the central bank purchases a specific asset, the supply of that asset falls, its price increases and its yield of return declines. The same happens for assets with different maturities. In what is commonly referred as "preferred habitat theory", due to Culbertson (1957) and Modigliani and Sutch (1966), investors have different preferences over different maturities, so, when the central bank reduces the supply of an assets with a certain maturity, investors with a preference for that maturity tend to reduce their demand of that asset and increase the demand of those assets whose yield has become relatively more convenient. In other words, imperfect substitutability makes investors willing to change the duration composition of their portfolio, making the price of those assets sensitive to the quantity available.

Being able to affect the yield curve allows the central bank to affect positively the economy in two ways: it makes credit cheaper and it makes households willing to save less and consume more. While the majority of the literature concentrates on the former of the two channels, we want in this chapter explore the latter, focusing on the role of preferences in the effectiveness of the central bank's interventions. To this end, we build a DSGE model with a "preferred habitat" channel, based on the framework of Ellison and Tischbirek (2014), in which we specify preferences as recursive à la Epstein-Zin (1989). This allows us to break the linkage between

[1] We refer to Fawley and Neely (2013) for a detailed description of the measures undertaken in different countries.

intertemporal elasticity of substitution (EIS) and risk aversion in a context in which households' saving decisions drive monetary policy. In fact, in our model, when the central bank buys long term government bonds, yields fall and households decide to save less and consume more. We are able to show how the different utility specification affects the impact of monetary policy and assess its sensitivity to different values of the risk aversion and time preference parameters.

The chapter is structured as follows. In section 2 we review the related literature, in section 3 we describe the model, section 4 presents the main results and section 5 concludes.

3.2 Literature review

The use of DSGE models for evaluating monetary policy has become very common in recent times, especially among central banks. A large part of literature has tried to model conventional policy into DSGE frameworks, from the simplest New-Keynesian type models to models that add different features such as financial frictions, open market economies or a stylized financial intermediaries sector. A new challenge for macroeconomic modelling has been to include in those models the recent unconventional measures undertaken by many central banks in a liquidity trap. The majority of those models explore the "credit" channel of those interventions, that is, they consider the boost in the economic activity caused by the improvement of credit conditions that LSAP generate. Usually, models like Gertler and Karadi (2011), Gertler and Kiyotaki (2011) and Curdia and Woodford (2010), rely on the inclusion of financial frictions that break the neutrality of the central bank interventions, that commonly consist in intermediating a fraction of the loans intermediaries provide to non financial firms.

Our work focuses more on the "demand" side of the economy, as monetary policy works through households' savings decisions. In fact, we exploit the "preferred habitat" channel, due to the theory developed by Culbertson (1957) and Modigliani and Sutch (1966), according to which agents have preferences over different maturities but with a certain degree of substitutability that makes the central bank's interventions effective in influencing the yield curve. The papers that are more strictly related to our work are Ellison and Tischbirek (2014), on which our framework is based, and Vayanos and Vila (2009).

Our work is also related to the strand of literature that tries to include recursive preferences into DSGE models. This has been done in order to make models more consistent with the financial markets evidence, as it is shown that recursive preferences à la Epstein and Zin (1989) generate a more realistic risk premium. Among them, we follow closely An (2010) and Uhlig (2010), who use perturbation methods to include recursive preferences in an otherwise standard new Keynesian model and study optimal policy. Other papers that include recursive preferences in DSGE models are Swanson and Rudebusch (2009), that study the term premium, Amisano and Tristani (2009), that generate a time varying risk premium in a model with stochastic regime changes, and Caldara et al. (2009), that explore several solution methods for new Keynesian models with recursive preferences.

3.3 The model

We summarise our model as follows. The economy is populated by five types of agents: households, firms, financial intermediaries and a government/central bank. Households supply labor and lend capital to firms, consume and save. Firms use labor and capital to produce an homogeneous good that they sell to households and that can be either consumed or invested. Financial intermediaries obtain funds from households in the from of deposits and invest them in both short term and long term securities issued by the government. As in Ellison and Tischbirek (2014), they perceive the different preferences of households over different maturities and build a "saving device" that reflects those preferences. The central bank, besides conducting traditional monetary policy controlling the nominal interest rate on short term securities, modifies the supply of long term securities to banks, affecting the investment decisions of the financial intermediaries.

3.3.1 Households

As in Caldara et al. (2009) and on Van Binsbergen et al. (2012), we define the representative household preferences over consumption and labor as being recursive and given by the following specification

$$V_t = \left[(1-\beta)\left(c_t^{\nu}(1-l_t)^{1-\nu}\right)^{\frac{1-\gamma}{\theta}} + \beta(U_{t+1}^{1-\gamma})^{\frac{1}{\theta}}\right]^{\frac{\theta}{1-\gamma}} \tag{3.1}$$

where c_t and l_t denote respectively consumption and labor at time t, ν is the parameter that controls labor supply, γ the parameter that controls risk aversion, while θ is given by

$$\theta = \frac{1-\gamma}{1-1/\psi}$$

with ψ being the elasticity of intertemporal substitution. U_t is the continuation value, that gives the recursivity to the utility function

$$U_{t+1} = E_t V_{t+1}^{1-\gamma} \tag{3.2}$$

The advantage of this formulation is that separates the parameter that determines risk aversion, γ, from the inverse of the intertemporal elasticity of substitution, ψ. When the two parameters are equal, the utility reduces to the standard CRRA case. Therefore, θ can be interpreted as an index that expresses how far we are from the standard CRRA case.

We assume that households receive a nominal wage W, consume c_t and invest i_t units of the homogeneous final good they buy from firms at price P_t. They lend capital to firms, remunerated at lending rate R_t^k, and are able to postpone consumption through bank deposits D_t, that are saving instruments issued by financial intermediaries that cost P_t^s and have unit payoff in the following period.[2] Hence, the representative household's budget constraint can be expressed as

$$R_t^k K_{t-1}^k + l_t w_t + s_{t-1} = P_t^s s_t + c_t + i_t \tag{3.3}$$

[2]Variables with capital letters denote nominal values.

Capital depreciates at rate δ and evolves according to the following law of motion

$$k_t = (1-\delta)k_{t-1} + i_t \tag{3.4}$$

Maximization yields the following first order conditions[3]

$$\frac{1-\nu}{\nu}\frac{c_t}{1-l_t} = w_t \tag{3.5}$$

$$E_t\Big[\lambda_t R_t\Big] = 1 \tag{3.6}$$

$$E_t\left[\beta\lambda_{t+1}\left(r^k_{t+1} + (1-\delta)\right)\right] = 1 \tag{3.7}$$

Where (3.5) and (3.6) are the standard labor supply and Euler equation, (3.7) determines the return of capital, and λ_t is the stochastic discount factor, given by

$$\lambda_t = \beta\pi_t\left(\frac{1-l_{t+1}}{1-l}\right)^{\frac{(1-\gamma)(1-\nu)}{\theta}}\left(\frac{c_{t+1}}{c_t}\right)^{\frac{\nu(1-\gamma)}{\theta}-1}\left(\frac{V_{t+1}^{1-\gamma}}{E_t V_{t+1}^{1-\gamma}}\right)^{1-\frac{1}{\theta}} \tag{3.8}$$

Note that the first order conditions differ from the standard CRRA case only for the presence of the last term in the stochastic discount factor expression. In other words, the CRRA case is nested in the Epstein-Zin case, with the two being the same when the two parameters that determine risk aversion and elasticity of substitution, ρ and χ, are equal.

3.3.2 Firms

There exists a continuum of monopolistically competitive firms indexed by $i \in [0,1]$, that produce a continuum of differentiated goods using the following technology

$$y_i = a_t k^{\alpha}_{i,t-1} l^{1-\alpha}_{i,t} \tag{3.9}$$

[3] We refer to Caldara et al. (2009) and to Van Binsbergen et al. (2012) for a detailed derivation of the FOCs.

where a_t is an exogenous technology shock process defined as

$$a_{t+1} = \rho_t + \xi_{a,t+1} \tag{3.10}$$

Cost minimization yields the following first order condition

$$\frac{k_{i,t}}{l_{i,t}} = \frac{\alpha}{1-\alpha}\frac{w_t}{r^k_{t+1}} \tag{3.11}$$

Marginal costs are given by

$$mc_t(i) = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r^k_t}{\alpha}\right)a^{\alpha} \tag{3.12}$$

We follow Calvo (1983) in introducing price stickiness in the model. We assume that firms are able to reset their prices in each period with a random probability $1-\theta$. Therefore, in each period θ firms leave their price unchanged, while $1-\theta$ firms reset their price. Denoting the reset price p^*, the maximization problem of a firm that reoptimses its price is

$$\max E_t\left[\sum_{i=0}^{\infty}\theta^i\lambda_t P^* y^* - PC^*\right] \tag{3.13}$$

The solution of the problem is standard in the literature[4] and yields the following equations

$$(\frac{\Delta_t}{Y_t})^{\eta-1} = \frac{1-\theta\pi_t^{\eta-1}}{1-\theta} \tag{3.14}$$

$$\Delta_t = (1-l_t)^{1-\nu}\nu c_t^{\nu-1}y_t + \theta\beta\pi_{t+1}\Delta_{t+1} \tag{3.15}$$

$$Y_t = \frac{\eta(1-l_t)^{1-\nu}\nu c_t^{\nu-1}mc_t y_t}{\eta-1} \tag{3.16}$$

[4]For instance, we refer to Gertler and Karadi (2011) and An (2010), for a full solution of the problem.

where Δ_t and Υ_t are auxiliary variables. Finally, inflation evolves according to the following relation

$$(1-\theta)(p_t^*)^{(1-\eta)} + \theta\pi^{(\eta-1)} = 1 \tag{3.17}$$

and price dispersion X_t is given by:

$$X_t = (1-\theta)\left(\frac{1-\theta\pi_t^{\eta-1}}{1-\theta}\right)^{\frac{\eta}{\eta-1}} + \theta\pi_t^{\eta} X_{t-1} \tag{3.18}$$

3.3.3 Financial Intermediaries

As in Ellison and Tischbirek (2014), financial intermediaries collect deposits from households and invest in short term and long term bonds issued by the government/central bank. Preferences of households between different investment horizons are assumed to be incorporated in the decision problem of the banks. In particular, financial intermediaries build a "saving device" that they sell to households and reflects their preferences over different maturities. Formally, banks maximize the following value function

$$\max_{Q_{t,t+\tau},B_{t,t+1}} = V\left(\frac{Q_{t,t+\tau}}{P_t}, \frac{B_{t,t+1}}{P_t}\right) \tag{3.19}$$

Where $B_{t,t+1}$ denotes one-period bonds with price P_t^b and return rate r_t^b and $Q_{t,t+\tau}$ bonds with maturity $\tau = 20$ with price P_t^q and return rate r_t^q in each period. In formulas, the following relations hold

$$P_t^b = 1 + r_t^b \tag{3.20}$$

$$P_t^q = \frac{1}{\tau(1+r_t^q)} + \frac{1}{\tau(1+r_t^q)^2} + ... + \frac{1}{\tau(1+r_t^q)^{\tau}} \tag{3.21}$$

The functional form chosen in the Generalised Translog (GTL).[5] Maximisation yields the following asset demand curves[6]

$$\frac{B_{t,t+1}}{P_t} = g^b + \frac{P_t^s s_t - P_t^b g^b - P_t^q g^q}{P_t^b}\left[a_1 + a_2 \log\left(\frac{P_t^b}{P_t^q}\right)\right] \tag{3.22}$$

$$\frac{Q_{t,t+1}}{P_t} = g^q + \frac{P_t^s s_t - P_t^b g^b - P_t^q g^q}{P_t^q}\left[a_1 + a_2 \log\left(\frac{P_t^b}{P_t^q}\right)\right] \tag{3.23}$$

where P_t^s is the price of the saving device.

3.3.4 Market clearing and Monetary Policy

The government/central bank is in the model only to supply short term and long term bonds to the financial intermediaries. In particular, by issuing and controlling the supply of short term bonds through open market operations, it conducts conventional monetary policy following a standard Taylor-type rule

$$\frac{1 + r_t^b}{1 + r_{ss}^b} = \left(\frac{\pi_t}{\pi_{ss}}\right)^{\gamma_\pi}\left(\frac{Y_t}{Y_{ss}}\right)^{\gamma_y}\xi_t \tag{3.24}$$

where the subscript ss denotes steady state values and ξ_t is an exogenous shock process with AR(1) structure defined as

$$\xi_t = \rho_c \log \xi_{t-1} - \epsilon_c \tag{3.25}$$

The amount of long term bonds issued is constant and determined by the relation

$$\frac{\bar{Q}_t}{P_t} = \psi Y_{ss} \tag{3.26}$$

[5] See Pollak and Wales (1980) for a detailed description of the GTL model.

[6] As in Ellison and Tischbirek (2014), we simplify the two expressions by imposing $a_2 = 0$ obtaining:

$$\frac{B_{t,t+1}}{P_t} = g^b + a_1\frac{P_t^s s_t - P_t^b g^b - P_t^q g^q}{P_t^b}$$

$$\frac{Q_{t,t+1}}{P_t} = g^q + a_1\frac{P_t^s s_t - P_t^b g^b - P_t^q g^q}{P_t^q}$$

where ψ is a positive parameter.

In each period the central bank changes the supply of long term bonds by purchasing an amount of assets Q_t^{CB} according to the following feedback rule

$$\frac{\bar{Q}_t - Q_t^{CB}}{\bar{Q}_t} = \left(\frac{\pi_t}{\pi_{ss}}\right)^{\gamma_\pi^{QE}} \left(\frac{Y_t}{Y_{ss}}\right)^{\gamma_y^{QE}} \varsigma_t \tag{3.27}$$

with ς_t being an AR(1) exogenous shock process defined as

$$\varsigma_t = \rho_u \log \varsigma_{t-1} - \epsilon_u \tag{3.28}$$

We close the model by defining the consolidated government/central bank profits π_t^{CB}

$$\pi_t^{CB} = B_{t-1,t} + \frac{1}{\tau}\sum_{j=1}^{\tau} \bar{Q}_{t-1,t+\tau-1} - P_t^b B_{t,t+1} - P_t^q \bar{Q}_{t,t+\tau} \tag{3.29}$$

and the market clearing condition

$$y_t = c_t + i_t \tag{3.30}$$

3.4 Calibration and Results

We follow the same calibration of Caldara (2010) for the the households block, Gertler and Karadi (2011) for the firms block, and Ellison and Tischbirek (2014) for the financial intermediaries block. We report the calibration values in Table 3.1.

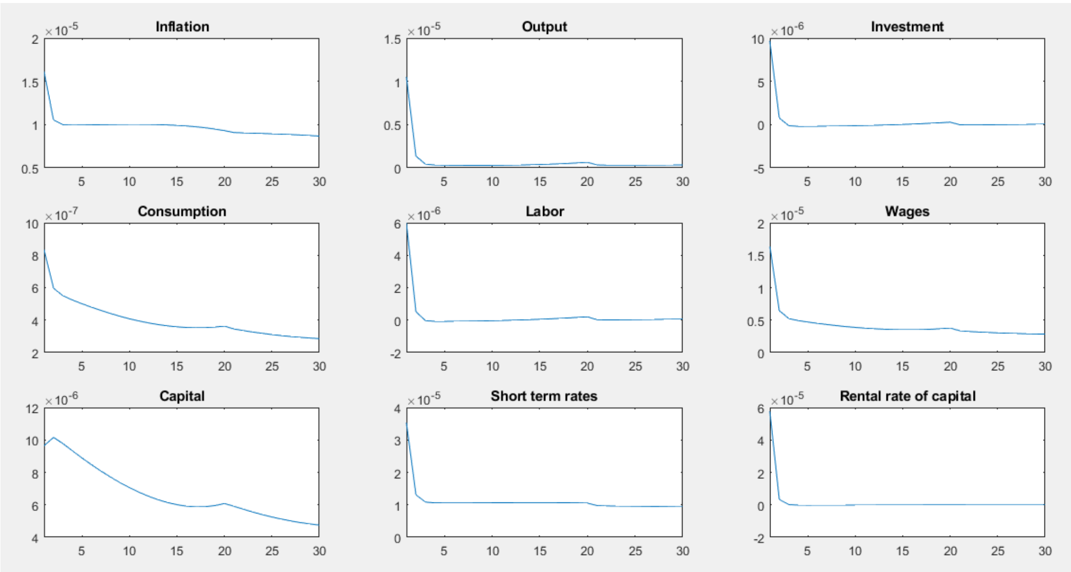
We focus on the impact of a shock to the unconventional policy rule in equation (3.27). When the central bank buys long term bonds, it reduces the supply of those bonds in the market, causing a rise in their prices and, hence, a fall in their yields. The demand of long term bonds decreases in favor of other assets available in the market that are imperfect substitutes and of a decrease of savings. This means more consumption and a boost in economic activity that should translate in a positive impact on output and inflation. In

TABLE 3.1: Parameter Calibration

Parameter	Value	Description
β	0.991	Discount factor
α	0.33	Capital share
δ	0.25	Depreciation rate
ν	0.43	Elasticity of substitution consumption/labor
η	6	Price elasticity of demand for intermediate goods
θ	0.8	Price stickiness: Calvo parameter
τ	20	Long term bond horizon
g^b	10.21	Subsistence level of B
g^q	0.59	Subsistence level of Q
a_1	0.95	Asset demand
a_2	0.05	Asset demand
$\bar{\pi}$	1.011	Steady state inflation
f	0.66	Parameter in long term bond supply
ρ_c	0.1	Persistence of shock to the conventional Taylor rule
ρ_u	0.1	Persistence of shock to the unconventional Taylor rule
ψ	2	EIS parameter (baseline)
γ	0.5	Risk aversion parameter(baseline)

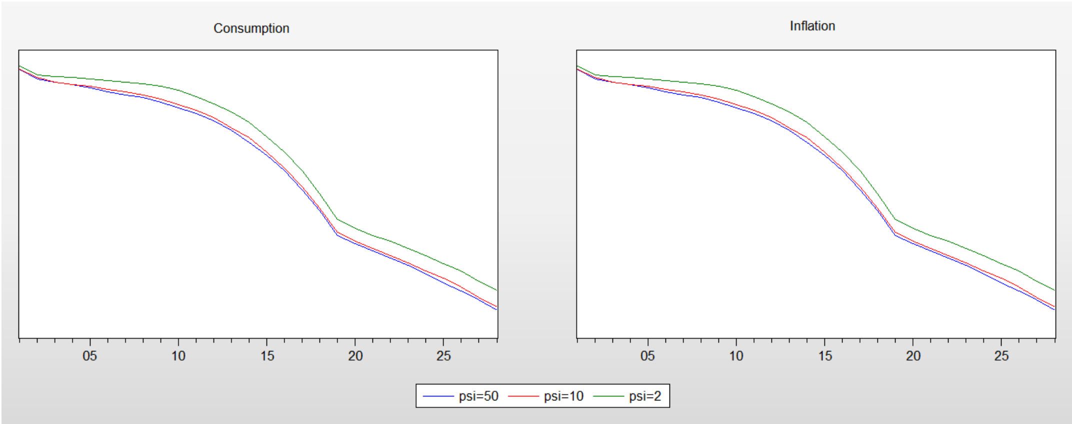
the baseline specification, we set $\rho = \chi = 2$. Since the parameters that govern risk aversion and elasticity of substitution are equal, the utility specification reduces to the standard CRRA case. We show the responses of the model in Figure 3.1. The positive response of output lasts only a few periods, while inflation responds more persistently up to 30 periods.

FIGURE 3.1: Responses of the model to a long term bonds shock



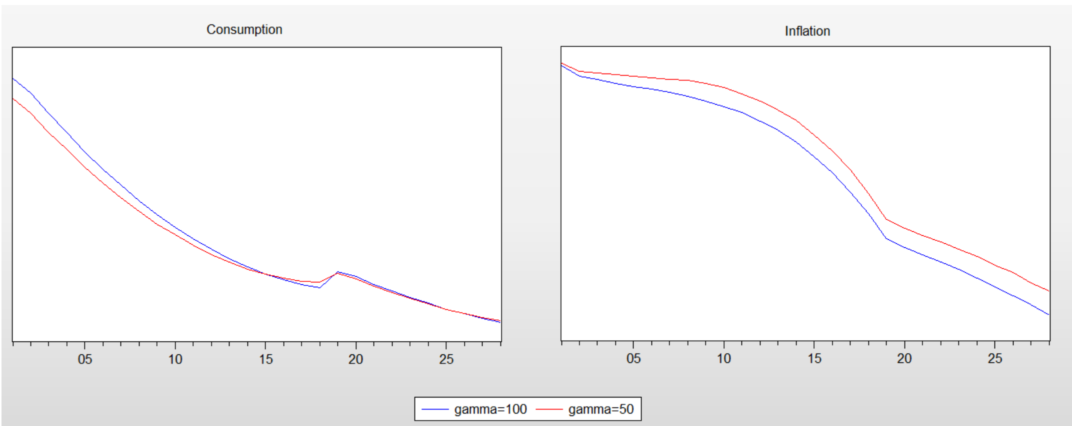
In Figure 3.2 and 3.3 we show the sensitivity of inflation to the EIS

FIGURE 3.2: Sensitivity to EIS parameter



parameter and to the risk aversion parameter. The response of inflation is larger for higher values of the EIS parameter. This in an expected result, as the central bank purchases assets, the return of (long term) bonds declines and households tend to save less and consume more. When the EIS is high, households are more willing to substitute consumption between periods and a fall in the yields makes them consume considerably more than they do when the EIS is low. This results in a larger effect on inflation, as documented in Figure 3.2. In the case of risk aversion the mechanism is inverted and also the magnitude is smaller: high values of the risk aversion lead to a smaller effects on inflation and consumption.

FIGURE 3.3: Sensitivity to the risk aversion parameter



3.5 Conclusions

This paper analysed the role of preferences in the unconventional monetary policy transmission. We built a DSGE model with a preferred habitat channel, based on the Ellison and Tischbirek (2014) framework, in which households have preferences over different investment maturities that are incorporated in the saving device sold by financial intermediaries. We specify households' preferences à la Epstein and Zin (1989) that have two advantages: (i) they are financially more realistic, as it is proven thet they generate a risk premium more consistent with the empirical evidence, (ii) they allow to break the linkage between elasticity of intertemporal substitution (EIS) and risk aversion. In the model, the central bank buys long term securities, influencing their yields and affecting housholds' intertemporal consumption decisions. We are able to show the change of the responses as the two parameters change. In particular, we show that a high value of the EIS parameter implies a stronger effect on inflation, as households are more willing to substitute consumption between periods and a central bank intervention makes them consume considerably more, while high values of the risk aversion tend to reduce the effect of the central bank interventions on inflation.

Appendix 1: model summary

$$V_t = \left[(1-\beta)\left(c_t^{\nu}(1-l_t)^{1-\nu}\right)^{\frac{1-\gamma}{\theta}} + \beta(U_{t+1}^{1-\gamma})^{\frac{1}{\theta}}\right]^{\frac{\theta}{1-\gamma}} \tag{A1}$$

$$U_{t+1} = E_t V_{t+1}^{1-\gamma} \tag{A2}$$

$$\lambda_t = \beta\pi_t \left(\frac{1-l_{t+1}}{1-l}\right)^{\frac{(1-\gamma)(1-\nu)}{\theta}} \left(\frac{c_{t+1}}{c_t}\right)^{\frac{\nu(1-\gamma)}{\theta}-1} \left(\frac{V_{t+1}^{1-\gamma}}{E_t V_{t+1}^{1-\gamma}}\right)^{1-\frac{1}{\theta}} \tag{A3}$$

$$\frac{1-\nu}{\nu}\frac{c_t}{1-l_t} = w_t \tag{A4}$$

$$E_t\left[\lambda_t R_t\right] = 1 \tag{A5}$$

$$R_t^k K_{t-1}^k + l_t w_t + s_{t-1} = P_t^s s_t + c_t + i_t \tag{A6}$$

$$k_t = (1-\delta)k_{t-1} + i_t \tag{A7}$$

$$E_t\left[\beta\lambda_{t+1}\left(r_{t+1}^k + (1-\delta)\right)\right] = 1 \tag{A8}$$

$$X_t y_i = a_t k_{i,t-1}^{\alpha} l_{i,t}^{1-\alpha} \tag{A9}$$

$$\frac{k_{i,t}}{l_{i,t}} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_{t+1}^k} \tag{A10}$$

$$mc_t(i) = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t^k}{\alpha}\right)a^{\alpha} \tag{A11}$$

$$(\frac{\Delta_t}{Y_t})^{\eta-1} = \frac{1-\theta\pi_t^{\eta-1}}{1-\theta} \tag{A12}$$

$$\Delta_t = (1-l_t)^{1-\nu}\nu c_t^{\nu-1} y_t + \theta\beta\pi_{t+1}\Delta_{t+1} \tag{A13}$$

$$Y_t = \frac{\eta(1-l_t)^{1-\nu}\nu c_t^{\nu-1} mc_t y_t}{\eta-1} \tag{A14}$$

$$(1-\theta)(p_t^*)^{(1-\eta)} + \theta\pi^{(\eta-1)} = 1 \tag{A15}$$

$$X_t = (1-\theta)\left(\frac{1-\theta\pi_t^{\eta-1}}{1-\theta}\right)^{\frac{\eta}{\eta-1}} + \theta\pi_t^{\eta} X_{t-1} \tag{A16}$$

$$P_t^b = 1 + r_t^b \tag{A17}$$

$$P_t^q = \frac{1}{\tau(1+r_t^q)} + \frac{1}{\tau(1+r_t^q)^2} + ... + \frac{1}{\tau(1+r_t^q)^\tau} \tag{A18}$$

$$\frac{B_{t,t+1}}{P_t} = g^b + a_1\frac{P_t^s s_t - P_t^b g^b - P_t^q g^q}{P_t^b} \tag{A19}$$

$$\frac{Q_{t,t+1}}{P_t} = g^q + a_1\frac{P_t^s s_t - P_t^b g^b - P_t^q g^q}{P_t^q} \tag{A20}$$

$$\frac{1+r_t^b}{1+r_{ss}^b} = \left(\frac{\pi_t}{\pi_{ss}}\right)^{\gamma_\pi}\left(\frac{Y_t}{Y_{ss}}\right)^{\gamma_y}\xi_t \tag{A21}$$

$$\frac{\bar{Q}_t}{P_t} = \psi Y_{ss} \tag{A22}$$

$$D_t = \frac{B_{t,t+1}}{P_t} + \frac{1}{\tau}\left(\frac{Q_t}{P_t}\sum_{k=1}^{t-1}\frac{Q_{t-k}}{P_t}\frac{1}{\prod_{j=0}^{k-1}\Pi_{t-j}}\right) \tag{A23}$$

$$\frac{\bar{Q}_t - Q_t^{CB}}{\bar{Q}_t} = \left(\frac{\pi_t}{\pi_{ss}}\right)^{\gamma_\pi^{QE}} \left(\frac{Y_t}{Y_{ss}}\right)^{\gamma_y^{QE}} \varsigma_t \tag{A24}$$

$$y_t = c_t + i_t \tag{A25}$$

$$a_{t+1} = \rho_t + \xi_{a,t+1} \tag{A26}$$

$$\varsigma_t = \rho_u \log \varsigma_{t-1} - \epsilon_u \tag{A27}$$

$$\xi_t = \rho_c \log \xi_{t-1} - \epsilon_c \tag{A28}$$

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Concluding remarks

In this thesis, we proposed three essays in which we have tried to assess the effect of unconventional monetary policy with a specific focus on the portfolio rebalance channel of transmission. We faced the problem with both an empirical analysis, using the VAR methodology in Chapter 2, and from a theoretical point of view, by means of a DSGE model in Chapter 3. The results in Chapter 2 suggest a significant role for quantitative easing in affecting the real economy in the euro zone, with a positive effect on both output and inflation. In Chapter 3 we explored the demand side of the same channel of transmission, concentrating on the role of risk aversion and intertemporal elasticity of substitution of households in the effectiveness of policy actions.

Our results leave the door open to different developments. In fact, if the assessment of the euro area QE effects is still in evolution, given the short time span passed since the implementation of the measures, also the DSGE model we presented has a number of possibible extensions. In particular, the structure of the banking sector à la Ellison and Tischbirek (2014) can be used also for exploring the credit channel of monetary transmission, that we do not explicitely included in the model. In fact, unlike what happens in other DSGE models, non financial firms do not play a specific financial role (i.e., they do not lend or borrow). The combination of a specific role for non financial firms and the presence of long term government bonds could help understand the "supply" side of the portfolio rebalance channel of transmission.