Did Quantitative Easing only inflate stock prices? Macroeconomic evidence from the US and UK*

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ABSTRACT

We examine the impact of US and UK Quantitative Easing (QE) on their respective economies, focusing on the stock market, output and prices. Our six-variable (B)VAR models combine macroeconomic, financial variables and a 'pure' and observable measure of QE. We find that the inclusion of forward-looking stock market variables is important in assessing monetary policy shocks. On impact, the response of equities and liquidity is negative and positive for volatility. In the medium-term, stocks rise and volatility declines. Output and prices, in contrast with some previous studies, show weak reactions. Economically, we argue that the anaemic economic stimulus is due to a limited expansion of credit.

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In this paper, we conduct an empirical assessment of the Federal Reserve Bank (FED) and the Bank of England (BoE) Quantitative Easing programmes, to investigate their domestic impact in the US and UK. Using vector autoregressions, also suitable for forecasting equity markets and the macroeconomy, we evaluate the efficacy of these monetary policies implemented by central banks during the Great Recession.

In the aftermath of the 2008 financial crisis, policymakers around the world adopted both conventional and non-conventional measures in the hope of alleviating the deepest recession since 1929 and taking the economy back to pre-crisis levels. The zero lower bound (ZLB)[1] was rapidly reached, yet the economic outlook still worsened and issues in the financial sector (e.g. credit (un)availability) persisted.[2] After the collapse of Lehman Brothers, major central banks decided to embark on additional unconventional monetary policy, in order to revitalise the real economy. The actions taken after September 2008 included both changes to the central bank balance sheet composition (*Qualitative* Easing) and size (*Quantitative* Easing).[3] The Federal Open Market Committee (FOMC), an organ of the FED, pioneered large scale direct market interventions by buying mortgage backed securities (MBS), agency debt and treasury debt to the value of hundreds of billions of US dollars.[4] Other central banks such as the BoE, the European Central Bank (ECB), the Bank of Japan, the Swiss National Bank and the Swedish National Bank also undertook open market operations, thereby vastly enlarging their balance sheets.

By early 2015, the equity market indices of major economies such as the S&P 500, the FTSE 100 and the DAX 30 not only regained their crisis losses, but also touched new historical nominal highs.[5] On the other hand, macroeconomic fundamentals, and inflation in particular, were still sluggish at the end of 2015.[6] At the time of writing, interest rates around the world are still found at the ZLB (or even lower), whilst the ECB is still implementing its QE policy and the BoE has

1. By ZLB we refer to that condition where a central bank intends to stimulate the economy by lowering short-term interest rates but faces a constraint when nominal rates reach zero. See, for example, McCallum (2000).

2. The lending market was still frozen, the unemployment level too high, GDP growth and inflation too low (Dudley, 2010).

3. Lenza, Pill, and Reichlin (2010) argue that there are similarities in the evolution of the balance sheets of the FED, BoE and the European Central Bank, namely an expansion in the proportion of unconventional to conventional assets and the nature of liabilities.

4. The Bank of Japan had implemented alternative monetary measures like QE to address domestic deflation in the late 1990s. Yet, the Japanese QE unlike the US, UK and Eurozone QEs, entailed an expansion of the liability side of the central bank balance sheet rather than the asset side (Bernanke, 2009).

5. The S&P 500 also touched new levels in real (inflation-adjusted) terms.

6. September 2015 inflation figures: US 0.00%; UK -0.10%; Germany 0.00%. (Source: US Bureau of Labor Statistics, Office for National Statistics, Federal Statistics Office)

initiated a third QE round, after having cut the base rate again in August 2016.

The perceived discrepancy between equity prices and macroeconomic figures, at a time when central banks were implementing asset purchase programmes, has led the media to talk about *'drugged markets'*.[7] Mervyn King, former Bank of England Governor, also expressed his concern that *"some of the optimism of financial markets, [...] may not be consistent with the speed at which the underlying data are likely to change"*. Whilst some articles refrain from speculating over its effectiveness, others take a stand against QE implementation and warn that *"stock market bubbles of historic proportions are developing in the US and UK markets"*.[8]

The academic literature has also taken interest in the analysis of unconventional monetary policy effects on interest rates (Gagnon, Raskin, Remache, and Sack, 2010; Hancock and Passmore, 2011; Joyce, Lasaosa, Stevens, and Tong, 2011; D'Amico and King, 2013). Yields and rates were, however, the intermediate target of the asset purchases, whereas economic variables, inflation and output, were the main policy goals. Yet, there is a dearth of evidence on the influence of QE on the real economy and (un)intended consequences on equity prices. In this study, we address this gap by investigating the effects of QE on both the stock market and the macroeconomy. In particular, we quantify the effects of the FED and BoE Quantitative Easing programmes on domestic capital markets and economic variables in a vector autoregressive model which allows us to capture the interrelations between the real and financial sectors.

Although there exists a consensus over the reduction in yields of a range of securities attributable to central banks' purchase programmes, it is less clear whether and to what extent these actions have influenced the real economy and stock markets metrics. QE can alter market expectations about the future path of short-term rates, and economic outlook – price developments and output growth in particular – and it can also trigger rebalancing in investors' portfolios. The activation of both of these channels can therefore be detected in yields and asset prices developments. Lower rates and higher asset prices, in turn, may support investments and consumption via lower cost of capital and wealth effect and discourage savings thereby generating upward pressure on prices and promoting output growth.

Economic theory is however ambiguous on the activation of these channels and thus on the

7. See, for example, Elliott, Larry. (2013, February 24). Quantitative easing: the markets are struggling with a serious drug habit. *The Guardian.*

8. Chang, Ha-Joon. (2014, February 24). This is no recovery, this is a bubble - and it will burst. *The Guardian.*

ultimate impact of central bank balance sheet expansions. Eggertsson and Woodford (2003), for instance, argue that there would be no portfolio rebalancing among investors since, in a zero interest rate environment, non-interest-bearing money and interest-bearing assets become perfectly substitutable. On the other hand, some researchers (e.g. Mankiw and Reis, 2002; Vayanos and Vila, 2009) have developed models that include market frictions and find scope of implementation of asset purchases. Thus, whether and to what extent the UK and US domestic economies and equity markets have been influenced by their respective central banks balance sheet operations depends on which channels are activated and the presence of market frictions and it is the empirical question we address in this paper.

The main contributions of this paper lay in the following aspects. First, we combine an 'intermediate' and 'ultimate' target performance analysis by including macroeconomic ('ultimate' objective) variables with financial ('intermediate' indicators) ones and the policy instrument (Quantitative easing amounts) in a single VAR framework.[9] We study the impact of QE on the stock market, in terms of the effects on prices, volatility and liquidity. On the real side, we find that the inclusion of financial variables – which could be regarded as a channel of transmission of the policy – is of key importance in determining the effects of monetary policy. This result suggests that the models estimated in previous studies may be mis-specified. Our findings also show that this is the source of the difference between our results and some of the previous literature.

Further, unlike previous studies on unconventional monetary policy evaluation, we employ a 'pure' and observable measure of QE, the policy instrument we analyse in this paper, namely the amount of securities held outright by the FED and BoE,[10] in a model that includes stock market variables as well as macroeconomic variables. When producing impulse responses, this allows a direct modelling of the unconventional monetary policy shock via an observable variable, rather than indirectly through a 'channel' and unobservable variable, such as the policy impact on yields.[11]

Importantly, we also extend the literature by considering all the rounds of QE implemented in the UK and US until 2015. The inclusion in our study of the UK, in addition to the US, allows a

9. The literature studying the central bank policy impact on interest rates can be grouped under the umbrella term 'intermediate' target or instruments, which could also be regarded as channels of transmission. The 'ultimate' target literature, instead, looks at the final goal of the policy such as price stability and/or output growth.

10. Unlike other studies, such as Gambacorta, Hofmann, and Peersman (2014), which focused on the entire central bank balance sheet, we consider the quantity of asset purchased for policy purposes.

11. An example of 'channel' variable is the 100bp reduction in government bonds used in Kapetanios, Mumtaz, Stevens, and Theodoridis (2012), which relies on the Joyce, Lasaosa, Stevens, and Tong (2011) estimates.

comparison between two countries of very different size and weight in the world economy and the different timing in the respective policy implementation.

Our assessment is carried out by vector autoregression to model the linkages and transmission channels among macroeconomic variables – production and prices – and financial market variables – stock market level, volatility and liquidity – which we validate in a forecasting exercise. We estimate the model via frequentist and Bayesian methods and identify unconventional monetary policy shocks via zero and sign restrictions. We argue that such a VAR enables a well-rounded assessment of Quantitative Easing as implemented in the US and UK, from the equity market to the ultimate targets of the policies, i.e. output and prices.

In a nutshell, we find that on the one hand QE boosted equity prices significantly and reduced its volatility in the medium term (4-5 months). However, on impact equities and liquidity tend to react negatively and volatility increases. On the other hand, the unconventional stimulus struggled to propel the macroeconomy. Interestingly, we also note that the US QE appears to have been more effective than its UK counterpart. We extensively test the robustness of our main findings by altering our baseline model in multiple ways and adding extra variables that might have a bearing on the analysis. Results point to the same verdict, thereby providing further reinforcement to our conclusions.

The rest of the paper is organised as follows. In Section 1, we provide a brief overview of the related literature. Section 2 describes the dataset used in the analysis and the chosen QE variable. Section 3 outlines the econometric framework employed for the estimation of the VAR models and the identification strategies for the impulse response analysis. In Section 4, we present the main findings on QE impact estimates. Section 5 and 6 explain the empirical results by analysing a channel of transmission and provide a comparison with the previous literature. Section 7 contains a range of robustness tests and Section 8 concludes.

1. Related literature

In the academic world, the likely effects of unconventional monetary policy began to be studied before the US QE took place. Economists can be divided into two factions. One strand follows new Keynesian models and is sceptical about the macroeconomic effects of Quantitative Easing.

Such is true of Eggertsson and Woodford (2003), who put forward an 'irrelevance proposition' of open market operations. They argue that at the ZLB, non-interest-bearing money is a perfect substitute for interest-bearing assets (e.g. 'bullet' bonds). The second strand allows for market frictions and claims that QE can indeed have economic implications (e.g. Mankiw and Reis, 2002). More recently, Williams (2016), the president of the San Francisco Fed, has called for a critical reassessment of the effectiveness of central banks' monetary policy. The issue of the efficacy of unconventional monetary policy is clearly of much interest among practitioners, policy makers and academics.

Researchers have tried to evaluate empirically the impact and effectiveness of QE policies on interest rates such as bond yields and mortgage rates, mainly in the US – QE1 and QE2 – (D'Amico and King, 2013; Hamilton and Wu, 2012; Gagnon, Raskin, Remache, and Sack, 2010; Hancock and Passmore, 2011; Belke, Gros, and Osowski, 2017) and the UK (Breedon, Chadha, and Waters, 2012; Bridges and Thomas, 2012; Joyce, Lasaosa, Stevens, and Tong, 2011; Steeley, 2015). Krishnamurthy and Vissing-Jorgensen (2011) conduct a detailed empirical analysis of the means through which US QE1 and QE2 have operated and conclude that different channels are altered by non-conventional monetary policy and assets are affected heterogeneously. This strand of literature has shifted the definition of monetary policy effectiveness from the final target, the macroeconomic impact, to an intermediate target, yields. By contrast, only a relatively few studies analysed of the output and price levels effects: e.g. Kapetanios, Mumtaz, Stevens, and Theodoridis (2012), Bridges and Thomas (2012), Gambacorta, Hofmann, and Peersman (2014), and Wu and Xia (2016). Other researchers (Fratzscher, Lo Duca, and Straub, 2016; Lo Duca, Nicoletti, and Vidal Martnez, 2016; Lim and Mohapatra, 2016; Barroso, da Silva, and Sales, 2016; MacDonald, 2017) have also considered the spillover effects from the US to other countries.

Notwithstanding the variety of methodologies employed by previous literature, there exists a partial consensus that QE measures in the US and UK have had a positive impact on their respective economies, although there is less agreement on the magnitudes of the effects. Chen, Cúrdia, and Ferrero (2012) and Engen, Laubach, and Reifschneider (2015) are among the few discordant voices, arguing that the FED QEs have had limited effect on the US economy.

Thus, the literature to date has focused on assessing empirically whether QE has been a successful policy instrument in lowering Treasury, agency and corporate bond and MBS yields, and to a lesser extent in promoting GDP growth, employment and inflation. Instead, only a few papers (**e.g.**; Joyce, Lasaosa, Stevens, and Tong, 2011; Fratzscher, Lo Duca, and Straub, 2016; Bridges and Thomas, 2012), have touched upon the effects of QE on equity markets, yet, volatility and liquidity are not considered. Furthermore, their estimates are by-products of the respective analyses and their samples do not include all rounds of QE.

Our findings may be especially relevant for the Bank of England given its stated intention to undertake further rounds of monetary stimulus following the outcome of the 'Brexit' referendum.[12]

2. Data

The dataset we employ in the exercise includes six variables with monthly observations for each of the two countries. It comprises macroeconomic variables, namely the index of real industrial production and prices, stock market variables such as equity prices, market volatility and liquidity and the Quantitative Easing variable. Such a dataset allows us to analyse the financial and economic impacts, thereby also capturing any linkages between the two. As suggested by Bjørnland and Leitemo (2009), it is important to jointly consider monetary policy and financial variables when analysing monetary policy transmissions.

The data sources are Datastream and FRED. The time span of the dataset covers the period from June 1982 to November 2014 for the UK and from January 1971 to November 2015 for the US. All variables are in log-levels except volatility and liquidity, which we divide by 100.[13]

We follow Bernanke, Boivin, and Eliasz (2005), in using industrial production and the consumer price index (CPI) to proxy for output and prices respectively.[14] In the spirit of Bhattarai, Chatterjee, and Park (2015), we use the amount of securities held outright by the central banks as our Quantitative Easing variable. Using an observable metric such as the quantity of assets bought by the BoE and the FED allows us to capture QE directly, rather than using estimates of unobservable variables that were affected by the policy such as interest rates. This leads us to extend the Quantitative Easing time series, in the first part of the sample where no data on securities

12. See, for example, Andy, Bruce. (2016, July 13). Bank of England readies new blast of QE for post-Brexit Britain. *Reuters*.
13. Where possible, we use seasonally adjusted variables.
14. We use UK RPI rather than CPI as the prices proxy, because of data availability constraints.

held is available, with M0, the narrow money metric.[15] For the stock market, the FTSE All-Share and the S&P 500 represent the UK and the US respectively. Market volatility is computed as a 30-day rolling standard deviation of log daily returns. Lastly, in the spirit of Goyenko, Holden, and Trzcinka (2009), we calculate stock market liquidity using Roll (1984), again from daily equity market data.[16] Roll (1984) provides a bid-ask spread estimate, thus the higher our measure the lower the market liquidity. Tables 1 and 2 provide a detailed description of the datasets.

[Place Table 1 about here]

[Place Table 2 about here]

3. Methodology

Determining the impact of Quantitative Easing is a challenging task as it requires isolating the effect of the monetary policy from the influence of other variables. A number of methodological approaches, such as event study analysis and time series regressions, have been applied to disentangle the effects of QE from other exogenous innovations. Event studies have been employed in past research such as D'Amico and King (2013) and Fratzscher, Lo Duca, and Straub (2016), who have shown that both the announcement and the implementation of QE can alter prices and yields. Rogers, Scotti, and Wright (2014) also found evidence of asymmetries in the effects of expansionary and contractionary unconventional monetary policy. Event study analysis around announcement dates is perhaps the most popular methodology in this strand of literature (Gagnon, Raskin, Remache, and Sack, 2010; Krishnamurthy and Vissing-Jorgensen, 2011; Joyce, Lasaosa, Stevens, and Tong, 2011; Rogers, Scotti, and Wright, 2014) given its simplicity.

Another technique to disentangle those price innovations caused by the monetary policy from those due to other factors (e.g. changes in the macroeconomic fundamentals and market environment) involves estimating vector autoregression (VAR) models to capture complex economic dynamics, and includes the analysis of counterfactual scenarios to estimate the influence. This is the approach used for instance in Lenza, Pill, and Reichlin (2010), Kapetanios, Mumtaz, Stevens,

15. We show in Section 4 that our results are not driven by our choice of augmenting the QE time series with M0. In fact, re-estimating the model over the period where there is data availability on QE amounts leads to even stronger conclusions.

16. As is customary in the literature, we substitute the Roll measure with zero when the autocovariance is positive.

and Theodoridis (2012), and Gambacorta, Hofmann, and Peersman (2014), and is also our methodology. In general, time series approaches may alleviate concerns about the window length to be employed in an event study, and they may also counter the scepticism regarding the time it takes distressed markets to 'digest' policy news. Lastly, low frequency (e.g. monthly and quarterly) macroeconomic time series can be included in the analysis.

Vector autoregressive frameworks have been used widely by researchers to assess the effects of conventional monetary policy (Christiano, Eichenbaum, and Evans, 1999) in the US as well as unconventional monetary policy in the Euro area (Lenza, Pill, and Reichlin, 2010). In this paper, we adopt a VAR approach to examine the repercussions of Quantitative Easing in the UK and the US on macroeconomic and stock market variables. We conduct the overall approach of this investigation in three steps:

1. Construct and estimate a VAR model with the aforementioned variables, in order to capture the dynamics of the UK and US economies.
2. Identify Quantitative Easing shocks as exogenous orthogonal innovations of the QE variables.
3. Apply shocks to the QE variables and compute the impulse response functions (IRF) of the variables in the model.

3.1. Vector autoregressive model

The reduced form VAR model we adopt is of the type:

$$\begin{aligned} &Y_t = C + \beta_0 t + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + ... + \beta_p Y_{t-p} + \varepsilon_t \\ &\varepsilon_t \sim N(0, \Sigma) \end{aligned} \tag{1}$$

where Y_t is an $n \times 1$ vector of endogenous variables, C is an $n \times 1$ vector of unknown constants, β_0 is an $n \times 1$ vector of time-trend parameters, $\beta_1, ..., \beta_p$ are $n \times n$ matrices of unknown parameters, and ε_t is an $n \times 1$ vector of disturbances. ε_t is assumed to be uncorrelated over time, but Σ is expected to be non-diagonal.[17]

As we focus on the domestic impact of Quantitative Easing, we estimate the model individually

17. We expect the variance-covariance matrix of the vector of disturbances in the standard VAR to be non-diagonal as our VAR is a reduced form and does not condition on contemporaneous information. The reduced form VAR disturbances are a combination of the structural shocks, which we will identify in a number of ways.

for the two economies. Furthermore, the variables are entered in log-levels since they might be characterised by unit roots; this approach implicitly admits possible cointegrated relationships among the variables (Sims, Stock, and Watson, 1990).

Our rather long sample period allows a variable-rich specification, which enables us to better capture the QE period dynamics. The aim is to model the macroeconomic features – output and prices – jointly with the stock market variables – equity prices, liquidity and volatility. The inclusion of stock market volatility serves a dual purpose. Not only can it offer further insight into the capital market consequences of the unconventional monetary policy, it is also relevant in identifying the exogenous and autonomous innovations of the amount of securities held by the central banks from the endogenous and automatic responses of central bank balance sheets to market uncertainty and risk peaks as Gambacorta, Hofmann, and Peersman (2014) suggest.

This empirical exercise allows us to establish a baseline against which the results of different specifications, proposed below, can be compared. We estimate VAR models in log-levels via OLS separately for the UK and the US using two lags as suggested by the Hannan-Quinn information criterion.[18]

Since we are extending the time series of securities held outright by the two central banks with the respective measures of M0, we want to rule out the possibility that our findings are driven by this proxy. Firstly, we note that, for the US, the correlation between the variable QE and M0 for the overlapping period (2006-2015) is 0.98. For the UK, the correlation between the QE amount and M0 (over the 2009-2015 period) is 0.86. BoE total assets have a larger overlapping span since the monthly data start in 2006 and their correlation with M0 is 0.97. These figures close to unity indicate that the assets held at the central banks comove significantly with M0. Secondly, we can re-estimate the VAR model only over the period for which we have data on QE amounts available. Given the drastically lower number of observations in this scenario, we use Bayesian techniques to handle smaller estimation sample. In particular, we estimate a BVAR model with Minnesota and sum of coefficients (SOC) prior. We choose conjugate prior distributions of the VAR coefficients that belong to the following Normal-Inverse-Wishart family:

18. Complete estimation results are available upon request.

$$\beta|\Sigma \sim N(b, \Sigma \otimes \Omega)$$
$$\Sigma \sim IW(\Psi, d) \tag{2}$$

where b, Ω, Ψ and d are the prior parameters. The Minnesota prior has the following first and second moments:

$$E[(B_s)_{ij}|\Sigma] = \begin{cases} \delta_i & \text{if } i = j \text{ and } s = 1 \\ 0 & \text{otherwise} \end{cases}$$
$$cov[(B_s)_{ij}, (B_r)_{hm}|\Sigma] = \begin{cases} \frac{\lambda^2}{s^2} \frac{\Sigma_{ih}}{\psi/(d-n-1)} & \text{if } m = j \text{ and } r = s \\ 0 & \text{otherwise} \end{cases}$$

δ_i is set to 1 for variables believed to be highly persistent (those we express in log-levels) and set to 0 for those believed to mean revert. The prior on the intercept is diffuse. The hyperparameter λ determines the overall tightness of the prior and is set equal to 0.2. For the SOC prior we construct the following matrices of dummy observations:

$$\underset{n\times n}{Y^+} = diag\left(\frac{Y_0}{\mu}\right)$$
$$\underset{n\times(1+np)}{X^+} = \left[\underset{n\times 1}{0}, Y^+, ..., Y^+\right]$$

where Y_0 is an $n \times 1$ vector of averages of the first p observations and the hyperparameter μ is set to 1. We show in Figure 3 that our main results are qualitatively similar. In fact, the conclusions on the impact of QE on the macroeconomy are even stronger and the stock markets still display a rise.

3.2. Identification

We adopt an identification strategy for the monetary policy shocks by combining sign and short run restrictions. For the short run restrictions we assume that the two macro variables (output and prices index) do not respond contemporaneously to shocks to other variables in the model.

First, we impose orthogonality among all shocks by computing a lower triangular Cholesky decomposition of Σ_ε, the variance-covariance matrix of the error term ε_t in Eq. 1 , such that

$\varepsilon_t = C\eta_t$. The candidate structural shocks w_t^c are computed as

$$w_t^c = Q'\eta_t \tag{3}$$

where Q' is a 6×6 matrix, such that $Q'Q = I_6$ and $\varepsilon_t = CQQ'\eta_t = CQw_t^c$. There exists an infinite set of structural shocks w_t^c that satisfy the above condition, however we restrict the set of candidate solutions by imposing zero and sign restrictions on the structural impact multiplier matrix CQ. We thus discard the non admissible solutions of the unknown structural shock w_t that do not satisfy our sign restrictions.

In order to characterise the space of all structural models which are consistent with our restrictions and the reduced-form parameters, we implement an augmented version of the Rubio-Ramírez, Waggoner, and Zha (2010) (RWZ) algorithm with QR decomposition.

In order to preserve the zero restrictions, we use sub-rotations of the Q matrix such that

$$Q = \begin{bmatrix} I_2 & 0 \\ 0 & q \end{bmatrix} \tag{4}$$

We obtain q from a QR decomposition of a draw of a 4×4 orthonormal matrix K.

RWZ(2010) demonstrate that picking q from a QR decomposition of K with $diag(R) > 0$ is equivalent to drawing q from a uniform distribution on the space of orthogonal matrices K. Thus, this algorithm allows a good characterisation of the space of admissible structural VAR models. Our identifying assumption on contemporaneous responses can be summarised as:

Output	Prices	QE	Stock Market	Volatility	Liquidity
0	0	$\geq$0	<0	*	*

Sign Restriction Identification. '*' means unrestricted.

We iterate the sign-restriction procedure until we have accepted 1000 draws.[19]

We also employ a second methodology to identity Quantitative Easing shocks as exogenous orthogonal innovations of the QE variables. For this purpose, we order the variables as in Tables 1 and 2 and distinguish between slow and fast moving variables following (Christiano, Eichenbaum,

19. On average, we accept 7.5% of draws from both countries.

and Evans, 1999). The former group includes macro variables, whereas the latter comprises financial variables. The ordering of the variables for identifying 'structural' shocks in the VAR analysis via a Cholesky decomposition is largely in line with the literature (see for example, Kapetanios, Mumtaz, Stevens, and Theodoridis, 2012; Bańbura, Giannone, and Reichlin, 2010; Lenza, Pill, and Reichlin, 2010), with slow macroeconomic variables followed by the monetary policy instrument and fast financial variables at the bottom. We assume that fast moving variables respond contemporaneously to monetary policy shocks, whilst slow moving ones only respond with a one period lag, i.e. one month. A Cholesky ordering that puts financial variables before the monetary instruments, was found to give similar results (See Section 7).

Formally, we compute the lower triangular Cholesky decomposition of the variance-covariance matrix of the VAR residuals. The identification strategy implies that each variable responds contemporaneously to the orthogonalized shock to variables ordered above it. Hence placing QE between the slow macro and fast financial variables implies that the financial variables respond contemporaneously to a QE shock, whereas the macrovariables only respond the following period. Such an identification scheme has been extensively used in the literature on conventional and unconventional monetary policy. Examples include Christiano, Eichenbaum, and Evans (1999), Bernanke, Boivin, and Eliasz (2005), and Bańbura, Giannone, and Reichlin (2010). In general, a positive disturbance to the QE variable can be interpreted as a loosening of policy.

3.3. Forecasting ability

A forecast evaluation procedure is conducted in order to gauge whether the model is able to produce competitive forecasts. The framework entails producing recursive forecasts for one and three months ($h = 1, 3$) ahead and comparing the projections with actual observations. We analyse the forecasting power out-of-sample. We reduce the dataset by the forecasting horizon, thereby estimating the VAR model with fewer data points. More specifically, data until 2011 are used as the initial sample, with an evaluation period of 2011:11-2015:11 (t =2011:11,...,2015:11). At each step, the model is re-estimated and forecasts for different horizons are produced using data from 1982:6 until $t - h$, for the UK, and from 1971:1 to $t - h$ for the US. We also calculate the forecasting errors for a random walk (RW) model and calculate Theil's-U statistic between the VAR framework and the RW. A value below one indicates greater forecasting power from our model compared to the RW. The random walk is a challenging benchmark as numerous studies have shown that many financial and some economic variables behave like a random walk. Should the VAR model outperform the RW, we can conclude that the model is capable of capturing systematic relationships between the variables and more generally, that these relationships can be exploited for forecasting and policy analysis.[20]

Tables 3 and 4 present the out-of-sample root-mean-square percentage errors (RMSPE) of point forecasts from the UK and US models respectively.[21] Starting with the 'VAR' column, it shows the smallest forecast errors for the two macro variables and market liquidity. On the other hand, stock market levels, volatility and QE amounts, unsurprisingly, produce larger RMSPEs. This holds true for both countries and across forecasting horizons. RW forecasting errors also display a similar pattern.

[**Place Table 3 about here**]

[**Place Table 4 about here**]

Let us now turn to comparing the two models. The last column of Table 3 exhibits only some Theil's-U statistics below one, suggesting that the RW is marginally better at one-step ahead prediction. The conclusion is reversed as we extend the forecasting horizon to three months. Indeed, the VAR model produces RMSPEs smaller than the benchmark model in the vast majority of instances. Unreported results at the 6- and 12-month horizons provide further evidence on the ability of the VAR to produce better forecasts at longer horizons.

Overall, our VARs predict quite well, suggesting that we have constructed plausible models capable of extrapolating valuable information from the dataset used. More specifically, they outperform the random walk benchmark on all financial variables (stock market, volatility and liquidity) and most macroeconomic ones (UK output, US prices and Quantitative Easing for both countries). In sum, these findings provide support for our modelling choice for both economies.

20. Unreported in-sample results show the vast majority of Theil's-U statistics to be less than unity at 1-, 3-, 6- and 12-month horizons. This supplies evidence that the VAR model forecasts better than the RW.

21. RMSPE are calculated as follows. $RMSPE = \sqrt{\sum \left(\frac{y_{t+h} - f_{t+h}}{y_{t+h}} \right)^2}$ where f_{t+h} is the expected value of the variable h steps ahead, forecasted at time t and y_{t+h} is the actual value.

4. Findings

4.1. Impulse response analysis

This analysis consists of calculating the impulse responses to a monetary policy shock in the VAR model for a 24-month horizon. In Figures 1-3 below, we present the 16^{th}, 50^{th} and 84^{th} percentiles of the impulse responses distribution.[22, 23]

We normalise the size of the shock to match the peak three-fold increase (200%) of the Bank of England and Federal Reserve balance sheets. Consequently, we give the system a 2-unit disturbance (equivalent to 200%) in the amount of securities held by the BoE (UKM0QE), which gradually declines but does not vanish completely over the 2-year horizon. In the case of the US, we apply a 0.75 unit shock to the FED securities (USM0QE) which rises to a peak equivalent to the 200% increase after about five months and progressively fades out in just less than two years.[24] The results of this procedure can be considered as an upper bound on the impact of Quantitative Easing since we assume that the entire QE amount was exogenous, whereas in reality only a fraction of it might have been unexpected.

A unit increase (decrease) in the response of a log-level variable can be interpreted as a 100% rise (fall) in the levels. An increase (decrease) of one unit in the response of a variable expressed as rates should be interpreted in absolute terms (for example, a response of +0.01 in unemployment is a 1% increase, say from 4% to 5%). The analysis of the magnitude allows us to perform a cross-country comparison of the sizes of the responses.

Our baseline approach to identifying the QE shock is achieved by sign and zero restrictions. We constrain the contemporaneous response of macro variables to QE shocks to zero and also allow the QE variable to respond with a one period delay, reflecting the fact that Quantitative Easing policies were first announced and then implemented. In line with the event study analysis of Fratzscher, Lo Duca, and Straub (2016) and Joyce, Miles, Scott, and Vayanos (2012), we restrict the contemporaneous impact of equity prices to be negative. The response of volatility and liquidity

22. The 16% and 84% quantiles are common in macroeconomic VAR models, in particular when sign restrictions are used for identification. See, for example, Giannone, Lenza, and Reichlin (2014), Giannone, Lenza, and Primiceri (2015), Gambacorta, Hofmann, and Peersman (2014), and Weale and Wieladek (2016).

23. For the VAR model estimated via OLS, we compute confidence intervals by 1000 wild bootstrap draws. For the Bayesian estimates, we report the quantiles of the IRFs based on the posterior distribution.

24. Due to the linearity of the model, the size of the shock is irrelevant to the shape and significance of the impulse responses. Thus, the following analysis is valid and robust to different magnitudes of shocks.

is left unrestricted. We now turn to the analysis of the results of this identification reported in Figure 1.

4.2. The macroeconomic impact

The first two plots in each panel of Figure 1 present an indication of the uncertainty that surrounds the estimates of effectiveness of Quantitative Easing in boosting the economy. Starting with output, the responses of US and UK industrial production are, in fact, insignificant and while for the former economy point estimates suggest marginally beneficial effects, for the latter they indicate a shrinkage. On the other hand, the impulse response function of prices are positive and increasing, reaching a plateau after about 24 months. The proportion of the responses' magnitude is about one-to-one and is in line with the existing literature on conventional monetary policy shocks (Christiano, Eichenbaum, and Evans, 1999; Bernanke, Boivin, and Eliasz, 2005; Eickmeier and Hofmann, 2013). In general, our macroeconomic analysis tends toward the conclusion of a neutrality of QE on output as the error bands of the responses of industrial production are centred around zero. However, we do find some evidence of a positive effect of prices following a QE shock, starting in the very short term for the US and after around one year in the UK.

When comparing response functions across countries, our results are in accordance with the previous literature. Indeed, similar to Weale and Wieladek (2016), we too find evidence indicating that the US QE was more successful than its UK counterpart. Since Lenza, Pill, and Reichlin (2010) argue for the presence of many commonalities between the evolution of the BoE and the FED balance sheets, thereby excluding that as discrepancy source, possible explanations for the contrasting efficacy include the vast leakages of the British monetary policy and differences in the effectiveness of transmission channels. Bridges and Thomas (2012) estimate that only 61 per cent (£122 billion out of £200 billion) of the BoE QE contributed to enlarging the broad money supply, which in turn only increased by eight per cent. This low growth of UK M4, as we show in the next section, can help explain the small and uncertain macroeconomic impact of the unconventional monetary policy. Weale and Wieladek (2016) argue that different transmission mechanisms operated in the two economies, with the 'portfolio balance' channel playing a role in the US and the 'risk-taking' channel being more prominent in the UK.

[Place Figure 1 about here]

[Place Figure 2 about here]

The impulse responses reported in Figure 2 are Cholesky identification estimates and display a number of similarities with our baseline model results. For instance, the shape of responses of the QE variables is similar - monotonically decreasing for the UK and humped-shaped for the US - and in both economies the impact fades away after two years.

4.3. The financial market impact

The three bottom row plots in the panels of Figures 2 suggest that Quantitative Easing had a substantial impact on the domestic capital markets.[25] Starting from the stock market level, both UK and US equities fell contemporaneously with the QE shock but rose afterwards, suggesting a strong and significant impact of the monetary policy on stock prices.[26] The immediate negative response of equities is also illustrated by the event study analysis of Joyce, Lasaosa, Stevens, and Tong (2011). On the one hand, the signalling message of policy makers who decide to implement such an unconventional measure might cause investors to revise their future macroeconomic forecasts downwards, thereby decreasing dividend expectations and raising equity risk premia, ultimately causing stock prices to fall in the short run, immediately after the QE shock. On the other hand, our results on the positive impact of the monetary policy on the stock market in the longer run match the findings of Bridges and Thomas (2012), in the UK case and of Fratzscher, Lo Duca, and Straub (2016) for the US. We argue that the liquidity injected in the markets operated, via lower interest rates as extensively reported in the literature, through the following mechanisms. First, the present value of future expected dividends was driven up. Second, firms' lower borrowing costs translated, *ceteris paribus*, into higher profitability and a higher propensity to expand and invest. Third, the low returns offered in the bond markets resulted in a shifting of investors away from it and towards the equity market. Overall, the results are consistent with the presence, in the short term, of a negative signalling channel that causes stock prices to drop. In the longer run,

25. In this subsection we place more emphasis on the analysis of the Cholesky identification estimates as is does not impose a directional response restriction on equity prices unlike the sign restriction. As we want to let the data 'speak', we focus on the methodology whereby the stock market does not react negatively by assumption.

26. The negative contemporaneous impact of equity prices is an identifying assumption for the sign restriction methodology, but not for the Cholesky identification.

the prevalence of positive factors and possibly gradual portfolio rebalancing activities by investors towards higher returns and yields contribute to higher equity market levels.

Our median estimates that result from a Cholesky identification of both the VAR and BVAR models, indicate a peak impact on equities, at the end of the 24-month horizon, of around 20-30% for the FTSE All-Share and around 40-50% for the S&P 500.[27] This implies that the unconventional policy measures adopted caused increases in equity prices of at least 30%. If the FTSE was trading at 1000 points, QE boosted it by 300 points over two years. Indeed, the UK and US stock markets grew by around 44% and 36%, respectively, over the two years following the first QE announcement.[28] Thus, QE acted on equity markets through time and promoted their growth on an economically meaningful scale.

Turning to the response of volatility, the shapes of the British and American response functions are again comparable. The initial impact is significantly positive but turns negative after four to five months and reaches a peak at seven months in the UK, and at 12 in the US, before returning to baseline, drawing an inverted 'V' shaped response. A quick calculation quantifies the maximum influence to be between 0.14% and 1.26% in the UK and 0.13% to 2.32% in the US compared to their respective average volatility levels.[29] This result indicates a spike in market turmoil in the shorter run after a Quantitative Easing shock, perhaps as the markets 'digest' the news. The extra volatility could also simply be due to the higher volumes of trading generated as the excess liquidity finds its way in the market (Shiller, 1981).Gambacorta, Hofmann, and Peersman (2014) structural identification of the impact of QE, implemented by sign restrictions, fails to find the initial increase of market volatility as the response is bounded to be negative by construction. In the longer run, instead, the impulse responses indicate a calmer period (six months to two years), as the injected liquidity seems to settle marginally reducing equity prices movements. The two identification strategies are unanimous in the reaction of volatility over the medium to long term. Indeed, Figure 1 shows that, albeit not well identified in the very short term, the impulse response

27. Note that there were, obviously, other forces acting on equity prices, both positively and negatively, during the QE period. The reader should interpret our estimates as an upper bound effect on the growth of stock markets attributable to the unconventional monetary policy.

28. In January 2009, when the BoE announced the first round of QE, the FTSE All-Share was trading at around 2150 points and in January 2011, it was trading at 3100 points, which implies an arithmetic growth of around 44%. In November 2008, when the FED announced the first round of QE the S&P 500 was trading at around 880 points and in November 2010, it was trading at 1200 points, which implies an arithmetic growth of around 36%.

29. $0.02/14.27 = 0.14\%$ and $0.18/14.27 = 1.26\%; 0.02/15.08 = 0.13\%$ and $0.35/15.08 = 2.32\%$.

function of stock market volatility is significantly negative after about five months in the UK and seven months in the US.

Lastly, when we compare the response of market liquidity, a difference between the two economies emerges. We find the UK spread measure to be influenced insignificantly, whilst the US one appears to increase, reaching a maximum around four months following the shock before the effect fades away over the 2-year horizon. This indicates that QE, in contrast to what one might expect, actually has a negative effect on market liquidity. One potential explanation for this puzzle could be that the monetary policy increases uncertainty. Although Quantitative Easing might provide fresh liquidity to market participants who are willing to rebalance their portfolios, it may deter market makers from building up large positions, thereby increasing the spreads of their two-way quotes. Upon closer examination, in fact, we discover a timely positive relationship between the increase in volatility and decrease in market liquidity, which might explain this otherwise puzzling result. A different possible vindication is that the short run demand function of money/liquidity is convex and becomes inelastic if a large quantity is supplied and therefore, fails to absorb the extra money injected.

Overall, the smaller influence of the BoE policy on its domestic financial market is consistent with the possibility that the UK QE was transmitted to its domestic market to a lesser extent, as the lower impact on the FTSE, volatility and liquidity seem to suggest, due to larger leakages of the monetary policy (see Butt, Domit, McLeay, Thomas, and Kirkham, 2012; Bridges and Thomas, 2012).

We also estimate a BVAR model for each country over the QE period. On the one hand, this allows us to drop M0 as a proxy to extend the QE variable time series. On the other hand, it leaves us with around one hundred observations. We thus estimate the model in a Bayesian fashion using the Minnesota and the Sum of Coefficients priors. For internal consistency, we plot the 16^{th} and 84^{th} percentiles of the impulse responses densities (computed with a direct sampling MCMC algorithm) to QE shocks, identified via zero restrictions as per Section 3.3.2. What we find is that our baseline results are robust to this model variation. The IRFs displayed in Figure 3 supply more evidence of little macroeconomic impact of QE, and relevant positive effects on equity prices in the UK and US. Importantly, we argue that this result, jointly with low out-of-sample forecast errors over the post 2008 period, indicates that our baseline model is able to capture economic dynamics even at the ZLB and the results are not driven by pre-QE observations.

[**Place Figure 3 about here**]

5. Transmission channels

We devote this section to analysing a transmission channel in order to offer a possible explanation of the findings on the macroeconomic ineffectiveness of QE. We argue that our results on the macroeconomic impact presented in Section 4.4.2 are attributable to a scarce growth of credit towards investments and consumption. We hypothesise that QE had a limited influence since it did not boost lending.[30]

To do so, we extend the model and include an additional variable, namely an aggregate measure of lending. In the spirit of Lyonnet and Werner (2012) we use M4, a broader measure of money, to proxy for credit in the UK. Unfortunately, in the US, the Board of Governors of the Federal Reserve System ceased to publish M3 in 2006 and the broadest measure of money now available is M2. Thus, we only run this empirical exercise using UK data.

We expect the real credit shocks to have sizeable effects on macroeconomic variables and QE shocks to have negligible bearing on lending. More precisely, the two tests we run are to: i) add a broader monetary aggregate and study the variables' responses to broad money shocks; ii) add a broader monetary aggregate and analyse its response to QE shocks. With this investigation, we aim to understand whether the money created by QE was transformed into real credit. Our hypothesis, based on the results presented previously, is that Quantitative Easing money was used to fund investments and consumption only to a limited extent.

[**Place Figure 4 about here**]

Figure 4 shows the impulse responses to a 2-unit broad money shock identified using zero restrictions as per Section 3.3.2. Just as hypothesised, such a loosening of monetary policy would indeed have a significant and permanent impact on the macroeconomy as the reaction of prices

30. Bowman, Cai, Davies, and Kamin (2015) analyse the Japanese case and also argue that overall the increase in bank lending was limited.

indicates. However, we detect no significant effect on asset prices. Furthermore, the fact that the output response is stable whilst price levels are boosted suggests that real credit creation in the UK supports consumer spending more than production investment. When contrasting Figures 2 and 4 in terms of magnitude, we note that the ratio between the the responses of prices to a shock of QE and Credit of the same size is around ten. This means that in order to achieve a certain inflation rate, a monetary policy aiming at increasing the size of M4 would be preferable as it would entail a more modest increase of the targeted policy variable than a QE-like policy which entails a vast enlargement of the central bank balance sheet.

In the second empirical exercise of this section we aim to study the impact of QE on broad money. As our results, in line with Lyonnet and Werner (2012), show that M4 can propel the real economy, we analyse how UK Quantitative Easing has affected the former. The supply of broad money in developed economies is driven by the provision of credit from the banking sector (including the central bank) to the money-holding sector (households, non-financial institutions, government and non-monetary financial intermediaries).[31] Thus a positive response of M4, which would suggest the presence of transmission channels that policy makers could exploit (Bridges and Thomas, 2012), would provide evidence in favour of QE effectiveness.

[**Place Figure 5 about here**]

Looking at the monetary aggregate IRF in Figure 5, we find that Quantitative Easing as implemented in the UK failed to stimulate a positive growth of M4. In fact, the shock to money supply was significantly negative. This finding is in line with what is found by Lenza, Pill, and Reichlin (2010) for the effects of unconventional monetary policy in the euro area: QE shocks have a negligible impact on M3. Such a result further supports our point that the unconventional monetary policy was not successful in providing a thrust to the real economy since it did not accomplish real credit creation.

31. See, for instance, ECB (2011).

6. Comparison with previous literature

Before turning to a robustness check of our baseline results, we aim to pinpoint the causes of the differences in findings between this paper and the previous literature. Since our methodology was inspired by Gambacorta, Hofmann, and Peersman (2014, GHP), their VAR model will be our benchmark for the following exercise. Similar to our model, they include proxy variables for output, prices, volatility and unconventional monetary policy, yet they do not include anything else. Instead, our model also comprises the stock market (and market liquidity). This examination thus involves repeating the exercise outlined in Section 3 dropping all the additional variables (stock market and liquidity) and only including the four variables used in GHP, which allows a direct comparison. We match the identifying assumption to theirs and impose the following restrictions on impact and on the month after:

Output	Prices	QE	Volatility
0	0	>0	≤ 0

Matching sign Restriction Identification.

We iterate the sign-restriction procedure until we have accepted 1000 draws. As Figure 6 captures, this small VAR model presents clear evidence of positive and significant macroeconomic improvements due to QE shocks. Both output and prices in the US and UK show positive impulse response functions.

[Place Figure 6 about here]

Our estimates, reported in Figure 6, indicate that once equity prices are excluded from the model, QE shocks would have a positive and significant effect on prices in both countries examined. These results are qualitatively comparable to the broad money shocks analysed in the previous section. The responses of output and volatility, instead, seem to be less dependent on the inclusion of stocks. The omission of the stock market from the model would lead us to similar conclusions to GHP as to the efficacy of unconventional monetary policy on the macroeconomy.[32]

32. Unreported IFRs of a VAR model including liquidity and excluding stock prices leads us to similar conclusions, providing further evidence that it is indeed the equity market that is the source of the different finding compared to the previous literature.
The further step we take is to add the stock market variable to the VAR model. As per the sign restriction identification procedure, we restrict the response of equity prices to be negative. The results presented in Figure 13 weaken

Overall, these findings corroborate our conclusion of this section where we argue that the joint modelling of macro and policy variables with the stock market as a crucial influence on unconventional monetary policy efficacy inferences.[33] We thus argue that the inclusion of the stock market in assessing the impact of unconventional monetary policy is of key importance and failing to do so can lead to biased inferences.

Econometrically, the significance of the presence of equity prices as a link between the financial markets and the macroeconomy in a vector autoregressive model to correctly evaluate the impact of Quantitative Easing can be compared to the importance of: i) including indicators of financial turmoil and uncertainty such as volatility in non-standard monetary policy VAR models to identify an unconventional monetary policy shock (see GHP), and ii) including inflation predictors such as commodities in standard momentary policy VAR framework to properly identify a conventional monetary policy shock (see Christiano, Eichenbaum, and Evans, 1999).

From a theoretical view point, researchers (see for instance, Forni and Gambetti, 2014; Forni, Gambetti, and Sala, 2014) have shown that numerous small-scale VAR models suffer from non-fundamentalness, rendering them unable to recover true structural shocks and IRFs and unreliable for monetary policy and business cycle analysis.[34] Thus, it is plausible that small scale VARs like the four-variable specification in GHP is non-fundamental. By adding informative and forward looking variables such as the stock market, we may avoid the fundamentalness issue and thus better recover structural shocks. This econometric caveat could therefore be the source of the difference in findings and would reinforce the relevance of including the stock market in the framework.

Lastly, economically, omitting the stock market from the VAR model would be equal to disregarding an important transmission channel, which would very possibly bias the conclusions.

7. Robustness tests

In addition to the different identification strategies and estimation methodologies presented in the previous sections, we also examine two classes of robustness tests to the baseline model in

the evidence in favour of the macroeconomic stimulus of asset purchases. Indeed, in both economies the response of prices is positive, while the reaction of output is not statistically significant.

33. implementing zero restriction rather than sign restriction identification, leads us to reach similar conclusions.

34. Using Forni, Gambetti, and Sala (2014)'s words, *"non-fundamentalness means that the variables used by the econometrician do not contain enough information to recover the structural shocks and the related impulse response functions"*.

order to evaluate whether our analysis is invariant to different modelling choices we made: model variations and model extensions. More precisely, for the former, we assess the robustness of our findings to i) estimating the model in first differences rather than levels for the variables that entered in log-levels and ii) altering the ordering of the variables in the Cholesky decomposition, positioning the monetary policy variable last.

Appendix A reports the IRFs of these alternative specifications. For comparability, Figure 7 reports the IRFs for the levels, not the differences. It provides support to the qualitative robustness of our results both in direction and significance with regard to estimating the model in (log) levels or first differences. The macroeconomic variables are not significantly affected by the QE but the stock market level and volatility are. The effects based on the estimation in first differences on the FTSE All-Share do not reflect the initial negative response of the baseline model. This is perhaps the only slight difference.

Figure 8 displays the impulse responses of the alternative identification scheme. Here we restrict all variables to respond to QE shocks with a one period delay, letting the new information carried in the policy surprise sink into the economy and financial markets more slowly. As the main qualitative conclusion is not altered, we find our results to be robust even to the different 'reaction time' assumption.

We further augment the analysis of robustness by adding extra variables that might be relevant in the analysis to our baseline model. In particular, we assess three alterations of the VAR presented in Section 3: i) an extension containing the unemployment rate, ii) an extension containing the central bank base rate, iii) an extension containing commodity prices and, iv) an extension containing long-term yields.

Generally, the charts contained in Appendix B display virtually no meaningful differences compared with our baseline findings. Figure 9, however, presents a positive aspect of the impact of Quantitative Easing: higher employment. More specifically, both UK and US unemployment appear to significantly decrease after a QE shock. We find a delayed response of unemployment of around two months in the United Kingdom and around seven months in the United States. Over the 2-year horizon studied, the influence seems to endure and records a decrease of between 0.5% and 4% in the UK and between 2% and 8% in the US. This result is in line with Wu and Xia

(2016). On the one hand, this is a welcome outcome as central bank policy was successful in reducing the unemployment rate. On the other hand, the higher employment level combined with the insignificant change of output suggests a decline in productivity. Low levels of productivity may also explain the scarce macroeconomic influence of QE. Albeit productivity has been stagnant after the Great Recession as Harari (2016) demonstrates, it is of key interest among UK media and policy makers since it can propel long-term economic growth. Thus, regulators should consider policies that directly address the possible causes of productivity decline, such as limited investment in equipment, restricted lending to highly productive firms and reduced levels research, development and innovation. We leave formal explanations on the enduring poor growth in productivity to future research.

While most of the Quantitative Easing in both economies analysed was undertaken at the effective zero lower bound, the sample still includes base rate cuts in 2008 and early 2009. We thus incur the risk that the Quantitative Easing shocks capture some of the consequences of these cuts in the policy rate. We expand the VAR model by adding the base policy rate to evaluate the importance of this possible caveat. In the identification of the QE shock, we do not allow a contemporaneous effect of QE on the policy rate to avoid mixing the effects of rate cuts (or hikes) with QE shocks. Figure 10 shows the impulse responses of this extended model and displays no significant differences compared with the baseline model. Further, we find the absence of evidence of a QE influence on the base rate reasonable.

In the third model extension, we consider the potential importance of commodity prices for the analysis. The literature on conventional monetary policy finds commodities to be relevant in assessing policy effectiveness since they are considered inflation indicators. We estimate a larger model that includes the Commodity Research Bureau (CRB) commodity index. In terms of identification, we treat commodity prices as a fast variable thus allowing it to have a simultaneous impact from the QE shock. Innovations to commodity prices are assumed to have a contemporaneous effect on the macro variables, output and prices. Such assumptions are standard in identification schemes in the unconventional monetary policy literature (see for instance, Lenza, Pill, and Reichlin, 2010). The IRFs to QE disturbances depicted in Figure 11 of this extended model show no notable differences compared to our main model. Interestingly, however, we find that the commodity index reacts positively and significantly to the UK QE and not to the US one. This might indicate where parts of the large leakages of the unconventional monetary policy implemented by the BoE flowed (see Bridges and Thomas, 2012) and provide further evidence as to why UK QE was ineffective in boosting the economy.

In the final model extension, we add 10-year government bond yields to our VAR model. This variable represents a key channel of transmission of the unconventional monetary policy since QE is supposed to operate by lowering long-term interest rates. For this exercise, we use the short-run identification scheme employed in the baseline model. In terms of ordering, we place 10-year yields among the fast moving variables, just below QE, in order to allow a contemporaneous impact of a QE shock on bond prices. Turning to the results, for the US model, Figure 12 shows a significant decrease in long-term interest rates contemporaneous to the QE shock, that fades away thereafter. This is a common result the literature (see for instance, Krishnamurthy and Vissing-Jorgensen, 2011; Gagnon, Raskin, Remache, and Sack, 2011; D'Amico and King, 2013). The responses of the other US macro and financial variables is qualitatively similar to our findings in Section 4. For the UK, we also find that our results are robust to the addition of long-term government bonds. However, there exist a difference between the US and UK impulse responses depicted in Figure 12, since 10-year UK yields show no significant decline after an unconventional monetary policy shock.

8. Conclusions

This paper is an empirical study of the effectiveness of the Quantitative Easing programme implemented by the Bank of England and the Federal Reserve Bank to tackle the Great Recession. We conduct an econometric analysis based on a six-variable VAR model, which we develop for each of the two countries. The models jointly include macro variables – output, prices, QE amounts – and financial markets variables – equity prices, stock market volatility and liquidity. Thanks to this comprehensive framework, not only are we able to study various influences of the monetary stimulus on stock markets, but also find the inclusion of financial measures relevant in policy assessment research. Unlike other studies (e.g. Kapetanios, Mumtaz, Stevens, and Theodoridis, 2012; Pesaran and Smith, 2012), our framework does not rely on the impact estimates of the yield curve - an unobserved variable - and its linkages with stock markets. On the contrary, QE enters our model directly as an observable variable on its own, thereby allowing for other possible transmission channels and removing estimation uncertainty of an unobserved component. Before turning to estimating the impact of unconventional monetary policy with a traditional and a Bayesian approach, we run a model validation analysis based on comparing the out-of-sample forecasting power of our base line model with the random walk benchmark. The results of this validation exercise, jointly with the model estimates, provide evidence that the model usefully captures the dynamic relationships between variables, indicating the adequacy of the model for the scope of our research.

In order to assess the effects of QE, we compute the impulse response functions of the variables included in the models to QE shocks, which we identify applying zero short-run and sign restrictions. We find that exogenous QE shocks only have a meaningful impact on financial variables. More specifically, the estimates generally suggest no significant effects on US and UK output and prices.

The analysis demonstrates some differences in the domestic effectiveness of the unconventional policies undertaken in the US and UK. The FED actions appear to have had a greater influence than those of the BoE, perhaps due to the large leakages of the money injected by the BoE in the small open economy.

The two economies' stock market reactions are found to be 'V' shaped: markets respond adversely following asset purchases announcements but subsequently regain the losses and increase even further. Stock market volatility paints the opposite picture as it is gradually lowered by QE shocks. Finally, our findings show a different reaction between US and UK stock market liquidity since we find that the former is negatively affected whereas the latter remains virtually unaltered. Our estimates formally lend support to the widespread belief that Quantitative Easing in the United States and in the United Kingdom had a considerable positive influence on equity prices.

These results are qualitatively similar to those in some of the previous literature (e.g. Chen, Cúrdia, and Ferrero, 2012; Engen, Laubach, and Reifschneider, 2015) but contrast with other papers (e.g. Gambacorta, Hofmann, and Peersman, 2014), especially in terms of the macroeconomic impact. We conduct a further empirical exercise which explores the source of the differences, and find that the inclusion of the stock market in VAR models to assess the impact of unconventional monetary policy is of key importance. This result provides econometric backing to the possible non-fundamentalness of the small scale VAR models used in some of the previous literature. Furthermore, within the channel of transmission analysis, we argue that the expansion of the central bank balance sheet was not channelled into credit creation for investments and consumption. The consequence was an evident increase in equity prices which did not go hand in hand with an improvement in the macroeconomic outlook.

In summary, our findings supply evidence on the limitations of 'unconstrained' Quantitative Easing, in addition to the massive central bank balance sheet expansion required in the process. Should policy makers intend to undertake new QE rounds, we argue that such measures need to be combined with 'constraining' policies aimed at channelling the monetary stimulus into lending that boost consumption and investments, rather than into financial assets. In other words, monetary policy targeting the size of larger monetary aggregates, such as M4, rather than the monetary base, warrant consideration.

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Tables and Figures

Table 1

Mnemonics	Variable	Description	Source	Levels
UKIP	Output	UK industrial production	DS	Log-levels
UKINF	Prices	UK RPI	DS	Log-levels
UKM0QE	UK QE	UK M0 & UK QE	DS	Log-levels
FTALLSH	Stock Market	FTSE All-Share	DS	Log-levels
UKVOL	Stock Market Volatility	FTALLSH 30-day StDev	OC	Levels/100
UKLIQ	Stock Market Liquidity	Roll(1984) bid-ask spread	OC	Levels/100

UK dataset. The data sources are Datastream (DS) and authors own calculation (OC).

Table 2

Mnemonics	Variable	Description	Source	Levels
USIP	Output	US industrial production	DS	Log-levels
USINF	Prices	US CPI	DS	Log-levels
USM0QE	US QE	US M0 & US QE	FR	Log-levels
FTALLSH	Stock Market	S&P 500	DS	Log-levels
USVOL	Stock Market Volatility	S&P 500 30-day StDev	OC	Levels/100
USLIQ	Stock Market Liquidity	Roll(1984) bid-ask spread	OC	Levels/100

US dataset. The data sources are Datastream (DS), FRED (FR) and authors own calculation (OC).

Table 3

Horizon	Variables	VAR	RW	Theil's-U
1M	UKIP	0.007	0.010	0.77
	UKINF	0.007	0.004	1.72
	UKM0QE	0.053	0.043	1.23
	FTALLSH	0.042	0.034	1.24
	UKVOL	0.039	0.034	1.15
	UKLIQ	0.004	0.005	0.75
3M	UKIP	0.010	0.012	0.86
	UKINF	0.009	0.008	1.18
	UKM0QE	0.077	0.078	0.98
	FTALLSH	0.035	0.049	0.71
	UKVOL	0.048	0.058	0.83
	UKLIQ	0.004	0.006	0.67

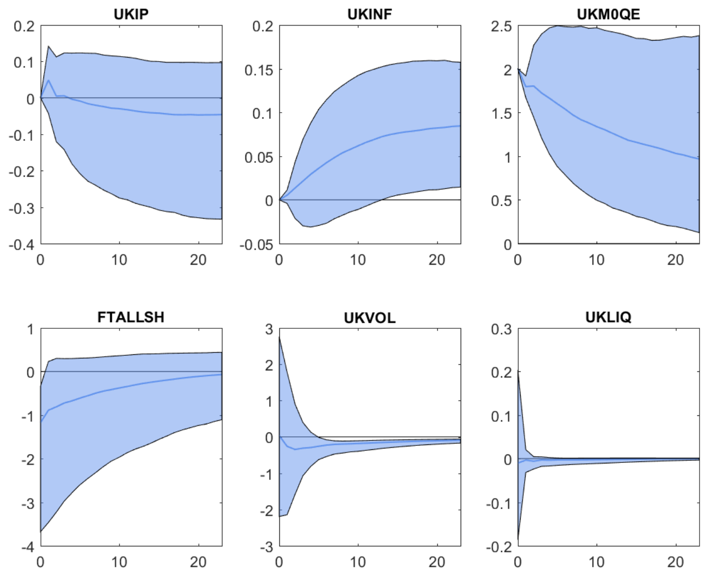
UK Out-of-sample forecasting errors.

Table 4

Horizon	Variables	VAR	RW	Theil's-U
1M	USIP	0.009	0.004	2.18
	USINF	0.004	0.002	1.74
	USM0QE	0.031	0.018	1.70
	S&P	0.050	0.040	1.24
	USVOL	0.043	0.039	1.10
	USLIQ	0.002	0.004	0.59
3M	USIP	0.016	0.009	1.79
	USINF	0.005	0.005	0.92
	USM0QE	0.013	0.054	0.24
	S&P	0.054	0.063	0.85
	USVOL	0.030	0.066	0.46
	USLIQ	0.003	0.004	0.82

US Out-of-sample forecasting errors.

(a) UK



(b) US

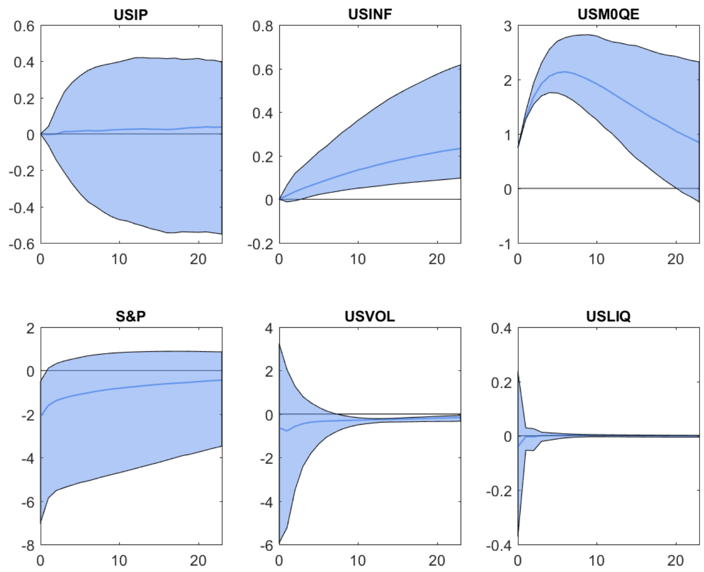
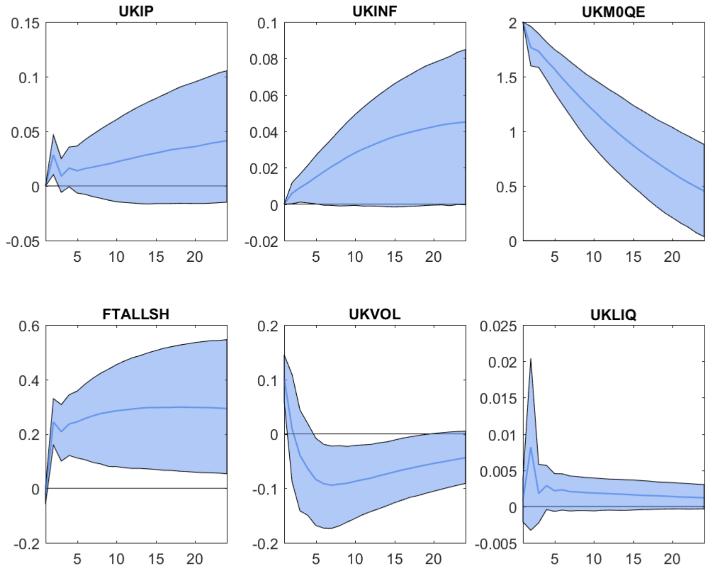


Figure 1. Sign restrictions identification. IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

(a) UK



(b) US

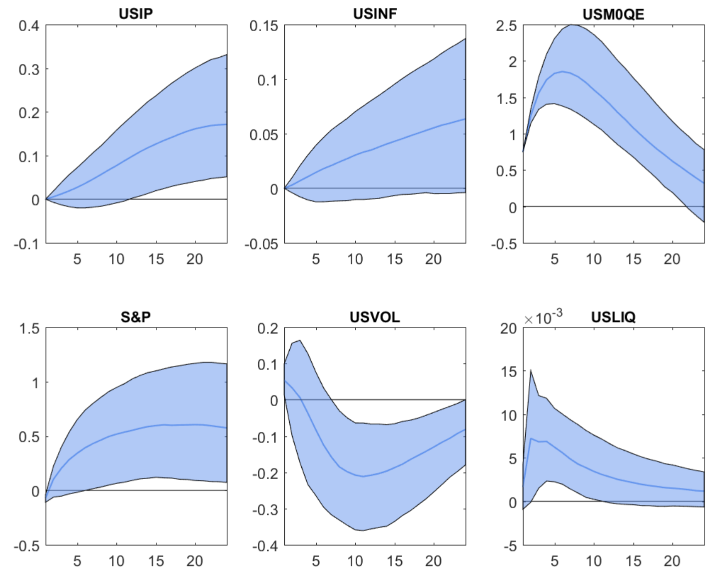
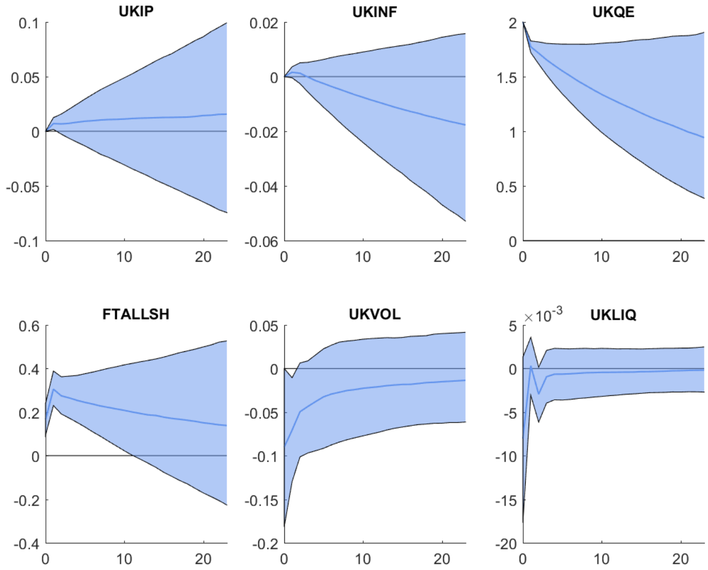


Figure 2. Cholesky identification. IRFs to QE shocks, 16th, 50th and 84th quantiles reported.

(a) UK



(b) US

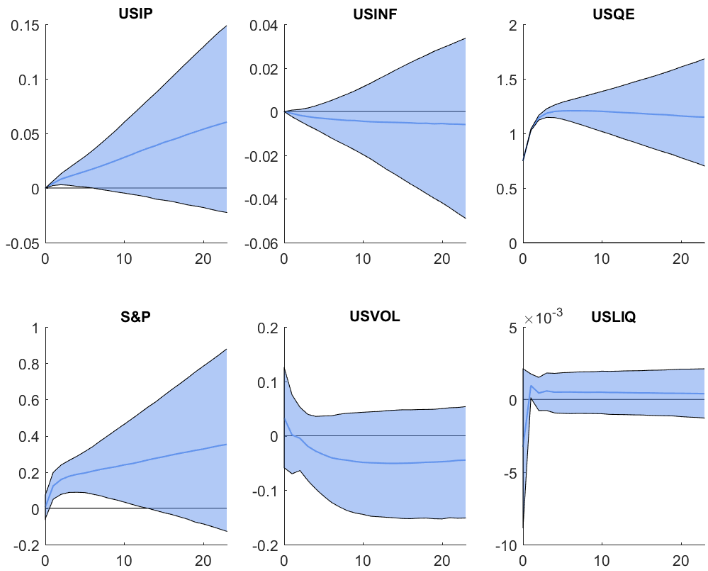


Figure 3. BVAR model, QE period. IRFs to QE shocks, 16th, 50th and 84th quantiles reported.

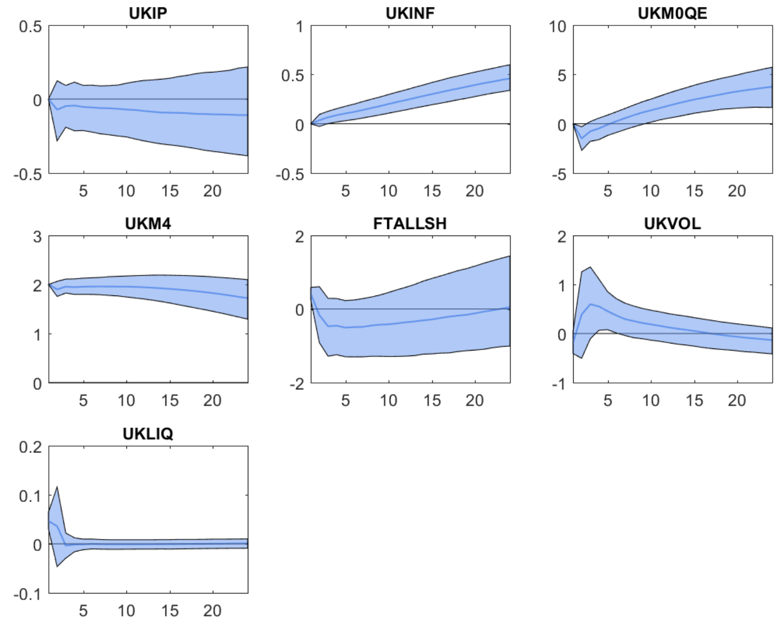


Figure 4. UK extended model Impulse response functions. IRFs to broad money (M4) shocks, 16th, 50th and 84th quantiles reported.

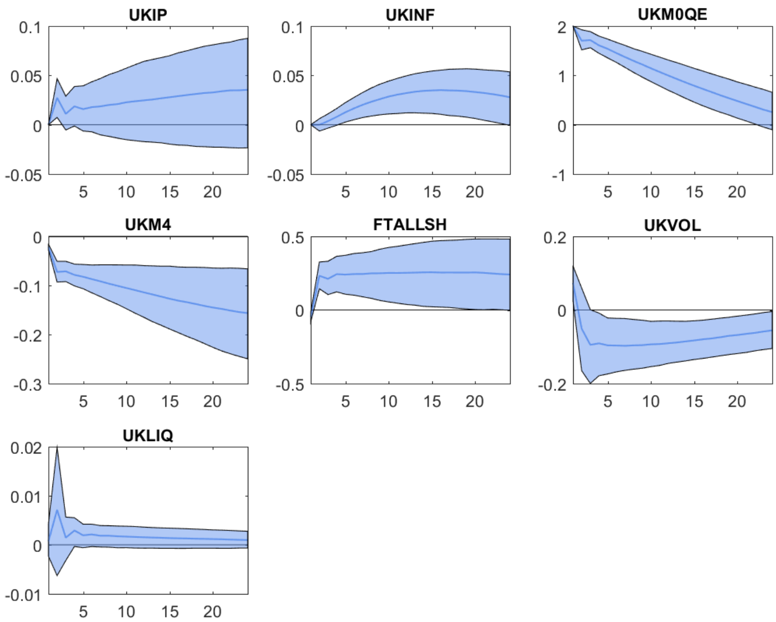
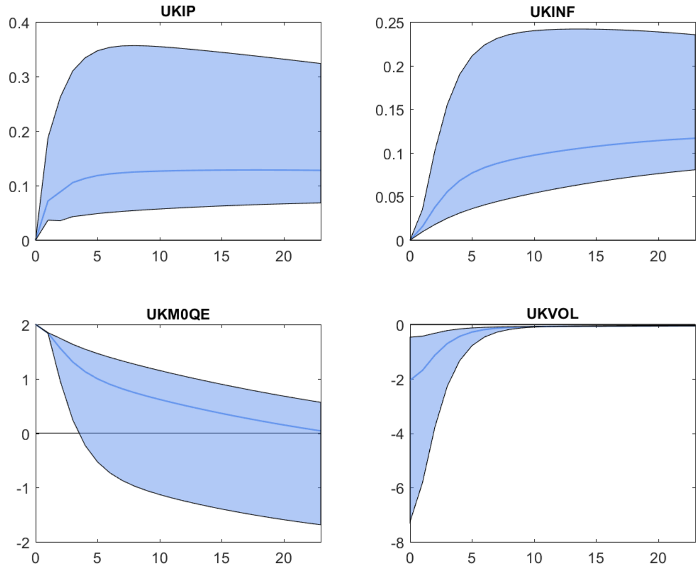


Figure 5. UK extended model Impulse response functions. IRFs to QE shocks, 16th, 50th and 84th quantiles reported.

(a) UK



(b) US

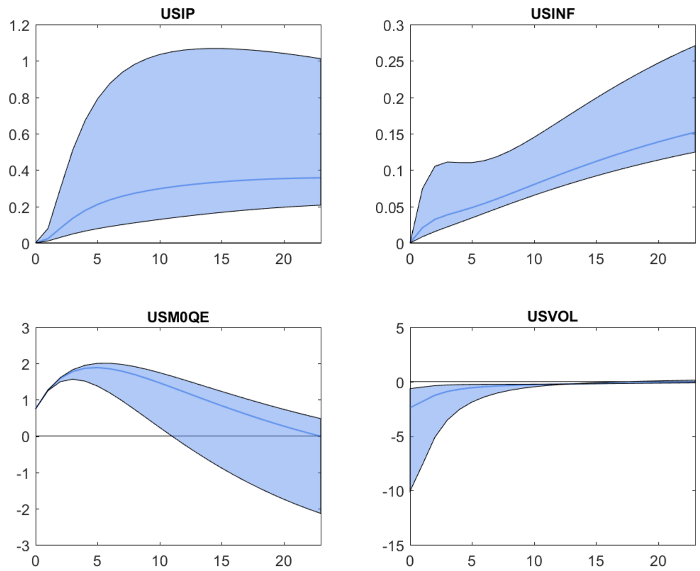
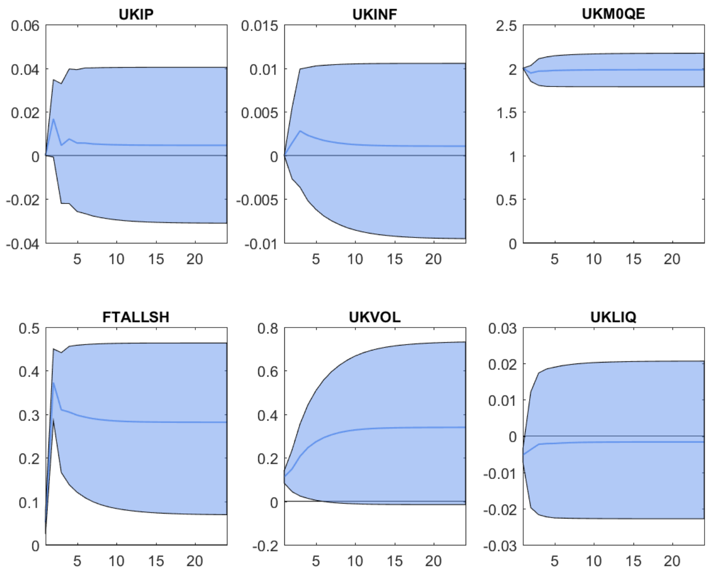


Figure 6. Sign restrictions identification on reduced 4-variable VAR. IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

Appendix A. Model variations

(a) UK



(b) US

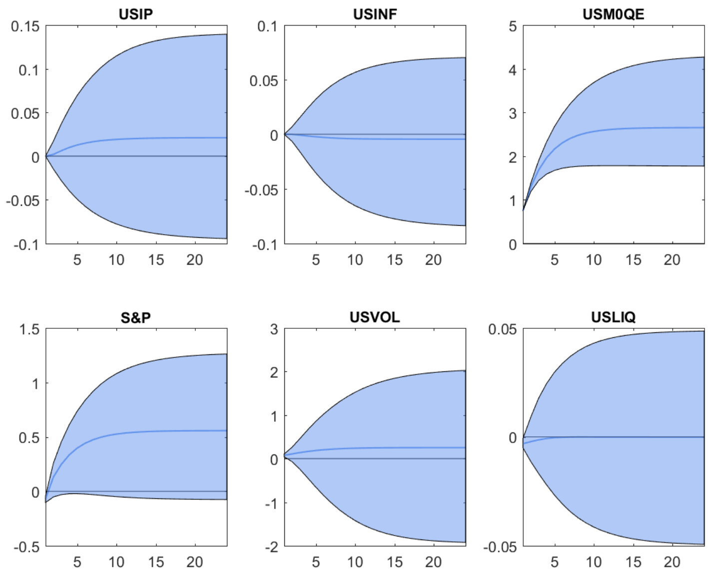
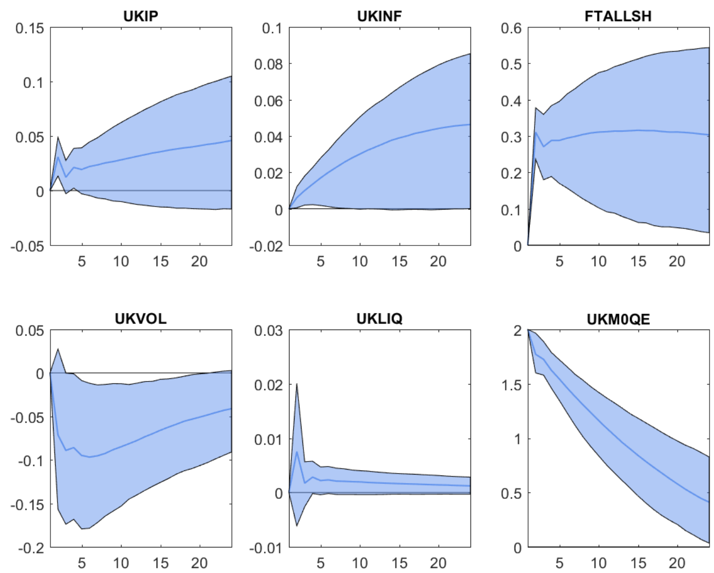


Figure 7. Models in first differences. Cumulative IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

(a) UK



(b) US

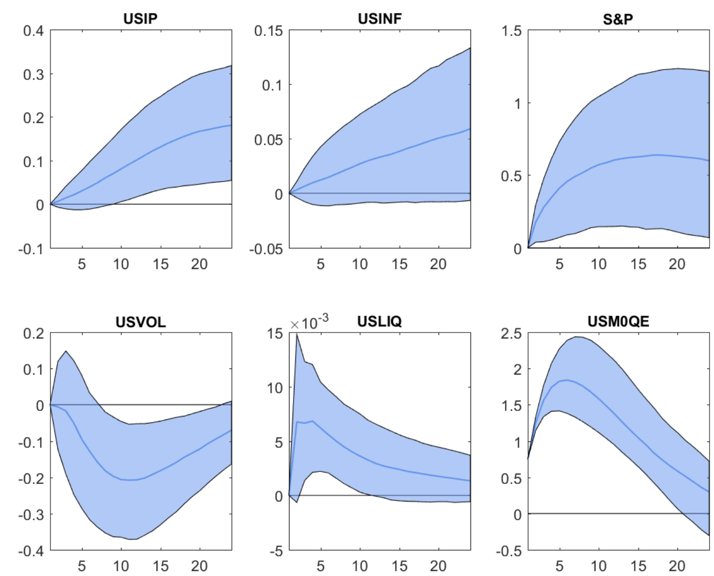
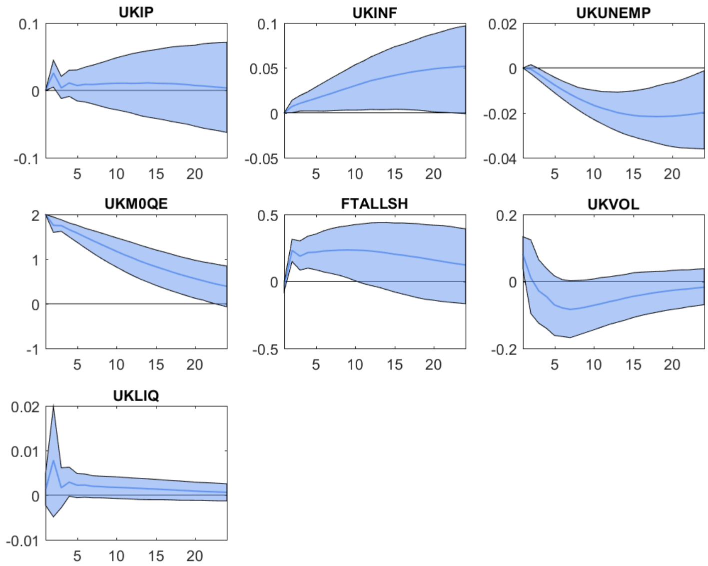


Figure 8. Altered cholesky ordering. IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

Appendix B. Model extensions

(a) UK



(b) US

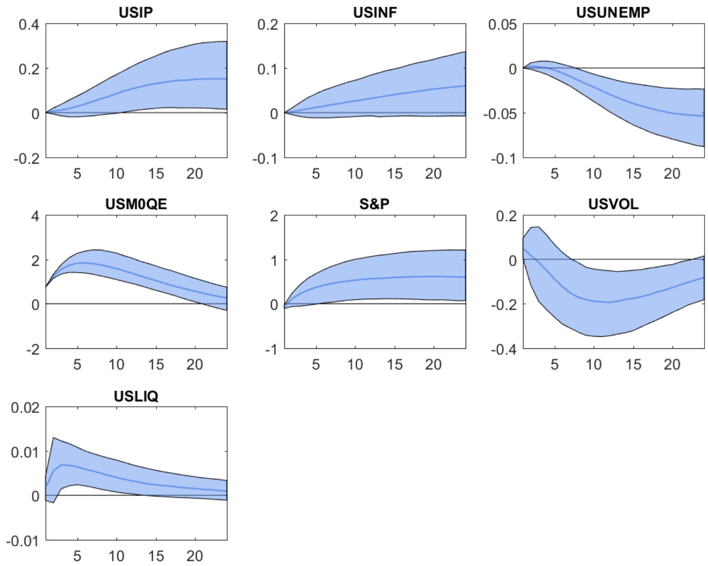
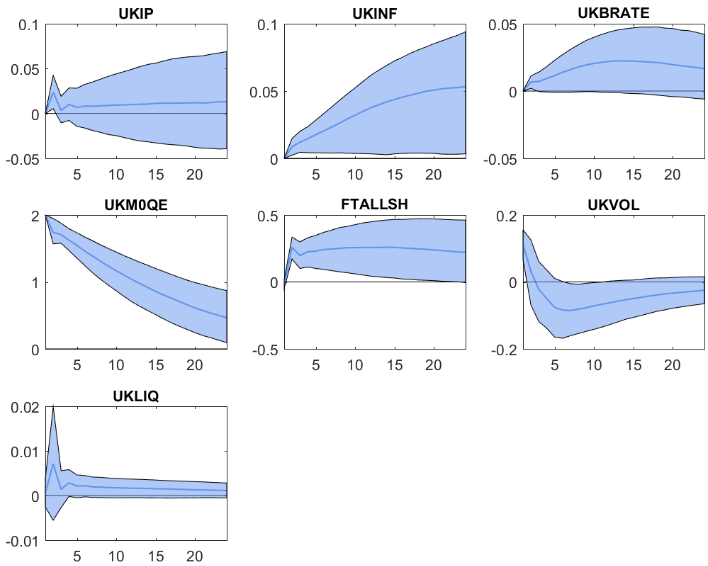


Figure 9. Adding unemployment. IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

(a) UK



(b) US

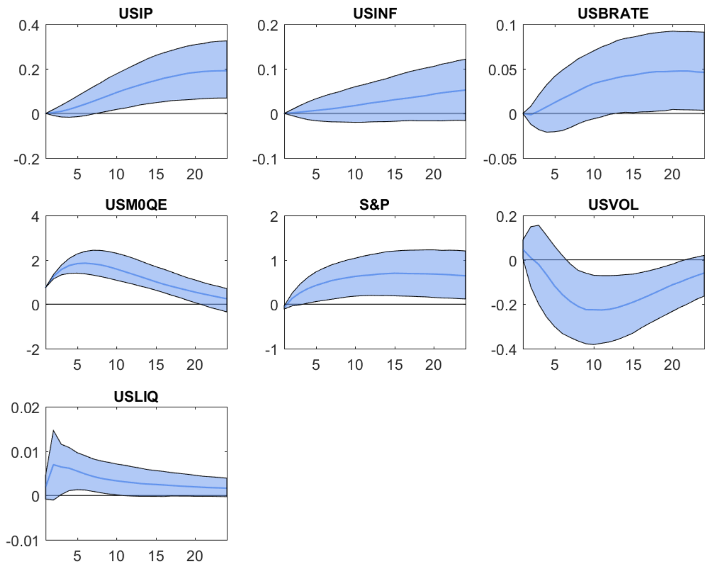
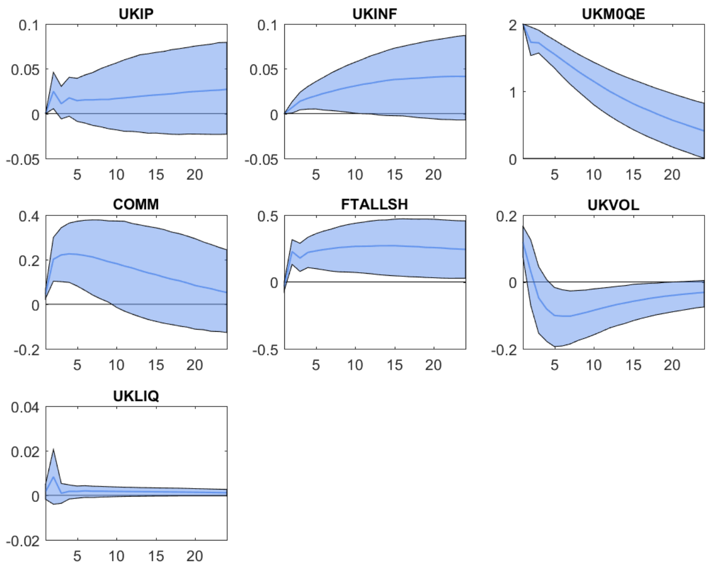


Figure 10. Adding Central Bank base rate (BRATE). IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

(a) UK



(b) US

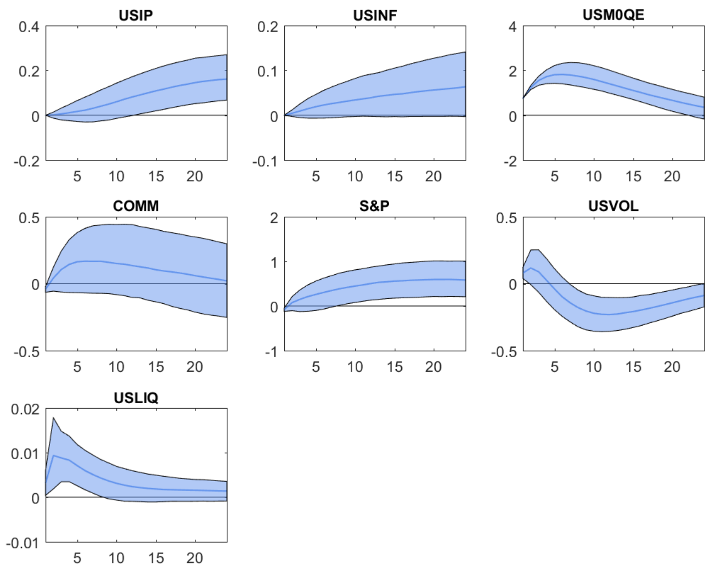
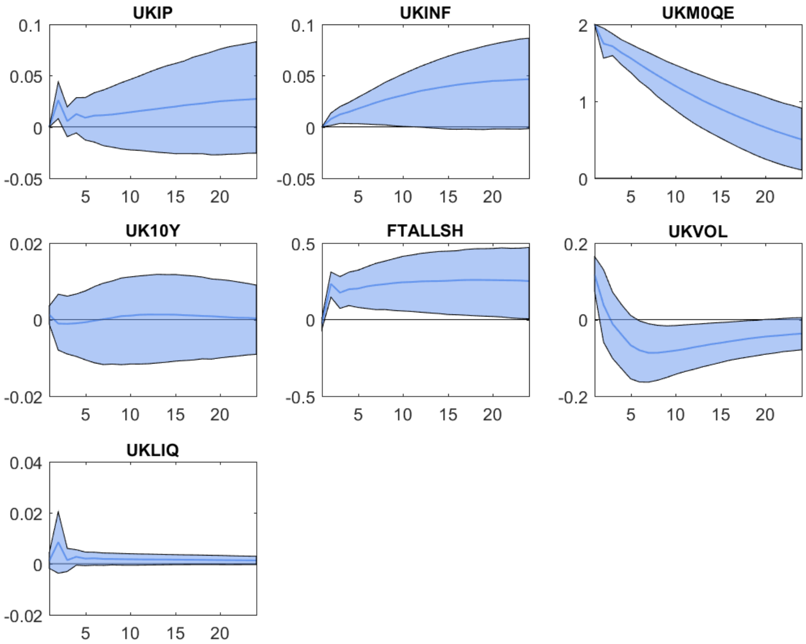


Figure 11. Adding Commodities (COMM). IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

(a) UK



(b) US

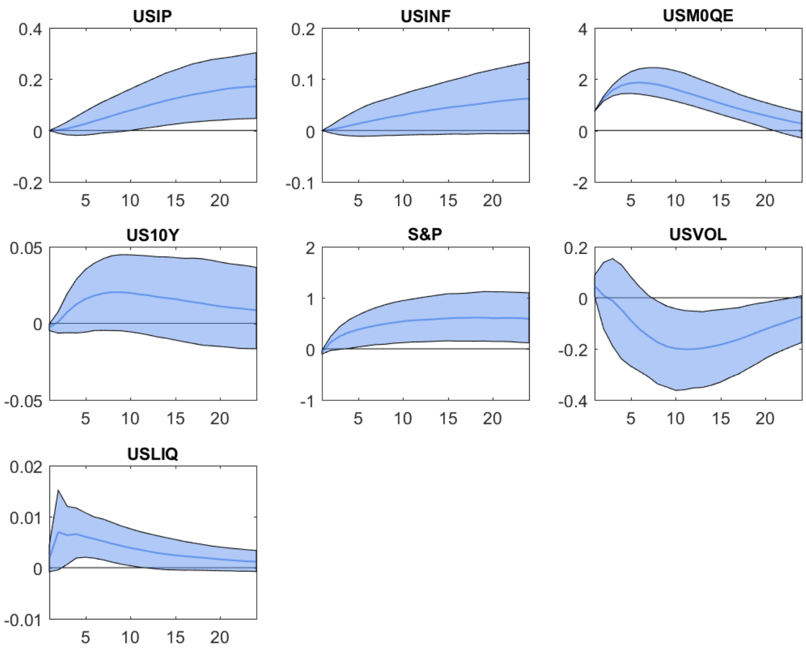
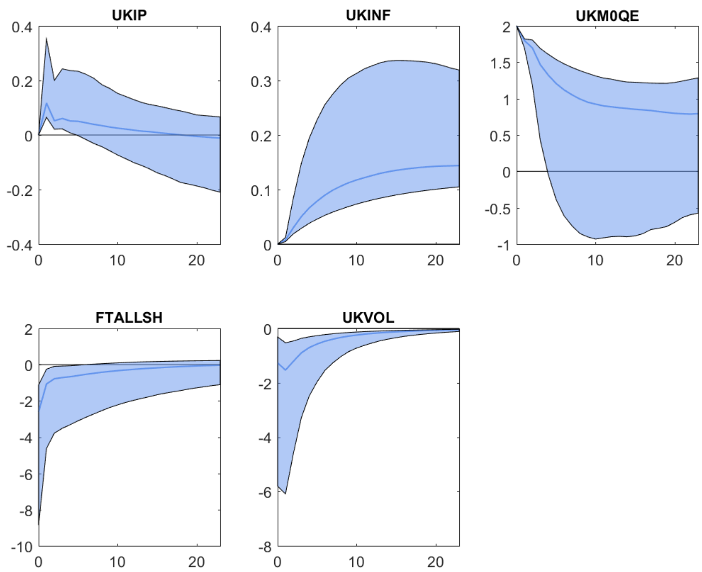


Figure 12. Adding Long-term yields (US/UK10Y). IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.

Appendix C. Sign restriction identification Robustness

(a) UK



(b) US

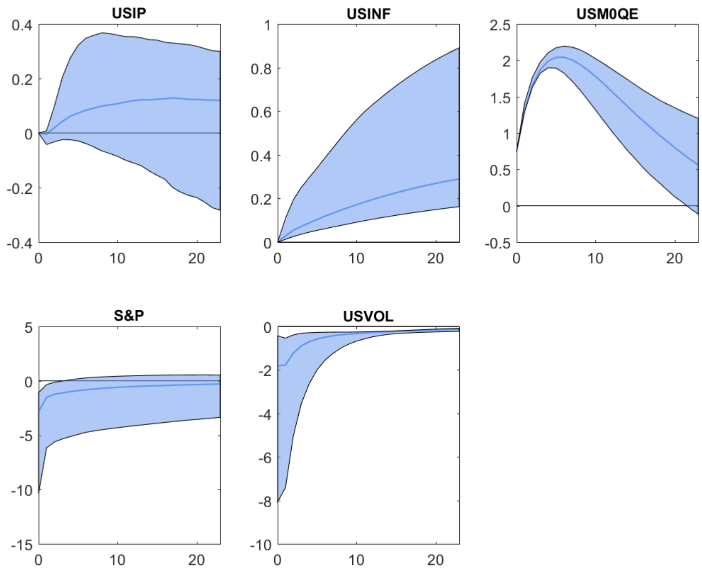


Figure 13. Sign restrictions identification on reduced 4-variable VAR + Stock Market. IRFs to QE shocks, 16^{th}, 50^{th} and 84^{th} quantiles reported.