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Department of Political Economy

In the aftermath of Brexit: the macroeconomic impacts of the UK's QE programme

Carlos Miguel da Costa Guerra Fernandes

Dissertation submitted as partial requirement for the conferral of

Master in Monetary and Financial Economics

Supervisor:

Professor Diptes Chandrakante Prabhudas Bhimjee, PhD,

Assistant Professor of Economics (Invited), ISCTE-IUL Business School

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Resumo

No seguimento da votação do Reino Unido de sair da União Europeia, as perspetivas de crescimento de curto e médio prazo diminuíram significativamente, levando o MPC do Banco de Inglaterra a introduzir um pacote de medidas, incluindo a descida na taxa de juro, a expansão do APF, um CBPS e um novo TFS, destinadas a dar apoio adicional ao crescimento e conseguir um retorno da inflação à meta de 2%.

Esta Dissertação avalia os efeitos macroeconómicos de algumas das medidas de política não convencionais implementadas pelo MPC sobre o produto, inflação, yields de longo prazo e nos preços das ações, assim como nos canais de transmissão ativados. Para tal, observamos os resultados das funções de resposta ao impulso utilizando um esquema de identificação através de um modelo VAR, com dados mensais, entre agosto de 2016 e janeiro de 2019.

Os resultados sugerem que o programa de QE originou um aumento significativo inicial das yields de longo prazo, uma depreciação da taxa de câmbio, e uma redução das medidas de incerteza do mercado financeiro. Para as restantes variáveis, não há evidência de respostas significativas ao QE. As estimativas são, em geral, semelhantes a estudos que utilizam o mesmo esquema de identificação. Contudo, as magnitudes dos resultados aparentam ser menores quando comparadas com os impactos dos primeiros programas de QE no Reino Unido, validando a hipótese de que os impactos das compras de ativos na economia estão a ficar mais reduzidos à medida que os programas de QE se vão expandindo.

Palavras-Chave: Efeitos do Programa de Compras, Brexit, Impulse Response Functions, Quantitative Easing, Modelo VAR, Política Monetária Não Convencional.

JEL Codes: E52, E58, E65

Abstract

Following the United Kingdom's vote to leave the European Union, the outlook for growth in the short to medium term weakened markedly, leading the Bank of England's MPC to introduce a package of measures, such as a cut of the Bank Rate, the expansion of APF, a CBPS and a new TFS, designed to provide additional support to growth and to achieve a sustainable return of inflation to the target of 2%.

This Dissertation assesses the macroeconomic effects of some of the unconventional monetary policy measures employed by the MPC on output, inflation, long-term yields and equity prices, as well as on the transmissions channels activated. Therefore, we observe the results from the impulse response functions with an identification scheme, under a VAR model, which relies on monthly data, between August 2016 and January 2019.

The results suggest the actual QE asset purchase programme led to a significant initial increase of long-term yields, depreciation of the exchange rate and a reduction of measures of financial market uncertainty. For the remaining variables, there is no evidence of significance response to QE. The estimates are, in general, similar to studies which employ the same identification scheme. However, their magnitude appears to be smaller when compared with impacts from early QE programmes in the UK, supporting the hypothesis that the impacts from asset purchases on the economy are getting smaller with the expansion of QE programmes.

Keywords: Asset Purchase Programme Effects, Brexit, Impulse Response Functions, Quantitative Easing, VAR Model, Unconventional Monetary Policy.

JEL Codes: E52, E58, E65

Table of Contents

Index of Figures

Index of Tables

Index of Appendix

List of Abbreviations

AIC: Akaike Information Criterion

APF: Asset Purchase Facility

APP Ratio: Asset Purchase Programme

BofE: Bank of England

BofJ: Bank of Japan

CBPS: Corporate Bond Purchase Scheme

CPI: Consumer Price Index

CPIY: Consumer Price Index, excluding the impact of indirect taxes

DSGE: Dynamic Stochastic General Equilibrium

ECB: European Central Bank

EMPLOYMENT_RATE: Total Employment Rate

EPU: Economic Policy Uncertainty Index

EQUITY_PRICES: FTSE 100 Index

EU: European Union

EXCHANGE_RATE: Real Exchange Rate

Fed: Federal Reserve

FLS: Funding for Lending Scheme

FRED: Federal Reserve Economic Data

FTSE: The Financial Times Stock Exchange

GDP: Gross Domestic Product

HOUSE_PRICES: House Prices

HQIC: Hannan-Quinn Information Criterion

LSAP: Large-Scale Asset Programmes

MPC: Bank of England's Monetary Policy Committee

OIS: Overnight Index Swap

ONS: Office for National Statistics

PTI: Production of Total Industry

QE: Quantitative Easing

SC: Schwartz Bayesian Information Criterion

TFS: Term Funding Scheme

VAR: Vector Autoregression

VIX: Implied Stock Market Volatility

UK: United Kingdom

US: United States

_10Y_YIELD: 10-year government bonds yields

_20Y_YIELD: 20-year government bonds yields

_30Y_YIELD: 30-year government bonds yields

1. Introduction

The Global Financial Crisis of 2008-2009 led to the introduction of unconventional monetary policies. In the aftermath of the latter crisis, the US Fed was the first Central Bank to announce the LSAP[1], in November 2008, after the exhaustion of the available conventional monetary policy instrument – the policy rate. Similarly, the UK also announced the beginning of a QE programme in January 2009. The establishment of such unconventional monetary policies programmes was intended to ensure financial stability and provide additional support to the economy. However, the Fed was actually not the first Central Bank to implement unconventional monetary policies. The BoJ introduced its own QE, in March 2001, as a way to combat the country's prolonged stagnation and deflation (in short, stagflation), after the bursting of the Japanese asset price bubble and the reduction of the policy rate to the zero-lower bound. More recently, the ECB also launched its own QE programme in January 2015, in order to stimulate inflation.

These Central Banks have continued to expand their balance sheets, as a result of financial, political, and economic distresses. Moreover, these interventions have been an important area of academic research, and there has been an extensive number of researches which have tried to assess the effectiveness of unconventional monetary policies in multiple economies throughout the past decades. However, the UK's QE expansion programme, due to the recent outcome of the Brexit referendum, appears to have been somewhat overlooked.

According to the UK's APF Reports, before 4th August 2016 the APF fund had been authorized to purchase £375 billion of high-quality assets financed by the creation of Central Bank reserves. These purchases were completed on 31st October 2012, and the stock was thereafter maintained at the same amount, through reinvestment of cash flows associated with the maturities of bonds owned by the APF, until 4th August 2016. The BofE's MPC introduced a package of measures intended to support the UK economy after the outcome of the Brexit referendum, increasing the target for the stock of purchases of UK government bonds by £60 billion, to £435 billion in total, as well as new TFS (although the latter is not addressed in present Dissertation) (BofE, 2016). In addition, the BofE launched a CBPS, in order to purchase high-quality private sector assets, equally financed by the creation of Central Bank reserves, purchasing up to £10 billion worth of sterling-denominated bonds of firms making a material contribution to the UK economy (BofE, 2016). Given that it is now possible to add more recent data, the CBPS has been included to the APF target of asset purchases in order to provide better estimations regarding the impacts of the QE expansion programme. Therefore, present Dissertation provides new empirical evidence for the effectiveness of the QE expansion programme on the financial markets, the economy, as well as on the respective transmission channels, in response to the UK vote to leave the EU (on 23rd June 2016). Hence, this Dissertation addresses the following research question: "What were the

[1] Also referred to as Quantitative Easing.

macroeconomic impacts of the expansion of the BofE's QE asset purchase programme, after the Brexit referendum?".

The analysis herein developed employs a VAR model combined with an identification scheme closely associated with the research advanced by Behrendt (2013), Weale and Wieladek (2014b; 2016), and Haldane *et al.* (2016), focusing on the results from the impulse response functions. These authors estimate the macroeconomic impacts of Central Bank balance sheet expansions in several countries (including the UK), as well as their implications through QE asset purchases. Previous researches assess macroeconomic impacts by applying shocks, through the reduction of yields in their models. However, this method may be subject to one possible criticism, namely, the extent to which this type of shock actually reflects asset purchases is not very clear (Weale and Wieladek, 2014b); but it is important to mention that when those studies were undertaken, time series were not of appropriate length to draw adequate conclusions. As time advanced, subsequent authors started to use asset purchase announcements series. Nevertheless, the actual amount of asset purchased is used, following the work of Weale and Wieladek (2014b; 2016), who found similar results in their models using actual purchases, when compared to the announcements. The results from Weale and Wieladek (2014b; 2016) for their first identification scheme provide lower bound estimations, when compared with the additional schemes. Correspondingly, the use of the same identification scheme in this Dissertation combined with a VAR model allows us to obtain results which can also serve as lower bound estimations, similarly to Weale and Wieladek (2014b; 2016). Therefore, this Dissertation's added value should be useful as a base for further empirical work on the effects of QE asset purchases after the Brexit referendum, with the use of both more sophisticated models, such as Bayesian VAR methods, and other identification schemes.

This work uses monthly data taken from a wide range of databases, such as APF Quarterly Reports, the Bank of England Database, Bloomberg, Datastream, Economic Policy Uncertainty, Eurostat, FRED, Investing.com financial platform, together with the ONS, using data for the UK. The time length incorporates the period from the beginning of actual asset purchases, in August 2016, including both the APF and CBPS series, until January 2019, a few months before the formally agreed date for the UK to officially leave the EU, thus avoids biased results related to the asset purchase programme.

The results from the mean maximum impact impulse response functions indicate there is little evidence that the expansion of QE asset purchase programme has had significant macroeconomic effects, namely on variables such as output, inflation, and equity prices in the UK. These unexpected findings are generally in line with the findings from previous authors that use the same identification schemes for the UK (Weale and Wieladek, 2014b; 2016; and Haldane *et al.*, 2016).

However, regarding the transmission channels, there are some significant meaningful impacts which are observed. An unexpected expansion shock of asset purchases leads to an initial significant increase in the long-term yields, similar to the observed estimations from Weale and Wieladek (2014b; 2016) for their first identification scheme. Moreover, the expectations management channel appears to be the most important transmission channel, leading to a significant reduction in financial market uncertainty, which may imply that it strongly helped sustain equity prices from suffering greater losses. Additionally, there seems to be sufficient empirical evidence sustaining that asset purchases lead to significant real exchange rate depreciation. While house prices do not have the expected positive effect (possibly due to the movements of the short-term rates, which were similar to the ones from the long-rates), where it was observed an initial increase of the yields, which may have had negative effects on house prices.

The present Dissertation is organised as follows. Section 2 introduces an extensive and diversified literature review regarding the studies on the effectiveness of QE asset purchase programmes, as well as on their respective transmission channels, including the specific case of Japan, all the way through the Global Financial Crisis and beyond for the US, UK, and Euro Area. Section 3 discusses in detail the components of the dataset. Section 4 explains the empirical methodologies and the identification scheme specifications herein used. Section 5 presents the macroeconomic impacts of QE asset purchases on both the baseline model and transmission channels, and assess the robustness of our results. Finally, section 6 concludes.

2. Literature Review

According to the BofE (2020), its main objectives are to maintain financial and monetary stability. Financial stability is achieved through the supervision, protection, and enhancement of the resilience of the financial system as a whole and through liquidity provision, in order to reduce the cost of disruption to critical financial services. On the other hand, monetary stability is achieved by influencing market interest rates to deliver the specific decisions advanced by the MPC. Every year, the Chancellor[2] sets out a framework under which the MPC has to set monetary policy.

The main objective of the MPC is to maintain price stability, setting monetary policy to achieve the Government's target of keeping inflation at 2%, while helping to sustain growth and employment (BofE, 2016). To maintain monetary stability, the MPC currently influences monetary conditions, including the level of prices of goods and services and the availability of credit, taking into account the available monetary policy tools. In terms of conventional monetary policy, the MPC intervenes through open-market operations in the sterling overnight money market, influencing short-term market interest rates (which is the interest rate that banks charge to borrow money among them), thus setting the BofE policy rate – the Bank Rate, and by playing a key role in the implementation of monetary policy (Jackson and Sim, 2013; and BofE, 2020).

The Global Financial Crisis of 2008-2009 had devastating impacts on both the financial sectors and real economies, and Central Banks have used every possible instrument of conventional monetary policy in order to provide additional support in the short to medium term, thus cutting policy rates close to zero. The MPC decided to lower interest rates from 4.5%, in October 2008, to a record low of 0.5%, in March 2009. Nevertheless, the MPC felt that additional stimulus to the economy was required given the severe impact of the Great Recession. Therefore, at the March 2009 meeting, the MPC also announced, in addition to the interest rate cut, the introduction of an unconventional monetary policy – QE, through a recently created fund – APF. The MPC would continue to use it as a monetary policy tool, long after the Global Financial Crisis subsided, purchasing government debt (gilts[3]) and corporate debt, financed by Central Bank reserves, specifically after the Brexit referendum (on 23rd June 2016) and, more recently, due to the global pandemic crisis (2020). The figures[4] below show the evolution and the cumulative APF purchases[5] by type, since the beginning of the QE programmes in the UK, made by the BofE (Asset Purchase Facility Quarterly Report – 2021 Q1).

[2] The Chancellor leads the Treasury, which is the UK Government's department for economic and financial matters. They generate income (through tax and borrowing) and control government spending.

[3] According to the United Kingdom Debt Management Office, gilt is a UK Government liability in sterling, issued by Her Majesty's Treasury (https://www.dmo.gov.uk/responsibilities/gilt-market/about-gilts/).

[4] In the interests of openness and transparency, the BofE publishes quarterly reports on the transactions carried out as part of the APF since 2009 Q1, shortly after the end of each quarter.

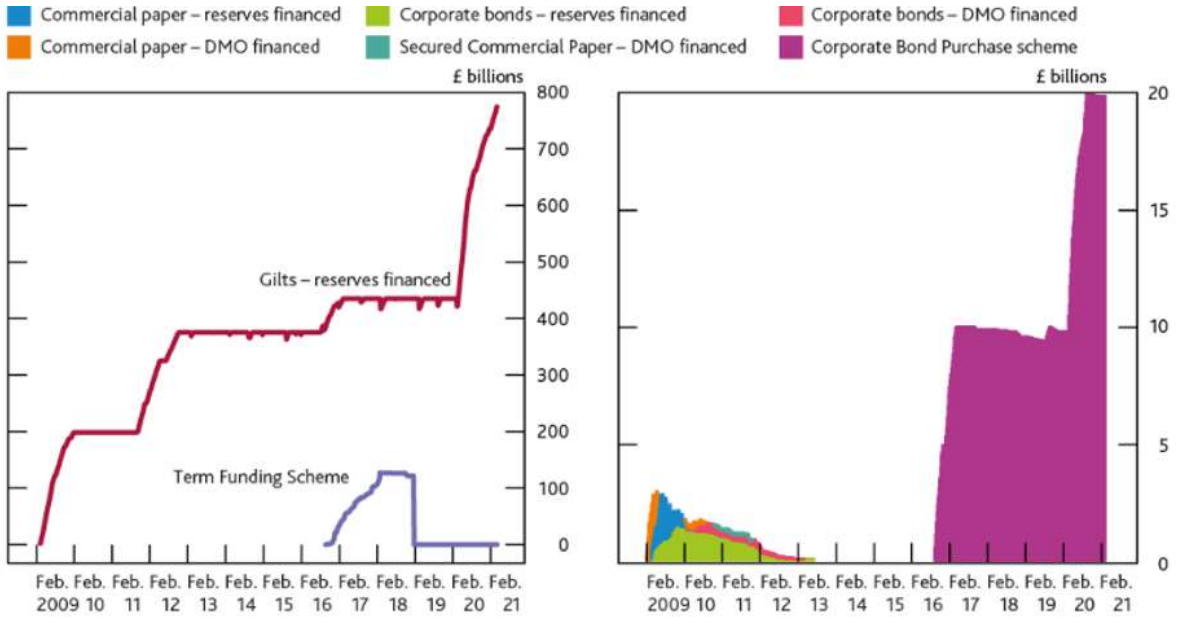
[5] Data based on settled transactions.

Table 1 - BofE purchases of bonds (£ billion)

Date of QE programme	BofE purchases of bonds (£ billion)
November 2009	£200 bn
July 2012	£375 bn
August 2016	£445[6] bn
March 2020	£645 bn
June 2020	£745 bn
November 2020	£895 bn

Source: Bank of England website (https://www.bankofengland.co.uk/monetary-policy/quantitative-easing)

Figure 1 - Cumulative APF purchases by type: amount outstanding



Source: Bank of England website (https://www.bankofengland.co.uk/asset-purchase-facility/2021/2021-q1)

Nevertheless, the BofE was not the first Central Bank to implement such measures[7] due to the Great Recession, as the Fed also introduced the LSAP after the zero-lower bound had been reached, as a way to ease the effects of the economic crisis and boost the financial and real economies. However, prior to the Global Financial Crisis, the BofJ had already employed the use of such unconventional monetary policies – namely QE. Japan's economy experienced a prolonged stagnation following the burst of the asset price bubble in the early 1990s, and with the failure of the BofJ reduction of its policy rate to zero, by 1999, allied to the continuing decline of consumer prices, weak banking system, and the prospect of

[6] Includes £60 billion of government bonds and £10 billion of corporate debt.

[7] On 21st January 2019 the TFS drawings were moved to the Bank's balance sheet and therefore are not reported after this date.

recession, these circumstances further led the BofJ to embark on a QE policy, from March 2001 to March 2006, in order to overcome persistent deflation (Bowman *et al.*, 2011).

2.1. Empirical findings and effectiveness of QE programmes

There are various articles that examine the effectiveness of QE policies at the zero-lower bound in different countries, throughout the implementation of several programmes, before and in the aftermath of the Great Recession of 2008.

The BofJ was the first to introduce QE policies, which have since been adopted by several other Central Banks. Ugai (2007) examines the effects of the BofJ QE policy, discovering that it maintained financial market stability and an accommodative monetary environment by removing financial institutions' funding uncertainty, preventing additional deterioration of the economy. On the other hand, it also finds that the QE effects solely from increasing the monetary base under the zero-lower bound constraint on interest rates, in raising aggregate demand and prices, are not detected or are small, when compared with periods without constraints on interest rates. Additionally, Schenkelberg and Watzka (2011) assess the real effects of QE measures adopted by the BofJ for a liquidity trap episode and find that the QE-shock positively and significantly affected industrial production by about 0.5%, after around two years, following an increase in reserves. In contrast, it also has practically no effect on CPI, hence the rate of inflation, and it does not significantly reduce long-term government bond yields. Moreover, the exchange rate channel is not significant, but the importance of this channel will be further discussed in the next section. Therefore, the author implies that QE can positively affect real economic activity, but not inflation, when the economy is in a liquidity trap and yields appear not to have been reduced by the policy shock. Nevertheless, it is not clear whether the experience of the BofJ during that period can be generalized to a worldwide financial crisis (Gambacorta *et al.*, 2014).

Later on, in response to the Global Financial Crisis of 2008-2009, Central Banks extensively used their conventional monetary policies and lowered policy rates to values close to zero. However, given the scale and impact of the said crisis, additional measures were thought necessary to support the financial markets and real economies. As a result, the Fed promptly initiated the first in a series of LSAP's, buying government and financial securities, starting in November 2008. Shortly after, on March 2009, the BofE launched their own series of QE asset purchases programmes, combined with the reduction of the Bank's policy rate. In the similar way to the events related to the BofJ QE policy, multiple researchers have investigated the effects of the Fed, BofE, and ECB unconventional policies on the financial markets and economies, in order to adequately estimate their impacts.

First, as a means to assess the effectiveness of unconventional monetary policies, researchers applied shocks to the spreads of yields. Baumeister and Benati (2010) innovatively examine the macroeconomic impacts in the US and UK, among other countries, using a compression in the long-term bond yield of the respective countries analysed, during the Global Financial Crisis. They find that

for all the countries involved, an unconventional monetary shock operating through the compression of the long-term yield spread exerted a prevailing increasing effect on both output growth (3% in the UK) and inflation (1% in the UK). In addition, based on the estimates of the impact of the Fed and BofE asset purchase programmes on long-term government bond yields spreads, the authors also conclude that unconventional monetary policies actions were successful in preventing not only deflation, but also output collapses comparable to those of the Great Depression.

Similarly, Lenza *et al.* (2010) also address the impact of unconventional monetary policies during the Global Financial Crisis through interest rate spreads, but focusing on the Euro Area. They compare their estimates between a policy and no policy scenarios, leaving the analysis of the US and UK open for future work. The applied Bayesian VAR model suggests that the measures implemented had a positive impact on economic activity, resulting in an unemployment rate of around 0.5% lower than would have been in the absence of such measures and an increase of 1.5% in the annual growth rate bank loans to household and corporate sectors. In general, the unconventional monetary policies induced economic stimulus and played a significant role in stabilising the Euro Area financial sector and economy. However, it was insufficient in order to avoid a significant drop in both economic and financial activity.

Joyce *et al.* (2011) address the impact of the BofE first round of QE programmes on UK asset prices. The authors look at various transmission channels of QE that might affect asset prices, paying special attention to the portfolio balance, which will be further examined in the next sections. The main conclusion is that QE asset purchases may have depressed gilt yields by about 1%, varying between 0.55% and 1.20% across the five- to twenty-five-year segment of the yield curve, which otherwise would not have had a significant impact on the financial markets.

Based on the empirical findings proposed by Joyce *et al.* (2011), Kapetanios *et al.* (2012) also examine the macroeconomic impact of the first round of QE asset purchases by the BofE, which started in March 2009, and attempted to quantify the effects of these purchases by focusing on the impact of lower long-term interest rates on the wider economy through three different models. The authors ignore other transmission channels, but the average estimates for simulations from the three models suggest that QE may have had a peak effect on the level of output of around 1.5% and on annual inflation of about 1.25% for the UK, varying across the models.

As time progressed and the programmes advanced, researchers have started to apply shocks either to the Central Bank balance sheets, announcements or quantities of assets purchased, rather than simply to the spreads of yields. Behrendt (2013) estimates the effects of unconventional monetary policies focusing on consumer price inflation, lending, and asset prices, through a VAR analysis for 9 countries each with different window lengths via Central Bank balance sheets, rather than through the decreasing

yields, and the results of the model are quite similar to those found during the Japanese monetary easing period in the mid-2000s. Contrary to expectations, in all countries sampled, inflation does not increase above the Central Bank targets, a finding which is due to an underutilisation of capacity in the depressed economies. Credit acceleration after the financial crash cannot be seen in the data. Industrial production rose ever slightly for a short period of time, but this effect is not persistent. Additionally, the stock market falls, but then reacts slightly positive, though it does not appear to stem directly from balance sheet policies. Nevertheless, Behrendt (2013) finds balance sheet policies to be effective as an immediate response to a given financial crash following excessive loan origination and the burst of an asset price bubble, but are then exposed to diminishing returns in the long run.

Gambacorta *et al.* (2014) assess the macroeconomic effects of unconventional monetary policies by estimating a panel VAR for 8 advanced economies over the Global Financial Crisis period. The authors simulate an increase in the Central Bank balance sheet of about 3%, that fades out after approximately 6 months, with a combination of zero and sign restrictions imposed, through the use of identification schemes, and explore the dynamic effects of the shock on output, price level, and the VIX. The responses of output and prices indicate that unconventional monetary policy measures, after the zero-lower bound had been reached, are effective in supporting the macroeconomy, displaying a significant increase. However, it appears that the shocks had a relatively large impact on output and smaller price effects than conventional monetary policy shocks. The estimations also suggest that the macroeconomic effects were quite similar across countries. This may have potentially reflected the fact that the different Central Banks have tailored their unconventional policy measures with similar success to specific needs of their respective financial sectors and economies. Nonetheless, the findings do suggest that the measures provided temporary support to their economies. Yet, they do not necessarily imply that an expansion of Central Bank balance sheets will in general have positive macroeconomic effects.

Weale and Wieladek (2014b) research the effects of Central Banks' unconventional monetary policies on the real economy, namely on output and prices, for the UK and US, from March 2009 to May 2013, closely following Gambacorta *et al.* (2014). While previous Bayesian VAR researches employed a compression in spread shocks as an expansionary unconventional monetary policy shock (Baumeister *et al.*, 2010; Lenza *et al.*, 2010; Kapetanios *et al.*, 2012), Weale and Wieladek (2014b) use shocks to the asset purchases announcements. They use a Bayesian VAR study and implement three identification schemes using zero and sign restrictions, and estimate the results based on a positive shock worth 1% of the asset purchase announcement, both for the US and UK. The results are on average 0.36% (0.18%) and 0.38% (0.30%) in real GDP and for price level for the US (UK), (Weale and

Wieladek, 2014b). In addition, they use two different estimators[8] to examine robustness across estimation techniques. Overall, their findings are encouraging, because they suggest that unconventional monetary policy in the form of asset purchases can actually be effective in stabilising output and prices.

Churm *et al.* (2015) evaluate the macroeconomic effects of the additional QE programmes and the introduction of a FLS during the latter stages of the Global Financial Crisis (2011-2012) in the UK. First, they use existing and new approaches to determine the effect of unconventional policies on relevant financial variables, such as spreads and bank funding costs. Second, they use two models to map out the effect that changes in financial variables and bank funding costs had on the macroeconomy. The policies are seen as complements, as QE effectively bypasses the banks by attempting to reduce risk-free yields directly in order to have a wider effect on asset prices. Starting with FLS, the authors have documented the schemes effect on bank wholesale funding spreads and consider the effect this drop in spreads had on GDP growth and inflation. They find that the second round of BofE QE and the initial phase of the FLS has boosted GDP growth by between 0.5% to 0.8% and inflation by about 0.6%.

Andrade *et al.* (2016) analyse the effects of the early ECB expanded asset purchases programme both on yields and macroeconomy, shedding some light on its transmission channels using VAR methodologies. The research provides evidence suggesting that the ECB asset purchase programme is effective in further easing the stance of monetary policy in the euro area economy. The authors mention several transmission channels that appear to have been activated, some of which will be further investigated in the next sections. Overall, they demonstrate that the QE announcement, on January 2015, significantly and persistently reduced sovereign yields on long-term bonds by 0.45%, raising the share prices of banks that held more sovereign bonds in their portfolios, while at the same time elevating economic output by 1.1% and inflation by 0.4%.

Haldane *et al.* (2016), estimate the impact on financial markets and on real economy of Central Bank balance sheet expansion, through the use of a structural VAR model for six countries, including the estimation of international spill-over effects of QE. Similarly to Weale and Wieladek (2014b), they impose several identification schemes with different restrictions, including zero and sign restrictions, into the model. On the first identification scheme they also use a lower-triangular scheme and look at the impulse responses to an 1% Central Bank asset purchase announcement (as a % of GDP), for each country. The time frame for the countries varies from one to another, but they include the Global Financial Crisis period and the period during which QE was actively used by the Central Banks. They find that it is only when Central Bank balance sheet expansions are used as a monetary policy tool that they have a significant impact on financial markets, generating a significant loosening in credit

[8] Weale and Wieladek (2014b), employ two different priors as a way to overcome the problem associated with short times series for the sample period, namely the Litterman prior (1986) and the hierarchical panel VAR prior, proposed by Jarocinski (2010).

conditions. Regarding the impacts on real GDP and CPI for identification scheme I, the authors find an impact of 0.11% for GDP, but none for CPI. The average for all the schemes used for the UK regarding the impact of an expansion of the BofE balance sheet on real GDP is 0.24% and 0.34% for CPI. In addition, there is also evidence of QE having served to temporarily boost output and prices, in a way not associated with other Central Banks balance sheet expansions. However, the effectiveness of QE policies does vary both across countries and time, depending on the state of the economy and liquidity of the financial system. There is also some evidence of QE interventions being more effective when financial markets are disturbed and of strong positive international spill-overs effects of QE from one country to another via financial transmission channels.

Subsequently, Weale and Wieladek (2016) expand their initial 2014 study and continue to explore the impact of the announcements of LSAP of government bonds on real GDP and the CPI, in the UK and US, through a Bayesian VAR, implemented from March 2009 to May 2014. They use four different identification schemes of zero and sign restrictions, leaving the reactions of both GDP and CPI unrestricted. The impact of an asset purchase announcement shock worth 1% of GDP on the variables led to a statistically significant increase on average of 0.58% (0.25%) and 0.62% (0.32%) rise in real GDP and CPI for the US (UK). For the first identification, which is a lower-triangular scheme, the shock led to an impact of around 0.15% (GDP), 0.10% (CPI), 0.08% (Long Rate) and 1% (Real Equity Prices) at its peak, in the UK. Moreover, they look at the different transmission channels, some of which are used in the present Dissertation, and the effects on such channels will be studied in the next sections. Despite using the asset purchases announcements, the authors test with actual purchases and found little difference in their findings. Overall, the authors reach the same conclusion as in their previous research, where asset purchases were effective in supporting GDP in both the US and UK in the aftermath of the Global Financial Crisis, and these programmes continue to retain effectiveness beyond the acute phase of the crisis. The authors argue that this should provide reassurance to those who argue that monetary authorities will not be able to respond to renewed global demand weakness, even with interest rates in their zero-lower bound.

Hesse *et al.* (2018) assess the macroeconomic effects of the LSAP's launched by the Fed and the BofE, from November 2008 to October 2014 (for the US), and from January 2009 to November 2016 (for the UK). They employ a Bayesian VAR and look at the impulse response functions results, in order to investigate the macroeconomic impact of an asset purchase announcement shock worth 1% of GDP and assess changes in their effectiveness based on a sub-sample analysis. The impulse responses were broadly in line with the ones observed in Weale and Wieladek (2016), both for the US and UK, with a maximum increase of around 0.20% both for real GDP and CPI, while bond yields displayed a short-lived fall of up to 0.10% in the US and up to 0.20% in the UK. Stock prices, in turn, increased persistently by up to 2% in the US and 4% in the UK. Their results suggest that the early asset purchase programmes have had significant positive macroeconomic effects while the subsequent programmes were less

effective and partially not significantly different from zero. A similar conclusion is reached, but in terms of spread shocks, by Baumeister and Benati (2010) and Kapetanios *et al.* (2012). Borio and Hofmann (2017) suggest these findings are consistent with the notion that monetary policy transmission may have softened because of macro-financial "headwinds" that blew in the recovery from the Global Financial Crisis and because of persistent low interest rates eroding transmission effectiveness through adverse effects on bank profitability, saving behaviour, resource allocation, and confidence. A better anticipation of asset purchase programmes over time seems to partly, but not fully, explain their measured ineffectiveness during the recovery from the Global Financial Crisis. The estimated effects are still smaller in size than the ones they obtained before for the early asset purchase programmes which could, if anything, even be downward biased if anticipation effects were also present in this earlier period. Furthermore, in all estimations, there is a significant and persistent positive impact of asset purchase shocks on stock prices, suggesting that they may have been driving factors of rising stock market valuations in recent years.

Lastly, Hohberger *et al.* (2019) estimate an open-economy DSGE model with Bayesian techniques to provide a structural empirical evaluation of the macroeconomic effects of the ECB's QE programme, from the first quarter 1999 to the fourth quarter of 2018. They introduce and identify several parameters enabling to capture a large number of the transmission channels put forward in the literature, including the saving, financing cost, and exchange rate channels. In addition, they rely on a methodological extension that measures the non-linear contribution of QE in a shock decomposition under an occasionally binding zero-lower bound. Their results suggest an average contribution of ECB QE to annual Euro Area GDP growth and CPI inflation in 2015-18 of 0.30% and 0.50%, respectively, with a maximum impact reached in 2016.

According to the present academic literature review, it is possible to observe that Central Banks have tailored their unconventional policy measures and, as a whole, unconventional monetary policies, through QE asset purchases, which have been successful in preventing not only deflation but also greater output collapse. The programmes appear to have served as a viable instrument to help stabilize and stimulate the financial markets, inflation, and output, having retained effectiveness well beyond the Global Financial Crisis (Weale and Wieladek, 2014b; 2016). In addition, early asset purchase programmes seem to have had greater macroeconomic effects than those subsequent this systemic event, due to the possibility of better anticipation from economic agents (Hesse *et al.*, 2018), giving indication of possible diminishing returns in the long run (Behrendt, 2013). Nevertheless, the empirical results[9] presented previously do not necessarily imply that an expansion of Central Bank balance sheets will, in general, have positive effects on the macroeconomic variables (Gambacorta *et al.*, 2014), as seen in the

[9] The different results from previous QE asset purchase programmes referenced in the present literature review are included in Appendix A.

case of Japan. The effects may vary both across countries and time, depending on the state of the economy and liquidity levels of the financial system (Haldane *et al.*, 2016).

In the next section we will explain some of the several transmission channels addressed by previous authors, through which QE asset purchases can impact the macroeconomy, as some channels are also relevantly addressed in the present Dissertation.

2.2. Main Transmission Channels

There is a vast empirical work on the QE effects of Central Bank interventions in the financial markets as well as on macroeconomic variables that could serve as transmission mechanisms. Originally, initial researches assessed the macroeconomic impact of QE programmes through a compression in the long-term bond yield, leaving the short-term rate unchanged due to the zero-lower bound. Subsequently, more recent researches started to apply shocks either to Central Bank balance sheets, announcements, or quantities of assets purchased.

According to economic theory, asset purchases affect the macroeconomy and this impact can be assessed by means of certain transmission channels.

2.2.1. Portfolio Rebalancing

One channel which can be activated through asset purchases is the portfolio rebalancing effect[10]. This channel has long been addressed by several researchers and has become increasingly relevant more recently with the implementation of unconventional monetary policies.

This particular channel depends on the assumption that economic agents have a preferred-habitat for a given maturity in the bond market, thus causing imperfect substitutability between assets (Vayanos and Villa, 2009). According to Tobin (1958), investors do not view different financial assets, such as bonds and Central Bank reserves, as perfect substitutes, otherwise the purchases would not have the effect intended (Joyce *et al.*, 2011; Rosa, 2012). Tobin (1961), among others, showed that if assets are not perfect substitutes, then a change in the quantity of an asset will lead, *ceteris paribus*, to a change in its relative expected rate of return (Joyce *et al.*, 2011). Therefore, asset purchases would lead to a reduction of the supply of long-term bonds, pushing up their prices, as well as the price of other assets that are closer substitutes for the purchased asset than money, lowering their yields and passing it onto other assets prices, stimulating demand (Rosa, 2012).

The impact may happen both on the announcement date and over time, as investors are able to adjust their portfolios, since this channel depends on perceptions of the path of outstanding stocks of gilts and money (Joyce *et al.*, 2011). Therefore, when investors are faced with a scenario of diminishing

[10] Also known as asset valuation channel (Andrade *et al.*, 2016).

expected returns, they feel motivated to rebalance their portfolios in response to QE asset purchases, switching into longer duration or riskier assets (Gagnon *et al.*, 2010; Haldane *et al.*, 2016).

Ugai (2007) researches the effects of the BofJ QE policy, finding mixed results as to whether the portfolio rebalancing has any effect on narrowing the premium portion of bond yields. Those who detect a positive effect generally conclude that the magnitude of the effect is relatively small (Kimura *et al.*, 2002). Additionally, Schenkelberg and Watzka (2011) in their assessment of the real effects of QE measures adopted by the BofJ, suggest that a direct quantity effect through the portfolio rebalancing channel has not been at work following the QE policies of the BofJ. More recently, results show that the primary channel through which asset purchases appear to work is the portfolio rebalancing effect (Gagnon *et al.*, 2010; Joyce *et al.*, 2011; Christensen and Krogstrup, 2016). However, the portfolio rebalancing channel may be stronger under stressed financial market conditions, but consequently weaker once conditions normalise (Hesse *et al.*, 2018).

This channel has been shown to have an important role in the transmission of QE policies not only in the UK, but also in the US and the Euro Area, as mentioned by Gagnon *et al.* (2010), Krishnamurthy and Vissing-Jorgensen (2011), Joyce *et al.* (2011), Kapetanios *et al.* (2012), D'Amico and King (2013), Weale and Wieladek (2014b; 2016), Andrade *et al.* (2016) and Haldane *et al.* (2016). Moreover, it appears to be important in the early stages of the LSAP programmes for certain types of assets (Gagnon *et al.*, 2010).

In the current Dissertation we examine the impact on the 20-year and 30-year government bond yields and whether the portfolio balance channel is the main transmission channel. In the affirmative case, one would expect a significant reduction of yields, in accordance with Weale and Wieladek (2014b; 2016). In addition, portfolio rebalancing channel may lead to effects on other asset classes such as the real exchange rate and real house prices, which are also taken into consideration in the present Dissertation.

2.2.2. Signaling Channel

There are additional transmissions channels through which the QE asset purchases are expected to work, such as the signaling channel. This channel, along with the portfolio rebalancing, have been the most important and most discussed channels in past researches.

Eggertson and Woodford (2003) and Bernanke *et al.* (2004) were among the first to mention the signaling channel and they suggest this particular channel should be taken into account by Central Banks when monetary policy is constrained by the zero-lower bound on short-term nominal interest rates. The channel works through changing market expectations about future monetary policy (Christensen and Krogstrup, 2016). Therefore, QE asset purchases signal that the policy interest rate will remain at its effective lower bound for longer (Weale and Wieladek, 2016). Moreover, it can be usefully combined

with a reinforced form of forward guidance, in order to avoid unwarranted beliefs of an earlier lift-off of the nominal interest rate from its effective lower bound, in light of subsequent upward increases in expectations of future inflation (Andrade *et al.*, 2016).

Contrary to the non-existent or rather small magnitude of a portfolio rebalancing channel in Japan, the signaling channel appears to have been present during certain phases, where the effect from an increase in the BofJ current account balances encouraged the expectations that monetary easing would continue into the future (Ugai, 2007). Gagnon *et al.* (2010) discovers little evidence to support this notion in the early programmes of QE in the aftermath of the Global Financial Crisis, but a large number of researchers have found evidence of the importance of the signaling channel as a way of lowering yields during the QE programmes in the UK, US, and Euro Area.

Krishnamurthy and Vissing-Jorgensen (2011) find significant evidence of the signaling channel, which has driven down the yields[11] of all bonds during the first two QE programmes in the US, although with greater impact in the first programme than in the second programme. Bauer and Rudebush (2014) also suggest the presence of strong signaling effects in the Fed's first QE programme, which has led to lower expected future short-term interest rates. The authors then extend their research into subsequent programmes and the results indicate that signaling effects are relatively small, which comes as no surprise since market participants already expected exceptionally low policy rates over a substantial time horizon at the time of the new announcements. According to Hesse *et al.* (2018), the signaling effect may weaken when short-term rates have been at very low levels for an extended period of time. In the case of the Euro Area, Andrade *et al.* (2016) suggest that the ECB's extended asset purchase programme is effective in further easing the stance of monetary policy in the euro area economy and also find that the signaling channel contributes to edge down market expectations of future short term interest rates, while inflation expectations tend to increase. Regarding the UK, Weale and Wieladek (2014b; 2016) conclude that the signaling channel appears to have played a more significant role than the portfolio rebalancing, where asset purchases have had a greater impact on interest rates futures than on long-term bond yields (the opposite is observed in the case of the US).

An announcement heightens risk concerns, affecting all bond market interest rates, because interest rates depend on the expected future path of the policy rates. They should have a larger impact on shorter and on intermediate maturities rather than on long-maturity rates since the commitment to keep rates low lasts only until the economy recovers (Krishnamurthy and Vissing-Jorgensen, 2011; Weale and Wieladek, 2014b; Kenourgios *et al.*, 2015). One way to examine this channel would be by looking at the reaction of the OIS futures of the 3-month interest rate, 6 months, 1 year, and 2 years ahead, following the research design adopted by Weale and Wieladek (2014b; 2016). However, the current

[11] It had larger effects on intermediate- than on long-term bonds.

Dissertation chooses not focus on this current channel, due to space constraints, leaving it as a suggestion for further research, along with additional transmission channels, such as the liquidity channel (Bowman *et al.*, 2011; Krishnamurthy and Vissing-Jorgensen, 2011; Joyce *et al.*, 2011; Steely, 2015; Haldane *et al.*, 2016) and the credit channel (Bowman *et al.*, 2011; Churm *et al.*, 2015; Haldane *et al.*, 2016).

2.2.3. Expectations Channel

Additionally, Weale and Wieladek (2014b; 2016) mention a third channel through which QE asset purchases can affect the macroeconomy – the expectations channel[12].

Through the expectations channel, QE asset purchases may reduce uncertainty about the future path of interest rates and the economy overall (Weale and Wieladek, 2014b). Therefore, these asset purchases help to manage expectations about future economic outcomes and consequently economic uncertainty, reflecting a general positive effect of purchases on consumer and investor confidence (Weale and Wieladek, 2016; Hesse *et al.*, 2018). However, its effectiveness is only assured when economic agents believe QE will improve future economic outlook (Haldane *et al.*, 2016).

Bernanke *et al.* (2004) also address the importance of the expectations channel, concluding that this channel appears to have led to lower long-term yields than would otherwise have been expected. More recently, Tsuji (2016) suggests that the expectation channel is the primary channel during the BofJ QE policy. For the case of the US and the UK, Weale and Wieladek (2014b; 2016) conclude that QE asset purchases reduced measures of financial market and household uncertainty in both countries for the period of the Global Financial Crisis, suggesting that managing expectations through reducing uncertainty may be relevant for both countries. Also, Hesse *et al.* (2018) find that expansionary asset purchases shocks exert some positive confidence effects in financial markets, reflected in a significant drop in the VIX. Moreover, for the US there was a considerable drop in the VIX in the first[13] period, but no significant effects on the second[14], while the opposite results were found for the UK. Regarding, uncertainty around economic policy, Hesse et al. (2018) conclude that for both countries, no effect is found on the first sample, and a very short-lived positive initial effect is found on the second.

That said, we examine the impact of the BofE asset purchases shock on the financial market's indicator of uncertainty, commonly known as the VIX, following Weale and Wieladek (2014b; 2016). Moreover, due to the uncertainty after the Brexit referendum, we also include a measure of economic policy uncertainty – EPU. This index captures uncertainty from news, policy, market, and economic

[12] Also known as either the uncertainty channel, risk aversion channel, or confidence channel (Weale and Wieladek, 2014b; 2016; Haldane *et al.*, 2016; and Hesse *et al.*, 2018).

[13] Period spreading from November 2008 until mid-2011, for the US, and from January 2009 until mid-2011, for the UK.

[14] Period spreading from mid-2011 until October 2014, for the US, and from mid-2011 until November 2016, for the UK.

indicators (Al-Thaqeb and Algharabali, 2019). This phenomenon may lead to postponement in spending and investments by businesses and individuals because of the prevalence of economic uncertainty in the markets, as well as consumption decrease, affecting economic growth (Al-Thaqeb and Algharabali, 2019). Additionally, this index is highly correlated with the VIX.

2.2.4. Exchange Rate Channel

To the extent that the portfolio rebalancing channel may lead to effects on other asset prices, we also consider another transmission channel through which QE asset purchases are expect to work as a result of variations on interest rates – the exchange rate channel.

This channel is expected to work through the depreciation of the price of domestic currency relative to others, as a result of QE asset purchases.

Svensson (2001; 2003) suggests[15] the nominal exchange rate as an alternative policy instrument when the economy is faced with a zero-lower bound. Subsequently, Bernanke *et al.* (2004) agrees to the possibility of changing the current policy instrument by the Central Banks, in order to help future policies to be more effective and have a more visible impact.

Schenkelberg and Watzka (2011) discover evidence of depreciation of the domestic currency, but it was not significant in the initial QE programme in Japan. Similarly, Dell'dAriccia *et al.* (2018) find that the BofJ's subsequent unconventional monetary policies and forward guidance programmes, initiated in October 2010, did not led to the depreciation in the Japanese Yen exchange rate. Later on, in February 2013, the BofJ launched a new QE asset purchase programme, and still, deflationary pressures re-emerged in late 2014, leading the BofJ to increase the QE asset purchases and initiate a new programme. In general, the impact on the exchange rate was marginal, possibly explained by the previous depreciation of the Japanese Yen a few months earlier, during Abe's (Japan's then Prime Minister) electoral campaign, when he called for extraordinary monetary easing. Despite the extraordinary size of the new QE asset purchases programmes, these actions failed to deliver a sustained increased in inflation.

On the other hand, Joyce *et al.* (2011) state that because investors do not regard money as a perfect substitute for government bonds (gilts), investors would be expected to reduce their holdings related to QE by buying other sterling assets, such as corporate bonds, equities, and foreign assets. This is likely to lead to an upward pressure on the prices of such assets and a possible downward pressure on the sterling exchange rate. Rosa (2012) finds impact of asset purchases on the British Pound exchange rate and that an unanticipated QE announcement of asset purchases, when none was expected, was associated with a depreciation of the value of the British Pound against major currencies of about 0.4%. Moreover,

[15] See, for example, Svensson (2001; 2003) and Bernanke *et al.* (2004) for more information.

Glick and Leduc (2012) show that the QE announcements during the first QE programmes had a depreciation effect on both the US Dollar and on the British Pound. Later on, Weale and Wieladek (2014b) observe that asset purchases led to a greater exchange depreciation in the US Dollar than in the British Pound. More recently, Broadbent *et al.* (2019) demonstrates that Brexit induced a sharp drop in the UK real exchange rate as a result of the outcome of the referendum and remained persistently below the levels observed immediately before the referendum, which is consistent with their simulation.

Belke *et al.* (2017), who also discover large announcement effects related to US programmes, suggest that the exchange rate channel should work only if QE has effects on international interest rate differentials, but a problem in estimating the impact of QE is that asset markets tend to anticipate future policy actions. Long interest rates and exchange rates are often said to be more impacted by expectations about the future than by present economic conditions. Therefore, QE announcements may have a larger impact than its implementation. Furthermore, Boechx *et al.* (2017) conclude that an ECB balance sheet shock leads to a depreciation of the nominal effective exchange rate for the euro of approximately 0.4%, which is consistent with the existence of an exchange rate channel related to balance sheet policies. Cova *et al.* (2015) also find a significant role in the exchange rate channel through the depreciation of the currency, which contributes to a persistent increase in both output and inflation in the Euro Area.

The present Dissertation assesses the relevance of this channel through the impact on the variations in the real effective exchange rate throughout the period of QE asset purchases in the UK. In addition, it is considered another asset price instrument, house prices.

There have been multiple studies regarding QE asset purchases, not only in the UK, but also for the US, Euro Area, and Japan, amongst others. However, none addresses the specific expansion of the BofE QE asset purchases programme of August 2016, as a way to meet the 2% inflation target, thus helping to sustain growth, employment, and alleviate uncertainty, following the UK's vote to leave the EU – Brexit on the 23rd June 2016.

Therefore, the present Dissertation is guided by the following research question: "What were the macroeconomic impacts of the expansion of the BofE's QE asset purchase programme, after the Brexit referendum?". The current Dissertation extends previous works (Weale and Wieladek, 2014b; 2016; and Hesse *et al.*, 2018), by attempting to provide lower-bound estimates to the effects related to the BofE expansion of the QE asset purchase programme on the UK macroeconomic variables, after the Brexit referendum took place. Finally, this research provides a base for future investigations on other transmission channels and provides further suggestions for improvements to the model and restrictions applied.

3. Data

Following the United Kingdom's vote to leave the EU ("Brexit"), the economic outlook for growth in the short and medium term weakened substantially (BofE, 2016). These developments led to the introduction of a package of measures designed to support economic growth and price stability, as mentioned in previous sections.

The VAR model is estimated using monthly time series data from August 2016 to January 2019 (including these months). The time length associated with the adopted research design incorporates the period from the beginning of the implementation of asset purchases until January 2019. This latter date is chosen due to the fact that March 2019 signals the formally agreed date where the UK would officially leave the EU. By putting aside these two months, this procedure allows for the elimination of data that otherwise would greatly bias the results of the programme due to the increase of uncertainty in the financial markets and significant drops in both economic growth and inflation.

3.1. Variables Description

Regarding the variables used in the baseline VAR model, it is necessary to consider the following:

(i) Inflation, computed as a monthly percentage change, is measured through the CPIY, where the effects of changes to indirect taxes are excluded allowing to avoid possible distortions, at monthly frequency, as per the statistics from observed from the ONS.

(ii) Since macroeconomic data for variables such as GDP are not available on a monthly basis, the PTI series is used as a proxy for economic growth, in the UK. This is computed as a monthly percentage change, seasonally adjusted at monthly frequencies from the FRED.

(iii) The asset purchases series is computed from the published APF Quarterly Reports, which is reported as the accumulated actual purchases of gilts (government bonds) and corporate bonds, made by the BofE, over the window length of this research. To arrive at a scaled value, the asset purchases are subsequently divided by the value of the third quarter nominal 2016 GDP (2016Q3), at market prices, seasonally and calendar adjusted data obtained from Eurostat.

(iv) The 10-year government bond yield is used as a measure for the long-term interest rates and the data is obtained from Bloomberg, through daily rates and subsequently interpolated to monthly data.

(v) Real asset price growth is measured as the FTSE 100 Price Index, as observed in Datastream, and this metric is deflated by CPIY and linearly interpolated from daily to monthly data.

In order to fully describe and discuss the possible transmission mechanisms related to the implementation of the addressed QE programme by the BofE, it is necessary to analyse the impact of the latter Central Bank's asset purchases on additional variables.

Therefore, several other variables are included, separately. First, the portfolio balance transmission channel, through the critical analysis of 20-year and 30-year government bond yields, where the same methodology used for the 10-year government bond yield has been applied, using data extracted from Bloomberg. According to previous academic literature, one would expect a relatively large impact through the reduction of yields from asset purchases, thus demonstrating the relevance of this transmission channel. Secondly, the expectations management channel, through the monthly percentage change in both VIX and EPU, using data obtained from the Investing.com financial platform and the Economic Policy Uncertainty, respectively. A reduction of economic/financial uncertainty will typically have a positive impact on economic activity and investment. Finally, other asset price channels, such as the monthly percentage change in house prices and the real exchange rate are also used, in order to measure possible lower costs of borrowing and domestic currency depreciation, as the effects of asset purchases could be felt on the latter variables in a subsequent moment. The multiple variable mnemonics and data sources for each variable included in the present Dissertation are described in Appendix B.

3.2. Summary Statistics

Before estimating the baseline VAR model, it is important to ascertain whether the time series related to the sample's variables (described in the previous section) are stationary. Stationarity is a desirable property, where according to Brooks (2014) if the distribution of its values remains the same as time progresses, implying that the probability that a variable fall within a particular interval is the same now as at any time in the past or the future, becomes even more important when trying to correctly estimate impulse response functions results. Therefore, all variables are subjected to the Augmented Dickey–Fuller tests, which reflects the possibility of rejection of the null hypothesis of a unit root.

From the reduce form summary statistics presented in Table 2, it is possible to observe monthly average growths for several important variables, as well as the yield for the 10-year government bonds. However, a more detailed summary statistics table is present in Appendix C.

Table 2 - Reduced form Summary Statistics of the variables

Variable	Inflation	PTI growth	10-year yield	Real Equity growth	VIX
Mean	0.177777	0.071177	1.258988	-0.079133	0.234995
Median	0.197922	0.100859	1.281184	-0.333959	-1.572455
Maximum	0.788181	1.608075	1.569550	4.998447	44.20608
Minimum	-0.846267	-1.235855	0.605087	-6.358726	-30.45078
Std. Dev.	0.381474	0.724321	0.212124	2.565139	14.53547
Skewness	-1.132366	0.290983	-1.207316	-0.209816	0.783846
Kurtosis	4.432492	3.033971	4.848052	2.817202	4.634770
Probability	0.011241	0.808642	0.003093	0.877269	0.040505
Sum	5.333305	2.135312	37.76963	-2.373976	7.049851
Sum Sq. Dev.	4.220154	15.21457	1.304900	190.8182	6127.115
Observations	30	30	30	30	30

According to Table 2, the characteristics for the variables in our sample include the mean, maximum and minimum, standard deviation and measures of normality. Concerning the dispersion of the variable's standard deviation, we would expect the time series concerning uncertainty in the financial markets and in the economy to show greater values. This is a direct consequence of the high uncertainty around Brexit during the time window adopted in this research, as both the VIX and EPU are actually more dispersed. In order to analyse normality, we first look at the skewness, followed by the kurtosis. According to Brooks (2014), skewness measures the asymmetric distribution of the series around its mean and for most of our sample has a negative skewness, which means that the distribution has a long-left tail where it has lower values than the sample mean. On the other hand, kurtosis measures the peakedness or flatness of the distribution of the series and most of our sample is leptokurtic, which means it has a peaked distribution relative to the mean, a fact which is in line with the general characterization of economic series.

Regarding the limitations associated with the dataset mentioned in the beginning of this section, QE purchases of gilts (government bonds) and corporate bonds lasted only 6 and 18 months, respectively, and these observations make for a very short sample. Therefore, most of the variables do not have a normal distribution and the latest observations of the dataset may mirror the increased uncertainty in the financial markets which is then transmitted onto the real economy. The variables subsequently introduced in our baseline VAR model reflect some of the possible transmission's channels herein previously discussed, but then again not all of them. However, it is well known that small[17] VARs may also suffer from omitted variable bias, where an asset purchase shock may reflect the reaction of the monetary authority to coincident developments (Weale and Wieladek, 2016).

[17] Our baseline VAR model consists of five variables.

4. Methodology

The present section addresses the empirical methodology (sub-section 4.1.) and the identification scheme (sub-section 4.2.) herein used.

4.1. Econometric Model

As previously mentioned in the literature review, multiple authors have addressed the impact of LSAP on macroeconomic variables since these programmes were introduced to the markets, by designing and implementing different types of models in order to assess their efficiency.

On the one hand, Gagnon *et al.* (2010), Chen *et al.* (2011), D'Amico *et al.* (2013), Gertler *et al.* (2013), and Hohberger *et al.* (2019) employ DSGE models to assess the impact of these programmes. Nevertheless, it should be observed that the use of the latter models is fraught with some issues, often making identification of real economic impacts somewhat difficult (Weale and Wieladek, 2014a).

On the other hand, Bayesian vector autoregressive models appear to provide a significantly more accurate depiction related to the identification of real economic effects, as long as they are combined with identification schemes in which economic growth and inflation are not restricted (Baumeister *et al.*, 2010; Lenza *et al.*, 2010; Kapetanios *et al.*, 2012; Hesse *et al.*, 2018; Evgenidis *et al.*, 2020; Weale and Wieladek *et al.*, 2014b; 2016; and Boechx *et al.*, 2017). Still, due to the relative brief history and duration of QE programmes, small sample sizes are a common research issue in studies attempting to investigate QE effects. One solution is the implementation of Bayesian VAR interference techniques which rely on the imposition of either the Litterman (1986) prior (Weale and Wieladek, 2014b) or the normal inverse-Wishart prior, as per Uhlig (2005) and Weale and Wieladek (2016). However, the methods described above are out of the scope of this paper.

Therefore, for the purpose of this research, a VAR model is herein implemented for the U.K., following the empirical approach of Behrendt *et al.* (2013). The corresponding impulse response functions[18] are also critically analysed, using the Cholesky Decomposition. Therefore, the estimations of macroeconomic effects of the APF by the BofE, and the corresponding transmissions channels are performed through the following VAR model specification:

$$y_t = a_1 y_{t-1} + \cdots + a_k y_{t-k} + e_t$$

Where y_t is a vector of endogenous variables at time t: inflation (CPIY), economic growth (PTI), asset purchases divided by the nominal value of the third quarter of 2016 GDP, the 10-year government bond yields (_10Y_YIELD) and the real equity prices growth (EQUITY_PRICES). Moreover, in order to study the various transmission channels, multiple variables are included separately; a_k is a matrix of

[18] The impulse response functions show a one standard deviation shock to each of the macroeconomic variables in response to an impulse on the variable asset purchases.

autoregressive coefficients of lagged values $y_{t-k}$with k as the number of lags, and e_t is a vector of residuals.

This model uses monthly data from August 2016 to January 2019, a total of 30 observations for each of the respective variables included in the specification. The length of the time window chosen for this research takes into consideration the introduction of the QE programme, which on 3rd August 2016 the MPC approved a package of measures designed to provide additional support growth and to achieve a sustainable return of inflation to the original target (BofE, 2016). The APF programme expansion had a duration of 6 months and because the analysis covers a very brief period, it might originate rather precarious estimates. The inclusion of data prior to the introduction of the QE programme would be a possible way to solve this issue, but as pointed out by Weale and Wieladek (2014b; 2016), the corresponding estimates could be biased and might not correctly reflect the impact of the new QE programme on the macroeconomic variables. Therefore, we combine the APF expansion with the CBSP, which had a duration of 18 months, which will allow us to obtain better estimations for the impact of an actual asset purchase shock.

Finally, another important parameter specification is the determination of the optimal lag length, through the Lag Length Criteria Test, in order to adequately estimate our baseline VAR model. This can be achieved through different approaches, either by using some theoretical models as comparison, using a rule of thumb, or through the use of statistical information criteria which are optimally adjusted against the number of variables/parameters fitted in the specification (Ouliaris *et al.*, 2016). According to Ouliaris *et al.* (2016), the first method could be based on previous theoretical models' use of historical values[19]; however, the present Dissertation employs a monthly dataset in the VAR specification. Hence, one could use a rule of thumb and employ a lag length of six to monthly data (Ouliaris *et al.*, 2016), but due to the small sample, this is not possible. A final way is to look at multiple statistical criteria, such as the AIC, the HQIC, or the SC (Ouliaris *et al.*, 2016). In small samples, models based on AIC may have better properties of the estimators than SC, as well as the HQIC, and should produce superior forecasts, according to Lütkepohl (2005). Since the present research culminates in the performance of impulse response functions analysis, AIC is likely more appropriate than the remaining criterions. The results presented in Appendix D show that a lag of three should be used, based on the standard lag order selection test for the AIC. Despite the stationarity of all the variables in the sample, the stability of the baseline model is also critically examined. Lütkepohl (2001) evaluates the stability of the VAR process through the inverse roots of the characteristic AR polynomial. Accordingly, the results for the baseline model indicate stability, hence stationarity, due to the fact that all the roots have a modulus less than one and lie inside the unit circle, as shown in Appendix E.

[19] An example could be a DSGE model (Ouliaris *et al.*, 2016).

Therefore, the present research uses the lag specified by Eviews10 as the most appropriate AIC to the baseline VAR model. Nevertheless, as a robustness test, we use a lag length of two, as proposed by Weale and Wieladek (2016), which is the most commonly used lag in the literature and compare the maximum impact of a one standard deviation on both lags, as well as with the results found for the same identification scheme by previous authors. Moreover, given that some of the criterions suggest a lag order of one they are shown in Appendix H.

4.2. Identification Scheme

Different combinations of identification schemes have been applied by previous authors either using sign restrictions (Kapetanios *et al.*, 2012; and Hesse *et al.*, 2018), zero restrictions (Behrendt *et al.*, 2013), or a mixture of both (Baumeister *et al.*, 2010; Gambacorta *et al.*, 2014; Weale and Wieladek, 2014b; 2016; and Haldane *et al.*, 2016) when estimating the macroeconomic effects of asset purchases.

The present Dissertation replicates the Cholesky Decomposition scheme also proposed by Behrendt *et al.* (2013), Weale and Wieladek (2014b; 2016), and Haldane *et al.* (2016), as described in Table 3.

Table 3 - The lower grey triangle indicates the response of the variable (column) to the shock (row) is unrestricted

Cholesky Decomposition	CPI	PTI	Asset Purchases	Long Interest Rate	Equity Price
CPI	1	0	0	0	0
PTI		1	0	0	0
Asset Purchases			1	0	0
Long Interest Rate				1	0
Equity Price					1

Table 3, shows the restrictions imposed by the Cholesky Decomposition, which uses a lower triangular scheme, where it is possible to see inflation (CPI) and economic growth (PTI) ordered before asset purchases, while the remaining variables are ordered subsequently. According to Weale and Wieladek (2014b) and Haldane *et al.* (2016), the order is due to the fact that output and prices react with a lag and apart from responding to the latter two variables, asset purchases do not react to any other variable meaningfully. Furthermore, the findings of Weale and Wieladek (2014b; 2016) show that the zero restrictions of the Cholesky Decomposition produced the lowest magnitude in terms of coefficients and significance, when compared with the different restriction tables, thus resulting in lower-bound estimates.

Therefore, by employing more complex identification schemes into the model, a more significant and perhaps more profound impact upon the variables and respective transmission channels should be observable. Baumeister *et al.* (2010), Gambacorta *et al.* (2014), and Weale and Wieladek (2014b; 2016)

further employ additional identification schemes, although these were not estimated due to space restrictions. Despite the different identification schemes employed by different authors in the existing literature, it is not possible to claim that one scheme is necessarily better identified or preferable to another (Weale and Wieladek, 2016).

5. Results of the VAR analysis

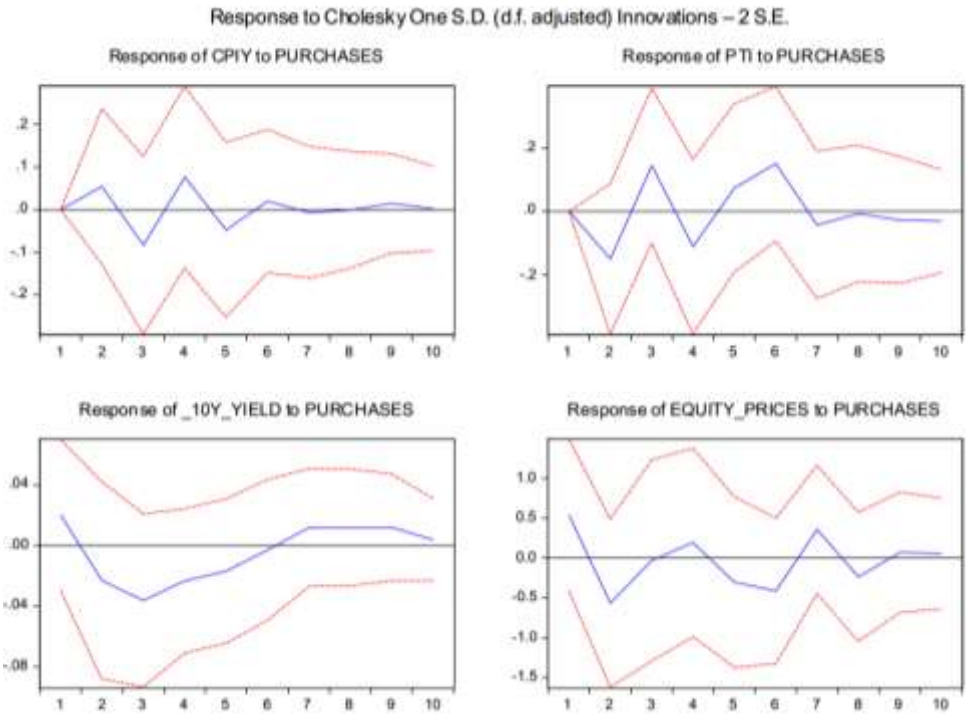
This section describes our empirical findings, which stand in comparison to those of previous studies regarding the impact of asset purchases in the UK, with both similar and different identification schemes. Additionally, the corresponding transmission channels are adequately addressed and the robustness of our findings are also examined.

5.1. Macroeconomic Effects

Firstly, we assess the effects of an unexpected asset purchase shock on multiple macroeconomic variables, from August 2016 to January 2019, including the sample period over which the asset purchase programmes were active in the UK. In the analysis, we normalise the asset purchase series by the respective value of GDP in August 2016, thus obtaining measures which can be compared with similar previous researches.

The impulses responses functions/estimations shown in Figure 2 are generated according to the Cholesky identification scheme, also used by Behrendt (2013), Weale and Wieladek (2014b; 2016), and Haldane *et al.* (2016). The sub-figures show the median impulse response of the macroeconomic variables in response to an unexpected actual asset purchase shock, where the units on the vertical axis represent the shock impact on each variable, whereas the horizontal axis indicates the number of monthly time periods since the asset purchase shock.

Figure 2 - Impulse response functions results of the baseline VAR model to an actual asset purchase shock of one Cholesky standard deviation



The results for the impact on both CPIY and PTI are quite mixed in terms of magnitude and signs, where the mean maximum impact on CPIY was -0.08% and 0.15% on PTI, though not statistically significant. This is in line with some previous studies, which also use the same identification scheme and find similar non-significant results for CPIY and slightly positive, but significant for output (Weale and Wieladek, 2014b; 2016; and Haldane *et al.*, 2016). One possible reason behind the small and non-significant results for CPIY and PTI could be associated with the specific use of a given identification scheme, which applies zero restrictions upon impact on these variables where the effect of the shock is not instantaneous, but reflected through the lag order in the model, according to which the lag length criteria suggested a lag order of three.

A closer examination of Figure 2 indicates the existence of the portfolio rebalancing transmission channel, which is in line with the main conclusions reported by Weale and Wieladek (2014b; 2016), as well as with general economic theory, which suggests that asset purchases would induce a compression of the yields (this actually happens in the short-run, as evinced by the corresponding sub-figure). Despite an initial increase, the 10-year government bonds yield displays a swift short-lived decrease with a mean maximum impact of -0.04%, similar to what Hesse *et al.* (2018) found (this channel will be more critically examined later on). According to Joyce *et al.* (2011), lower gilt (government bonds) yields should, *ceteris paribus*, lead to an increase in equity prices as investors attempt to rebalance their portfolios away from gilts towards riskier assets. However, if investors perceive the outlook for the economy to be worse than expected, this could lead to lower immediate expectations for future dividends, thus putting downward pressure on equity in the short-term. The FSTE 100 Price Index is thus stimulated for a brief period, although insignificant, after the asset purchase shock, but quickly drops to a mean maximum impact of -0.57%, appearing not to have any supportive effects, which may suggest that investors considered the consequences and implications of the Brexit referendum to lead to lower future dividends. In the same way, Joyce *et al.* (2011) also finds that equity prices did not react in a uniform way in response to the implementation of QE, falling sharply following the MPC announcement of the first QE programme in the UK.

Moreover, Weale and Wieladek (2016) discover the impact on the macroeconomic variables to be higher in different identification schemes than on the specific identification scheme used in the present Dissertation. These authors explain variances of results from different identification schemes as possibly reflecting the different identification schemes employed as a way to identify effects from economic theory.

Overall, the impulse response functions to an asset purchase shock for the baseline model show that the impacts tend to be in line with previous studies, which use similar identification schemes, though not statistically significant. The exception is the FTSE100 index, which does not seem to be positively impacted by QE effects in response to the shock, most possibly due to the economic uncertainty

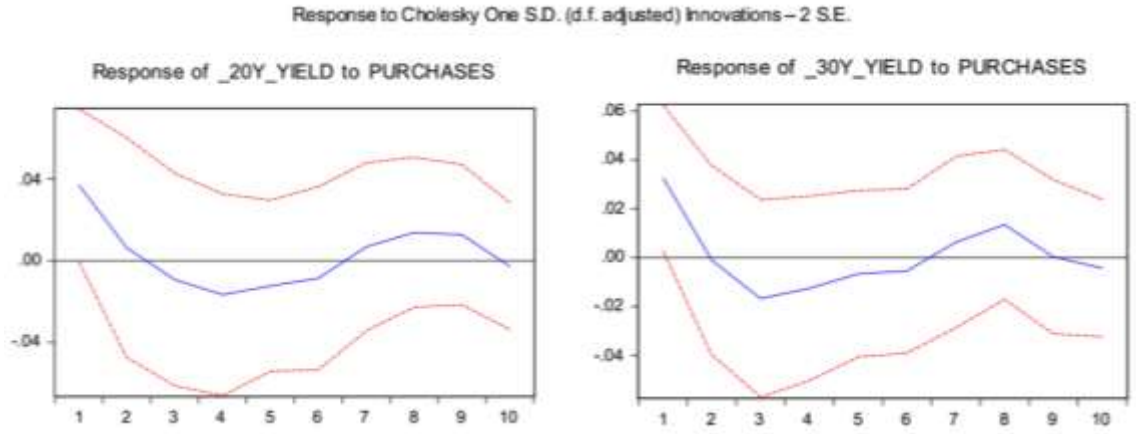
surrounding Brexit. Nevertheless, the baseline results appear to contribute to the knowledge/theory that QE may place a downward pressure on long-term yields, supporting the existence of a portfolio rebalancing channel (at least in the short-run). This channel will be studied subsequently along with several other transmission channels already mentioned in the literature review section.

5.2. Portfolio Rebalancing Channel

In the context of QE programmes, the portfolio rebalancing channel has been suggested as one of the most significant transmission channels related to asset purchases (Gagnon *et al.*, 2010; Krishnamurthy and Vissing-Jorgensen, 2011; Joyce *et al.*, 2011; Kapetanios *et al.*, 2012; D'Amico and King, 2013; Weale and Wieladek, 2014b; 2016; Andrade *et al.*, 2016; and Haldane *et al.*, 2016).

The findings related to the baseline VAR model for the 10-year long rate seem to suggest the presence of the portfolio rebalancing channel. Therefore, we have decided to examine additional long-term rates, in order to check for the possible effects of asset purchases on long-term yields. Hence, the 20-year and 30-year government bonds yields have also been included in the baseline VAR model, separately, as a sixth variable in our baseline VAR model.

Figure 3 - Impulse response functions results to an actual asset purchase shock to long-term government bonds yields of one Cholesky standard deviation



(i) 20-year government bonds yield (ii) 30-year government bonds yield

However, the results from the impulse response estimations shown in Figure 3, for the 20-year and 30-year government bonds yields seem to indicate a significant increase rather than their expected decrease. Following the outcome of the Brexit referendum, an unexpected QE asset purchase shock appears to result in a small, but statistically significant, increase of about 0.037% in the 20-year and 0.033% on the 30-year long-term government bonds yields, before decreasing and stabilizing. Weale and Wieladek (2016) discover analogous positive outcomes using the same identification scheme, where the shock led to a significant increase of 0.06% for the 20-year and 0.05% for the 30-year long-term government bonds yields, while on their previous research, the authors find relatively less impactful results. This is perfectly in line with the yield movements observed in the beginning of QE asset

purchases. While there is a short-lived decline in long-term government bonds yields, as a result of the outcome from the Brexit referendum - possibly due to lower expectations of future growth and inflation, as well as further unconventional monetary stimulus, we observe an increase in long-term government bonds yields by August 2016. One plausible explanation for the increase of long-term government bonds yields could be associated with higher market perception levels related to the future risk of the sustainability of the British economy in a post-Brexit environment, which might have increased bond yields.

5.3. Expectations Management Channel

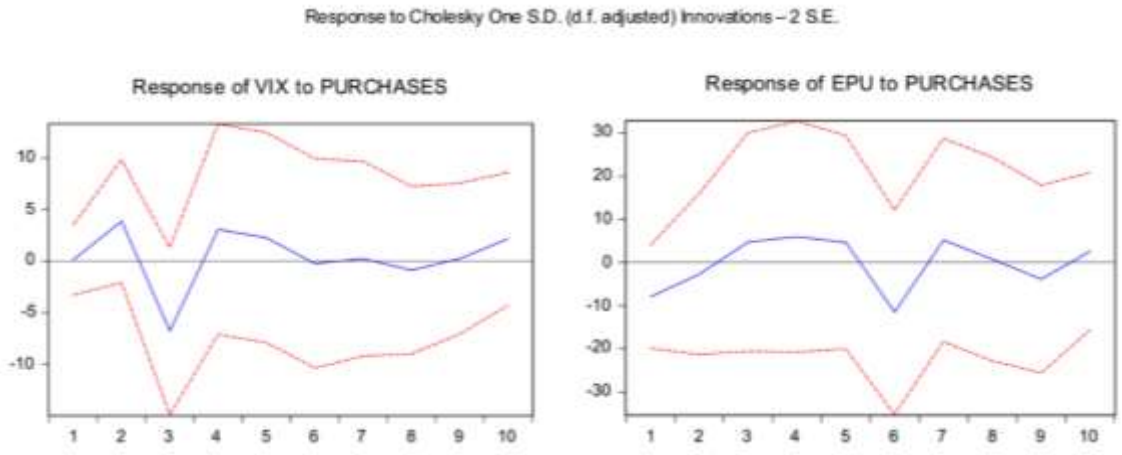
Furthermore, the present Dissertation also addresses another important transmission channel, the expectations management channel, by analysing measures of financial market and policy uncertainty. We have included the VIX[20], as a means to capture financial market uncertainty, through the implied stock market volatility, as implemented by Weale and Wieladek (2014b; 2016). In addition, the EPU[21] is also used, in order to measure policy-related uncertainty, similar to Hesse *et al.* (2018), as a way to include policy news regarding the impact of the Brexit referendum.

According to Gambacorta *et al.* (2014), the VIX is considered to be a general proxy for global financial turmoil, economic risk, and economic uncertainty. The importance of the inclusion of this variable in unconventional monetary policy VARs in order to identify unconventional monetary shocks is comparable to the importance of including indicators for future inflation, such as commodity prices in conventional monetary policy VARs (see e.g., Evans *et al.*, 1999; and Sims, 1992). The authors detect a significant negative initial impact on the VIX, not only in the UK, but in all the countries analysed, after an increase of central bank balance sheets. Moreover, Hesse *et al.* (2018) who introduced in their VAR model the EPU, discover a small positive effect, but not significantly different from zero, coming from asset purchases, while for the VIX a significant reduction of uncertainty is actually observed. Therefore, a negative sign is expected for both the VIX and EPU, implying a decreased level of financial and political uncertainty as a result of the asset purchase shock. The variables have been included, separately, as a sixth variable in our baseline VAR model, in order to establish whether there is a significant response to QE asset purchase shocks and the results of the impulse response functions are shown in Figure 4.

[20] Commonly referred to as the "fear index" (Whaley, 2000).

[21] According to the Economic Policy Uncertainty, the EPU includes the amount of news and articles containing the terms uncertain or uncertainty, economic or economy, as well as policy relevant terms, such as "policy", "tax", "spending", "regulation", "Bank of England", "budget", and "deficit" (scaled by the smoothed total number of articles).

Figure 4 - Impulse response functions results to an actual asset purchase shock on measures of uncertainty of one Cholesky standard deviation



Following the QE asset purchase shock, the VIX starts rising mostly as a consequence of the uncertainty around Brexit and the expected future global outlook in the financial markets, but it is then possible to detect a significant a short-lived decrease with a mean maximum impact of -6.80%, after which the impact subsides/stabilizes. Weale and Wieladek (2014b; 2016) find that asset purchases significantly reduce measures of financial market volatility in all the identifications schemes used, including the one herein implemented, both in the US and UK, suggesting that managing expectations through reduced economic uncertainty may be relevant for both countries. When comparing the movements of the FSTE 100 Price Index with the ones of the VIX, it is possible to observe opposite movements with the introduction of an unexpected asset purchase shock, which is in line with expectations where an increase in the VIX (reflecting increased financial market volatility) leads to lower equity prices, while a VIX decrease leads to the other way round.

On the other hand, we observe an initial negative impact in the EPU as a consequence to asset purchases with mean maximum impact months later of -11.52% (though not significant). Hesse *et al.* (2018) introduce in their VAR model the EPU as a measure for economic policy uncertainty and the authors discover a small positive effect, but not significantly different from zero, due to the asset purchase shock. News that the UK would be negatively affected from the referendum decision (Political Uncertainty) reached a record value, due to the fact that the extent of consequences from leaving the EU was unknown. However, asset purchases appear to reduce the level of political uncertainty.

The first QE announcements of asset purchases also seemed to have been effective in decreasing volatility in the stock markets, thus constituting a useful unconventional monetary policy to help reduce uncertainty regarding future macroeconomic expectations (Gambacorta *et al.*, 2014; Weale and Wieladek, 2014b; 2016; and Hesse *et al.*, 2018). Despite not having significant positive QE effects, both variables appear to respond accordingly to expected, and more sophisticated identification schemes and

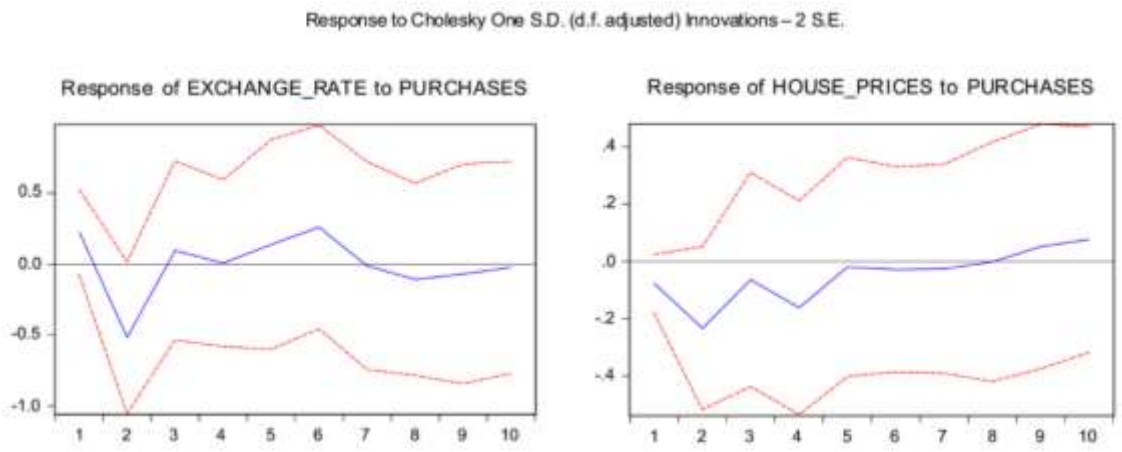
even combined with further econometric models should highlight the importance of expectations management as a relevant transmission channel.

5.4. Additional Asset Prices Channels

Finally, we also assess two other transmissions channels, which are closely related to the portfolio rebalancing channel: (i) the real exchange rate; and the (ii) real house price channels. To test for these transmission channels, we also included the variables as a sixth variable in the baseline VAR model. The results of the impulse response functions are shown in Figure 5.

Based on the assumption that investors do not regard money as a perfect substitute for gilts, they would be expected to buy other sterling assets, such as corporate bonds, equities, and foreign assets as a direct consequence of holding less assets included in the QE programme (Joyce *et al.*, 2011). Consequently, it is possible to expect a possible downward pressure on the sterling exchange rate, whereas the UK's real house prices would be expected to react positively to asset purchases.

Figure 5 - Impulse response functions results to an actual asset purchase shock on additional asset prices of one Cholesky standard deviation



There is some evidence that asset purchases led to a statistically significant real exchange rate depreciation with a mean maximum effect of -0.51%, short after the unexpected shock. The present results are in line with previous studies. Rosa (2012) also discovers that asset purchases are associated with a depression of the value of the British pound against major currencies of about 0.4%. Similarly, Weale and Wieladek (2014b) find that asset purchases led to exchange depreciation in most of the identification schemes used for the UK. Additionally, Broadbent *et al.* (2019) shows that Brexit induced a sharp drop in the UK real exchange rate due to the outcome of the referendum. The real exchange rate seems to be an important transmission channel, when faced with expansionary asset purchase shocks.

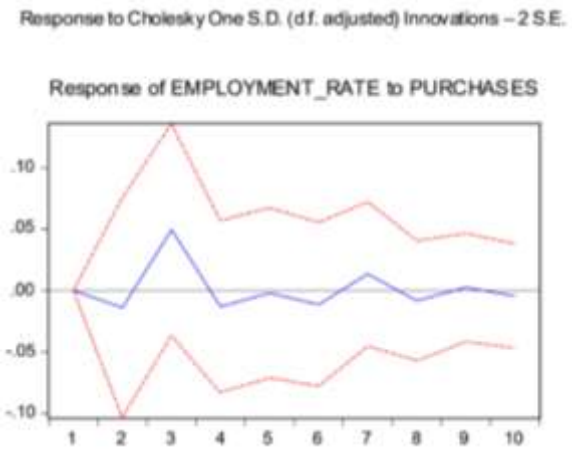
Interestingly, house prices appear not to react as expected, as we observe a mean maximum effect of -0.23%. One possible explanation may be associated with the movements in the short-term rates,

which had similar movements to long-term rates, where there was a small, but persistent, increase in the yields throughout the following year. House prices react more to changes in the short-term mortgage rates, given that the majority of mortgages track short-term rates fairly closely in the UK (Weale and Wieladek, 2014b). Nevertheless, Weale and Wieladek (2014b), find similar results and movements for house prices in the impulse response functions, following asset purchases in the context of several identification schemes in their model.

5.5. Robustness Analysis

As a first robustness check, we re-estimate the baseline VAR model replacing the PTI series with a variable[22] also used to measure economic activity, following Hesse *et al.* (2018). Specifically, we introduce the Total Employment rate in the UK. The impulse response function is reported in Figure 6 and shows that an unexpected asset purchase shock leads to a positive mean maximum impact of 0.05% (though not significant). The results of the Total Employment rate match the impulse response function movements of PTI, thus confirming the latter's use as an alternative measure for economic activity. In addition, the impulse response functions of the other variables present similar results as the baseline VAR, both in terms of significance and sign, to the alternative specification in the model, as shown in the Appendix F.

Figure 6 - Impulse response function result to an actual asset purchase shock on Total Employment rate of one Cholesky standard deviation

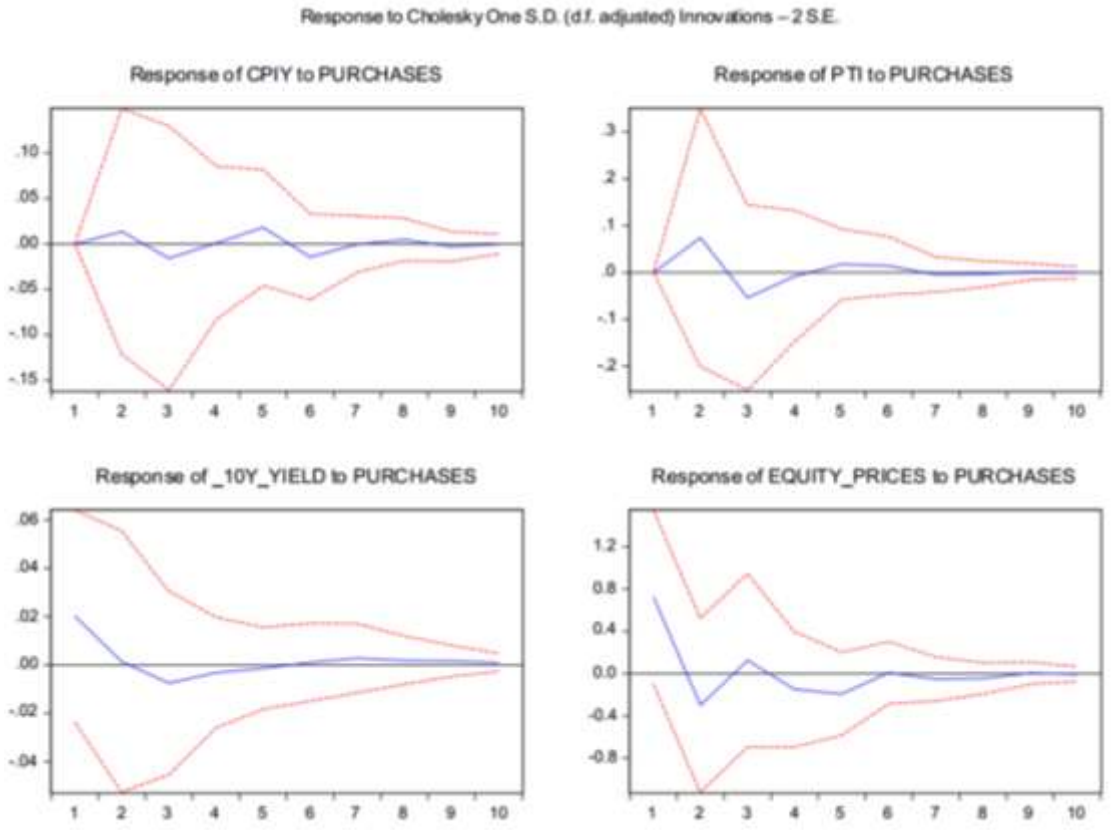


The methodologies and identification scheme used in the present Dissertation are in line with previous studies (Behrendt, 2013; Weale and Wieladek, 2014b; 2016; Haldane *et al.*, 2016; and Hesse *et al.*, 2018). However, regarding the Lag Length Criteria of those models, the authors find either the best lag for their model to be two or base their lag length choice on previous studies using a lag of two.

[22] The variable is also available in monthly frequencies, similarly to the variables used in the baseline model VAR. More information about the variables herein used can be found in Appendix B.

Therefore, as a second robustness test, we also re-estimate our baseline VAR model with the lag length specified by previous authors. The results are reported in Figure 7, where we observe the impulse responses with similar movements, though not significant, in response to an asset purchase shock. However, when faced with the mean maximum values, only the PTI remains unchanged with an increase of 0.07%. For the other variables there is a change in the sign, when compared to the baseline model, of the mean maximum values, though not significant. Nevertheless, we are still not able to find robust evidence for positive effects in the long run in the financial markets, where we observe an initial short-lived impact of 0.72%, followed by a sharp decline of the FSTE 100 Price Index. In addition, in response to asset purchases, the 10-year government bonds yield display similar positive results as the ones found in the transmission channels for the baseline model, with mean maximum impact of 0.02%, but then again not significant. Regardless of these differences, when extending the model to assess the impacts on all the transmission channels, with a lag order of two, the results are in general similar to the ones reported throughout the present Dissertation, which can be found in Appendix G.

Figure 7 - Impulse response function results to an actual asset purchase shock on the VAR model, but with a lag order of two, of one Cholesky standard deviation



Therefore, the results of the robustness check reported previously show that the baseline analysis is robust to the introduction of the employment rate as a substitute for PTI. Furthermore, despite the

changes in some of the variables' mean maximum impact signs from the change of the lag order, the impulse responses movements are, in general, comparable to those obtained from the baseline VAR and respective transmission channels. Nevertheless, the results of some variables appear to be contradictory, as we observe a change in the sign, which is not consonant with economic theory and the results from previous authors. As a potential explanation for this outcome, Weale and Wieladek (2016) find different impacts for all identification schemes, all of which were greater than the ones from the identical identification scheme used in the current Dissertation. In a comparison involving our baseline mean maximum impact results with those described in the robustness test, we see opposite signs in some of the variables. Therefore, the employed estimations of the model, identification schemes, and even time horizons may influence the estimations.

Overall, the results from our baseline VAR model (Figure 2) appear to be generally in line with previous studies, which employ the same identification scheme, and suggest that the effects on macroeconomic variables are mixed both in term of magnitude and significance, though not in line with the average results from different identification schemes of previous studies. However, we do find some significant impacts in several transmission channels, where we observe an increase in the long-term yields, together with a reduction of uncertainty, as well as a depreciation of the British pound, as a consequence of an unexpected asset purchase shock.

Following the Brexit referendum, asset purchases seem to contribute to the reduction of economic uncertainty, suggesting that the expectations management channel may be one of the most relevant transmission channels in the UK, providing economic stimulus to the economy. Nevertheless, there is little evidence that the BofE QE expansion, after the Brexit referendum, has had a large *direct* macroeconomic effect on real economy variables. Thus, our findings seem to support the idea that unconventional policies, through expansions of Central Bank balance sheets via QE programmes, do not necessarily lead to positive effects on the macroeconomic variables, as well as rapid and long-lasting economic recovery (Behrendt, 2013; Gambacorta *et al.*, 2014), but instead contribute to a reduction of economic uncertainty. Finally, the results also appear to support the hypothesis reported by Hesse *et al.* (2018), who claim that the impacts from asset purchases on the economy are getting smaller with the expansion of QE programmes.

6. Conclusion

In response to financial, political and economic distresses, Central Banks have implemented unconventional monetary policies via QE asset purchase programmes, after the zero-lower bound has been reached for the conventional policy rate, in order to help stimulate both the financial markets and the economy. Nevertheless, researchers have tried and continue to measure these programmes impacts and effectiveness for the past decades. However, the UK's QE asset purchase programme following the outcome of the Brexit referendum (on 23rd June 2016) has not been the focus of researchers, as were the first asset purchases programmes in the UK.

Therefore, the aim of the present Dissertation is to estimate the macroeconomic effects and provide new empirical evidence for the effectiveness of the latter QE expansion programme on financial markets and the economy. Additionally, the present Dissertation aims to address some of the transmission channels that can be triggered with asset purchase programmes and compare the results with the literature employing similar methodologies, allowing to differentiate their importance and impacts, especially after the UK vote to leave the EU. This Dissertation focus on the BofE asset purchases that took place from August 2016 until January 2019, a few months before the formally agreed date for the UK to officially leave the EU, thus allowing to present unbiased results from the asset purchase programme.

We have used a VAR model and analysed the impulse response functions with an identification scheme similar to Behrendt (2013), Weale and Wieladek (2014b; 2016) and Haldane *et al.* (2016), the Cholesky Decomposition. This identification scheme has been shown in previous studies to provide lower bound estimates, when compared with more complex identification schemes (Weale and Wieladek, 2014b; 2016). Moreover, the present research uses the most appropriate lag according to the AIC (a lag order of three), using monthly data taken from different databases.

Initial studies typically assessed the macroeconomic impacts of unconventional monetary policies by applying shocks, through the reduction of yields in their models. This method may be subjected to criticism, namely whether this type of shock actually reflects asset purchases (Weale and Wieladek. 2014b). Therefore, with the advancement of the programmes and data availability, researchers have started using asset purchase announcements series. However, given the conclusions from Weale and Wieladek (2014b; 2016), who find similar results in their models using actual purchases, when compared to the announcements, we use actual asset purchases series. Thus, in addition to the expansion of the APF target, we have taken into account the amounts from the CBPS and combine them into one asset purchase series, in order assess the impacts from the actual assets purchased.

The results from the mean maximum impact impulse response functions suggest there is little evidence that the expansion of QE asset purchase programme has had significant macroeconomic effects, namely on variables such as output, inflation, and equity prices in the UK. This is not what we

would typically expect from asset purchases. However, they are generally in line with the findings from previous authors that use a similar identification scheme for the UK (Weale and Wieladek, 2014b; 2016; and Haldane *et al.*, 2016), with the exception of the equity prices response, where we do not see significant increases following the shock. One possible explanation may be associated with the high levels of uncertainty around Brexit and its consequences on the British economy.

Furthermore, we address several transmission channels, which can be activated with asset purchase expansions, and find significant impacts on some channels. Our results appear to indicate that asset purchases lead to an initial significant increase in long-term yields, similar to estimations from Weale and Wieladek (2014b; 2016) for their first identification scheme. This increase in response to asset purchases could be related to higher market perception levels of future risk associated with the British economy, thus pushing government bonds yields up. Moreover, the expectations management channel appears to be the most important transmission channel during the current programme, where we observe that asset purchases lead to a significant reduction in financial market uncertainty, though insufficient to provide sustainable growth of equity prices, but which nevertheless has helped equity prices to withstand greater losses. Additionally, we find empirical evidence that asset purchases lead to a significant real exchange rate depreciation. On the other hand, house prices do not have the expected positive effect, possibly due to the movements of the short-term rates, which are similar to the ones from the long-rates, as we observe an initial increase of the yields resulting in negative effects on house prices.

Our findings suggest that the BofE expansion of the APF, combined with the CBPS, is effective in reducing macroeconomic uncertainty, indicating that the expectations management channel may be one of the most relevant transmission channels in the aftermath of the Brexit referendum, thus providing some economic stimulus to the economy. In addition, our results suggest the depreciation of the sterling exchange rate, despite showing little evidence of significant positive macroeconomic effects. These results have significant implications for policy formulation, since asset purchases appear to have lost some of their effectiveness as an instrument to support output and inflation. Therefore, the results seem to reinforce the idea that unconventional policies, through expansions of Central Bank balance sheets via QE programmes, do not necessarily lead to *direct* positive effects over the macroeconomic variables, as well as a fast and long-lasting economic recovery (Behrendt, 2013; Gambacorta *et al.*, 2014). Finally, our results also appear to support the hypothesis reported by Hesse *et al.* (2018), who claim that the impacts from asset purchases on the economy are getting increasingly smaller with the expansion of QE programmes.

Nevertheless, Weale and Wieladek (2016) discover the impacts on the macroeconomic variables to be higher in different identification schemes than on the same identification scheme used in the present Dissertation. The authors explain variances in their estimations due to the different identification schemes employed. Despite the different identification schemes employed by different authors in the

existing literature, it is not possible to claim that one scheme is necessarily better identified or preferable to another (Weale and Wieladek, 2016). For those reasons, the use of the Cholesky Decomposition in this Dissertation combined with a VAR model allows us to obtain quite effective results, which could serve as lower bound estimations, similarly to the results proposed by Weale and Wieladek (2014b; 2016). Consequently, the present Dissertation could serve as a base for further empirical work on the effects from QE asset purchases in the aftermath of the Brexit referendum, should more sophisticated models, such as Bayesian VAR methods similar to Weale and Wieladek (2014b; 2016), and corresponding identification schemes be used in order to assess the macroeconomic impacts from asset purchases.

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Appendix

Appendix A - Empirical results from previous researches

Research	Methodology	Sample Countries	Government Bond yields	Output	Inflation
Baumeister and Benati (2010)	Bayesian time-varying parameter Structural VAR responses to a spread shock	US, Euro Area, Japan and UK	-	-	-
Lenza *et al.* (2010)	Bayesian VAR via interest rate spreads	US, UK and Euro Area	-	-	-
Gagnon *et al.* (2010)	Event study and Dynamic OLS	US	-	-	-
Chen *et al.* (2011)	DSGE model with Bayesian methods via a reduction of risk-premiums	US	-	2%	0.5%
Krishnamurthy and Vissing-Jorgensen (2011)	Event-study and OLS	-	-	-	-
Joyce *et al.* (2011)	Event-study and OLS via purchase of 200 billion assets	UK	-1%	-	-
Kapetanios *et al.* (2012)	Bayesian VAR; Change-point SVAR; Time-varying parameter VAR via 100bps lower long-term interest rates (VAR based- term structure models)	UK	-	1.5%	1.25%
Baumeister and Benati (2013)	Bayesian time-varying parameter Structural VAR responses to a 50-bps reduction shock	-	-	3%	2%
Behrendt (2013)	VAR analysis	9 countries (includ. UK)	-	(0.33%)	(0.05%)
D'Amico and King (2013)	Two stage least squares	US	- 0.30%	-	-
Gambacorta *et al.* (2014)	Panel VAR (benchmark mean group IRF results)	8 Advanced Economies	-	Median of 0.06%	Median of 0.02%
Weale and Wieladek (2014b)	Bayesian VAR study using (Litterman & Panel VAR prior)	US & (UK)	-	0.36% (0.18%)	0.38% (0.30%)
Churm *et al.* (2015)	Event-study of 175 billion Q2 and Q3 and VAR estimates of macro impact	UK	-0.45%	0.5%/0.8%	0.6%
Cova *et al.* (2015)	Effects of APP in a DSGE model	Euro Area	-	1.4%	0.8%
Andrade *et al.* (2016)	Effects of APP using time series and DSGE models	Euro Area	-0.45%	1.1%	0.4%
Haldane *et al.* (2016)	Structural VAR model	6 countries (includ. UK)	-	(0.24%)	(0.34%)
Weale and Wieladek (2016)	Bayesian VAR	US & (UK)	-	0.58% (0.25%)	0.62% (0.32%)
Hesse *et al.* (2018)	Bayesian VAR	US & (UK)	-0.10% (-0.20%)	0.2%	0.2%
Hohberger *et al.* (2019)	Open-economy DSGE model with Bayesian techniques	Euro Area	-	0.3%	0.5%

Appendix B - List of variables, periodicity and sources

List of Variables	Periodicity and Sources
Production of Total Industry	Computed as monthly percentage change, seasonally adjusted at monthly frequencies from FRED.
Inflation	Computed as monthly percentage change of the CPIY, at monthly frequency, collected from ONS.
Asset Purchases Programme (APP Ratio)	Accumulated actual purchases series of gilts (government bonds) and corporate bonds, made by the BoE, obtained from the Asset Purchases Facility Quarterly Reports and divided by the value of the third quarter nominal 2016 GDP, at market prices, seasonally and calendar adjusted data obtained from Eurostat.
10/20/30-year government bond yields	Long-term interest rates of UK government bonds, obtained from Bloomberg at daily rates and subsequently interpolated to monthly data.
Real Equity Growth	Computed as monthly percentage change of the FTSE 100 Price Index, collected from Datastream, deflated by CPIY and linearly interpolated from daily to monthly data.
Volatility Index	Computed as monthly percentage change of the VIX, obtained from the Investing.com financial platform.
Economic Policy Uncertainty Index	Computed as monthly percentage change of the EPU, obtained from the Economic Policy Uncertainty.
Real Exchange Rate	Computed as monthly percentage change of the Real Exchange Rate of the UK, collected at monthly frequency from FRED.
Real House Prices	Computed as monthly percentage change of the House Prices, obtained from Eurostat, linearly interpolated from daily to monthly data, deflated by CPIY.

Appendix C - Summary Statistics of the variables

	Inflation	PTI	APP Ratio	10-year yield	Real Equity Prices	20-year yield	30-year yield	VIX	EPU	Real Exchange Rate	Real House Prices
Mean	0.177777	0.071177	0.866626	1.258988	-0.079133	1.752728	1.812040	0.234995	-1.960921	-0.025458	0.017043
Median	0.197922	0.100859	0.884369	1.281184	-0.333959	1.795857	1.823881	-1.572455	-0.652950	0.247268	-0.110849
Maximum	0.788181	1.608075	0.884978	1.569550	4.998447	1.959150	2.027273	44.20608	69.37375	3.052311	0.855600
Minimum	-0.846267	-1.235855	0.756042	0.605087	-6.358726	1.215435	1.352609	-30.45078	-60.29776	-5.390464	-0.917792
Std. Dev.	0.381474	0.724321	0.035901	0.212124	2.565139	0.166898	0.147373	14.53547	30.53743	1.653598	0.484788
Skewness	-1.132366	0.290983	-2.118042	-1.207316	-0.209816	-1.649265	-1.252707	0.783846	-0.144670	-0.960929	0.157713
Kurtosis	4.432492	3.033971	6.290349	4.848052	2.817202	5.865493	5.266721	4.634770	2.668549	5.058481	1.993408
Probability	0.011241	0.808642	0.000000	0.003093	0.877269	0.000007	0.000797	0.040505	0.886046	0.007035	0.498849
Sum	5.333305	2.135312	25.99877	37.76963	-2.373976	52.58184	54.36119	7.049851	-58.82763	-0.763746	0.511296
Sum Sq. Dev.	4.220154	15.21457	0.037377	1.304900	190.8182	0.807790	0.629843	6127.115	27043.51	79.29718	6.815575
Observations	30	30	30	30	30	30	30	30	30	30	30

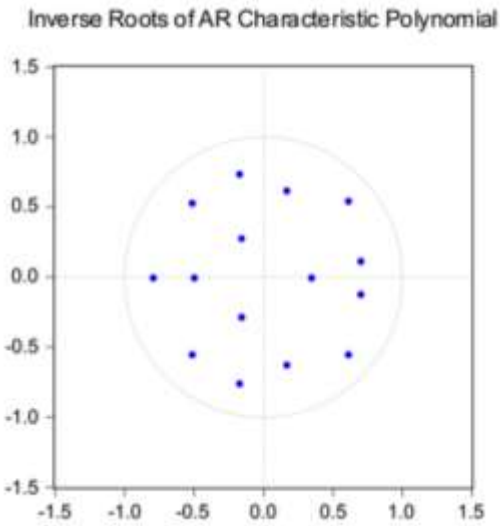
Appendix D - Lag Length Criteria Test to the Baseline VAR model

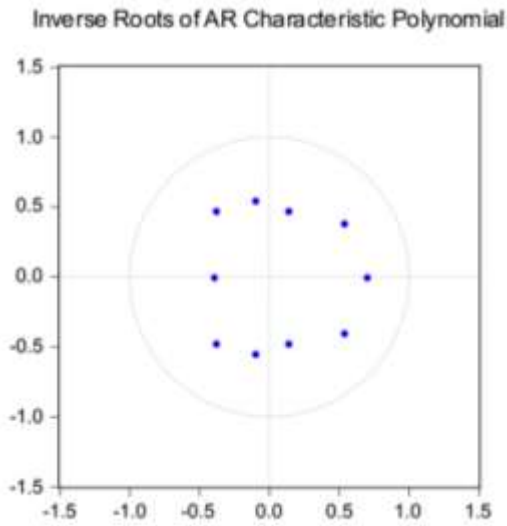
VAR Lag Order Selection Criteria
Endogenous variables: CPIY PTI PURCHASES _10Y_YIELD EQUITY_PRICES
Exogenous variables: C
Date: 05/16/21 Time: 16:02
Sample: 2016M08 2019M01
Included observations: 27

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-9.091299	NA	1.95e-06	1.043800	1.283770	1.115156
1	39.09151	74.95103*	3.64e-07*	-0.673445	0.766374*	-0.245311*
2	60.33864	25.18179	5.95e-07	-0.395455	2.244213	0.389456
3	90.35658	24.45906	7.78e-07	-0.767154*	3.072363	0.374535

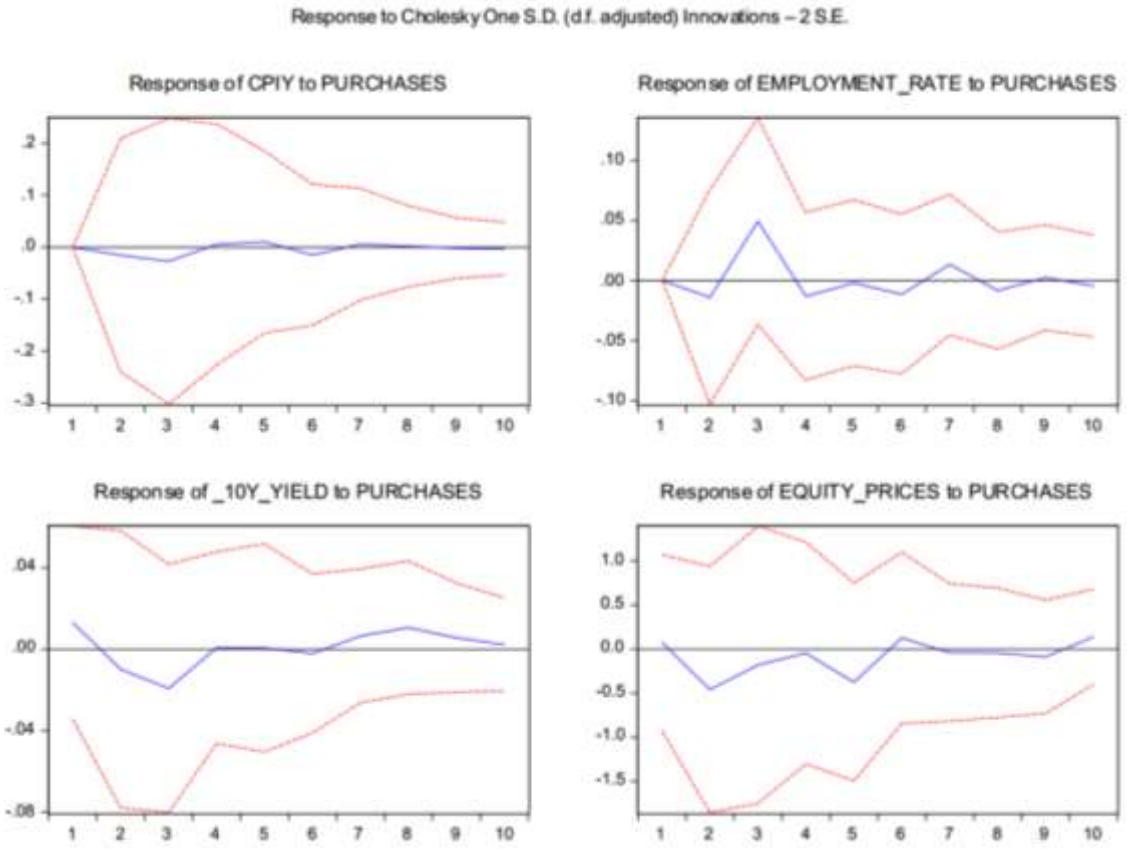
* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Appendix E - Inverse Roots of the AR Characteristic Polynomial of the Baseline VAR model (left figure) and the Robustness VAR model (right figure)

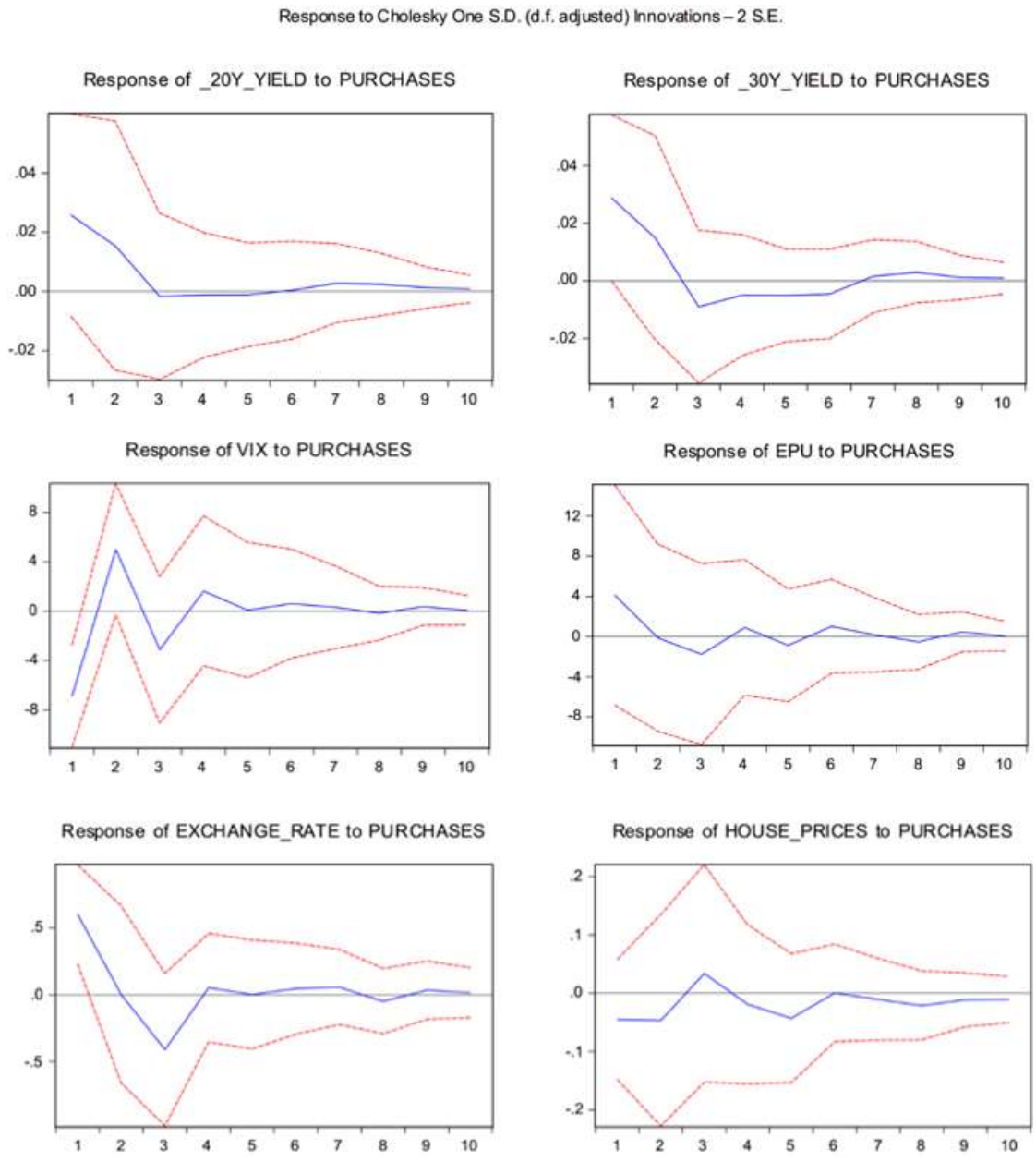




Appendix F - Robustness impulse response functions results, where PTI is substituted by Total Employment as a measure of output, to an actual asset purchase shock of one Cholesky standard deviation



Appendix G - Robustness impulse response functions results for all the transmission channels studied in the present dissertation, but with a lag order of two, to an actual asset purchase shock of one Cholesky standard deviation



Appendix H - Robustness impulse response functions results for the baseline model and the transmission channels studied in the present dissertation, but with a lag order of one, to an actual asset purchase shock of one Cholesky standard deviation