

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

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This version: January 2017

ABSTRACT

This paper considers the impact of US and UK Quantitative Easing (QE) on their respective economies with a particular focus on the stock market, production and price levels. We conduct an empirical quantitative exercise based on a novel six-variable VAR model, which combines macroeconomic and forward-looking financial variables and uses a ‘pure’ measure of QE. The results suggest a positive response of equity prices and bid-ask spreads and an inverted ‘V’ shaped reaction of volatility to the monetary stimulus. Output and inflation, in contrast with some previous studies, show an insignificant impact providing evidence of the limitations of the central bank’s programmes. We attribute the variation to this difference in our modelling approach, which includes stock market variables, and we conclude that its presence is of critical importance in the assessment of unconventional monetary policy. Economically, we argue that the reason for the negligible economic stimulus of QE is that the money injected funded financial asset price growth more than consumption and investments.

EFM classification: 330, 560, 570.

JEL classification: C32, C54, E51, E58, G1.

Keywords: Quantitative Easing, Monetary Policy, Stock Market, Vector Autoregression.

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Acknowledgements: We thank Torben Andersen, Lawrence Christiano, Giorgio Primiceri, Matt Roberts-Sklar and Viktor Todorov as well as Quantitative Finance seminar participants at Kellogg School of Management, Northwestern University for helpful comments and suggestions. The first author acknowledges financial support from the Economic and Social Research Council [grant number ES/J500148/1]

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“Some of the optimism in the financial markets, [...] may not be consistent with the speed at which the underlying data are likely to change” - Lord King, Former BoE Governor (February 2013)

I. Introduction

In the aftermath of the 2008 financial crisis, central banks 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. Initially, central banks acted as lenders of last resort, providing liquidity, accepting more risky and less liquid collateral, thereby effectively implementing a *Qualitative Easing* (not to be confused with *Quantitative Easing*) and cutting short term nominal interest rates (Lenza, Pill, and Reichlin, 2010; Gagnon et al., 2010). 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. The lending market was still frozen, the unemployment level too high, GDP growth and inflation too low (Dudley, 2010). After the collapse of Lehman Brothers, major central banks therefore decided to embark on additional unconventional monetary policy, in order to revitalize 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*). Lenza, Pill, and Reichlin (2010) argue that there are similarities in the evolution of the balance sheets of the Federal Reserve Bank (FED), the Bank of England (BoE) and the European Central Bank (ECB), namely an expansion in the proportion of unconventional to conventional assets and the nature of liabilities. The Federal Open Market Committee (FOMC), an organ of the US central bank, 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.² Other central banks such as the BoE, the 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.³ On the other hand, however, macroeconomic fundamentals, and inflation in particular, were still sluggish at the end of 2015.⁴ In fact, base interest rates around the world are still found at the ZLB (or even lower), although some people express concerns of economic overheating,⁵ whilst the ECB is still implementing its QE policy and the BoE has initiated a third QE round, after having

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 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).

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

4. 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)

5. See, for instance, Yellen (2015) speech and ‘Goldman warns of risk of US economic overheating’ *Financial Times* (2015, November 9).

cut the base rate again in August 2016 to 0.25%.

There is widespread interest in Quantitative Easing in the media. Whilst some articles refrain from speculating over its effectiveness since “*it is hard to separate the effects of QE from other factors*”,⁶ others take a stand against QE implementation and warn that “*stock market bubbles of historic proportions are developing in the US and UK markets*”.⁷ Even Mervyn King, former Bank of England Governor, said that he was “*concerned that some of the optimism of financial markets, [...] may not be consistent with the speed at which the underlying data are likely to change*”.

In the academic world, the hypothesized effects of such a novel monetary policy began to be studied before the US QE took place and divide economists into three 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). Finally, a third perspective emphasises the ineffectiveness of the unconventional monetary policy employed in Japan, by introducing credit in standard macroeconomic models. Indeed, Werner (2012) proposes a ‘Quantity Theory of Credit’ empirically supported by Lyonnet and Werner (2012). Krishnamurthy and Vissing-Jorgensen (2011) conduct a detailed empirical analysis of the means through which US QE1 and QE2 have worked, namely: signalling, safety, inflation, duration, liquidity, prepayment and default. They conclude that different channels are altered by non-conventional monetary policy and assets are affected heterogeneously. 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 the general public, practitioners, policy makers and academics.

Scholarly papers 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 et al., 2010; Hancock and Passmore, 2011) and the UK (Breedon, Chadha, and Waters, 2012; Bridges and Thomas, 2012; Joyce et al., 2011). Following Voutsinas and Werner (2010), the above literature can be grouped under the umbrella term ‘input performance’, i.e. the central bank policy impact on interest rates. Though informative and useful, this strand of literature has shifted the definition of monetary policy effectiveness from the final target, the macroeconomic impact, to an intermediate target, yields. The ‘output performance’ literature, instead, looks at the ultimate goal of the policy such as price stability and/or output growth. By contrast, only a few studies have been devoted to the analysis of the output and price levels effects.⁸ Lastly, other researchers (Neely, 2010; Fratzscher, Lo Duca, and Straub, 2013; Bhattarai, Chatterjee, and Park, 2015) have also looked at spillover effects from the US to other

6. Claire, Jones. (2013, October 18). Did QE only boost the price of Warhols? *Financial Times*.

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

8. Examples of this second strand of literature include Kapetanios et al. (2012), Bridges and Thomas (2012), and Gambacorta, Hofmann, and Peersman (2014).

countries.

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. The isolation of the policy repercussion in event studies is achieved in a temporal manner. By employing high frequency data, spikes in trading volumes or returns are detected and attributed to QE events, and the causal effect of the monetary policy is assumed. The computed price/yield changes around the announcement day or time are summed and the cumulative differences are taken to represent the influence of the policy. This approach is used in studies such as D’Amico and King (2013) and Fratzscher, Lo Duca, and Straub (2013), who have also 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 in this strand of literature (Gagnon et al., 2010; Krishnamurthy and Vissing-Jorgensen, 2011; Joyce et al., 2011; Rogers, Scotti, and Wright, 2014) given its simplicity. Yet, it suffers from a number of drawbacks. First, the arbitrary length of the event window might be too small to capture all the impact of the announcement or too long and include other news. There might also be news on the same day as the QE that affects prices, which can lead to under- or over-estimation of the effect of the monetary policy. Second, event study analysis is based on the strong assumption that markets efficiently and rapidly adjust to the news. This may not be the case in a tumultuous environment as in the wake of the 2008 financial crisis, where the market was suffering from a lack of liquidity. Thirdly, price/yield changes around QE news would only capture the difference between the average market expectation and the actual update. If, as was the case for the latest US QE announcements, the market estimates already priced in were close to the actual news, an event study approach would wrongly reveal little, if any, impact. Lastly, the application of event study analysis may be valid on daily (or intra-day) time series, such as financial data, but may be more problematic with monthly or quarterly macroeconomic statistics.

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 et al. (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.

Overall, notwithstanding the variety of methodologies employed, there is a general agreement that QE measures in the US and UK have had a positive impact on their respective economies, although the magnitudes of the effects vary across the literature. Lyonnet and Werner (2012),

Werner (2012), and Engen, Laubach, and Reifschneider (2015) are perhaps the discordant voices since they argue that the BoE and FED QEs had limited effect on the British and US economies, respectively.

Thus, so far, scholarly papers have focused on assessing empirically whether Quantitative Easing 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. To the best of our knowledge, very few papers (Joyce et al., 2011; Fratzscher, Lo Duca, and Straub, 2013; Bridges and Thomas, 2012), have touched upon the effects of QE on equity markets. Their estimates are, *de facto*, not the core results of the respective analyses and their samples do not include all rounds of QE.

The main contributions of this paper lay in the fact that we combine an ‘input’ and ‘output’ performance analysis by including (lower frequency, monthly) macroeconomic variables with (higher frequency, daily) financial ones in a single VAR framework. Regarding the latter, this allows us to study the impact of QE on the stock market in a holistic and multi-faceted fashion as we study prices, volatility and liquidity. With respect to the former, we find that the inclusion of financial variables, which could be regarded as a channel of transmission of the policy, to be of key importance for monetary policy assessment and suggesting that the models estimated in previous studies may have suffered from omitted variable bias and would therefore have been mis-specified. Our findings also show that this is the driver of the difference in results with some of the previous literature.

Further, unlike previous studies on unconventional monetary policy evaluation, we employ a ‘pure’ and direct measure of QE, namely the amount of securities held outright by the FED and BoE, in a model that encompasses stock market metrics as well as macroeconomic variables. When producing impulse responses, this allows a direct modelling of the unconventional monetary policy shock rather than indirectly through a ‘channel’ variable, like the 100bp reduction in government bonds used in Kapetanios et al. (2012), which relies on the Joyce et al. (2011) estimates.

We also fill a gap in the literature by assessing the impact of QE on a range of macroeconomic and financial variables using a time series approach that covers all 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 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 autoregressive modelling to capture the linkages among macroeconomic variables – production and inflation – and financial market variables – the stock market level, volatility and liquidity. 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 repercussions to the ultimate targets of the policies, i.e. output and inflation. 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). 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.

The analysis conducted and our results are of the utmost importance for policy makers around the world and in particular for the Bank of England given their stated intention to undertake further rounds of monetary stimulus following the outcome of the ‘Brexit’ referendum.⁹

The rest of the paper is organised as follows. 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 impulse response analysis. In Section 4, we present the main findings on QE impact estimates. Section 5 explains the empirical results by analysis a channel of transmission and provides a comparison with the previous literature. Section 6 contains some robustness tests and Section 7 concludes.

II. 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 inflation, 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. 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 100.¹⁰

We follow Bernanke, Boivin, and Elias (2005), in using industrial production and the consumer price index (CPI) to proxy for output and inflation respectively.¹¹ In the spirit of Bhattarai, Chatterjee, and Park (2015), we use the amount of securities held outright by the central banks. Using the quantity of assets bought by the BoE and the FED allows us to capture QE directly, rather than using other 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 held is available, with M0, since it is a narrow money metric.¹² 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.¹³ Roll (1984) provides a bid-ask spread estimate, thus the higher our measure the lower the market liquidity.

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 et

9. See, for example, Andy, Bruce. (2016, July 13). Bank of England readies new blast of QE for post-Brexit Britain. *Reuters*.

10. Where possible, we use seasonally adjusted variables.

11. We use UK RPI rather than CPI as the inflation proxy, because of data availability constraints.

12. We show in Section VI and Appendix D that our results are not driven by our choice of augmenting the QE time series with M0. Indeed, re-estimating the model over the period where there is data availability on QE amounts leads to similar conclusions.

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

al., 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. Tables I and II provide a detailed description of the datasets.

[Place Table I about here]

[Place Table II about here]

III. 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. 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. This allows us to exploit the time series dimension of our dataset of more than 30 years of historical monthly data, thereby reducing model uncertainty. 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.

A. Vector autoregressive model

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

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

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, β_1, \dots, β_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.¹⁴

14. 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. Equally, the cross-correlations cannot be exploited in estimation to generate better estimates. Indeed, the OLS estimation equation by equation of the VAR is optimal. Thus, since reduced form VAR disturbances are a combination of structural shocks, the non-diagonal elements of the variance-covariance matrix can take non-zero values.

As we focus on the domestic impact of Quantitative Easing, we estimate the model individually 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 (industrial production and inflation) 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, but 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.

B. Identification

Quantitative Easing shocks are identified as exogenous orthogonal innovations of the QE variables. For this purpose, we order the variables as in Tables I and II and distinguish between slow (S) and fast (F) moving variables following (Christiano, Eichenbaum, and Evans, 1999). The former group includes macro variables, whereas the latter comprises financial variables. We assume that fast moving variables respond contemporaneously to monetary policy shocks, whilst slow moving ones only respond with a one period lag. As suggested by Bjørnland and Leitemo (2009), it is important to jointly consider monetary policy and financial variables when analysing monetary policy transmissions. A Cholesky ordering that puts financial variables before the monetary instruments, thereby restricting the influence of a policy to lagged response, would be inadequate and could potentially bias results.

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 Elias (2005), and Bańbura, Giannone, and Reichlin (2010). In general, a positive disturbance to the QE variable can be interpreted as a loosening policy.

C. Model estimates and forecasting ability

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 the number of lags suggested by the Hannan-Quinn

information criterion, i.e. two lags for both countries.¹⁵

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 ($t = 2011:11, \dots, 2015:11$). 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.¹⁶

Tables III and IV present the out-of-sample root-mean-square percentage errors (RMSPE) of point forecasts from the UK and US models respectively.¹⁷ 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 III about here]

[Place Table IV about here]

Let us now turn to comparing the two models. The last column of Table III 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

15. Complete estimation results are available upon request.

16. 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.

17. 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.

most macroeconomic ones (UK output, US inflation and Quantitative Easing for both countries). In sum, these findings provide support for our modelling choice for both economies.

D. Impulse response analysis

This analysis consists of calculating the impulse responses to a unitary monetary policy shock in the baseline VAR model for a 24-month horizon. In Figures 1-5 below, we present the 16th and 84th percentiles of the impulse responses distribution (dotted lines).¹⁸ We compute confidence intervals by 1000 wild bootstrap draws in the spirit of Wu (1986).¹⁹

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.²⁰ 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 a growth rate 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.

IV. Findings

A. The financial market impact

The three plots in the bottom rows of Figures 1 and 2 suggest that Quantitative Easing had a substantial impact on the domestic capital markets. Starting from the stock market level, both UK and US equities fell contemporaneously with the QE shock but rose immediately afterwards, suggesting a strong and significant impact of the monetary policy on stock prices. The immediate negative response of equities is illustrated by the event study analysis of Joyce et al. (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

18. The 16% and 84% quantiles are common in macroeconomic VAR models. See, for example, Giannone, Lenza, and Reichlin (2014), Giannone, Lenza, and Primiceri (2015), Gambacorta, Hofmann, and Peersman (2014), and Weale and Wieladek (2016)

19. More recently, the wild bootstrap procedure has been applied, for instance, in Cesa-Bianchi, Thwaites, and Vicendoa (2016).

20. 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.

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 (2013) 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 and, in the longer run, the prevalence of positive factors that contribute to higher equity market levels.

Our median estimates indicate a peak impact on equities, at the end of the 24-month horizon, of around 30% for the FTSE All-Share and around 50% for the S&P 500.²¹ 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.²² 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.²³ 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). 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. 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.

Lastly, when we compare the response of market liquidity, a difference between the two economies

21. 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.

22. 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%.

23. $0.02/14.27 = 0.14\%$ and $0.18/14.27 = 1.26\%$; $0.02/15.08 = 0.13\%$ and $0.35/15.08 = 2.32\%$.

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. Quantitative Easing might provide fresh liquidity to market participants, who are willing to rebalance their portfolios, but deters 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 et al., 2012; Bridges and Thomas, 2012).

[Place Figure 1 about here]

[Place Figure 2 about here]

B. The macroeconomic impact

The first two plots in the top row of Figures 1 and 2 present an indication of the ineffectiveness of Quantitative Easing in boosting the economy. Starting with the UK, the responses of output and inflation are, in fact, insignificant. Industrial production is found to have a marginally significant positive peak one month after the shock. On the other hand, the impulse response function of prices is monotonically increasing but reaches 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 Elias, 2005; Eickmeier and Hofmann, 2013).

Moving to the US figures, output shows a significant increase after about 12 months, whereas the inflation response, similar to the UK, is insignificant. When comparing the two functions, their shape is analogous but their size is not. In fact, the magnitude of the US output response is almost three times as large compared to the inflation one. This proportion is consistent with more recent studies of unconventional monetary policy transmissions (Kapetanios et al., 2012; Gambacorta, Hofmann, and Peersman, 2014). Table V provides a summary of these findings.

When comparing individual country estimates, 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 BoE and the FED balance sheet evolutions, a possible explanation for the different efficacy might be the vast leakages of the British monetary policy or 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 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 plays a role in US and the ‘risk-taking’ channel is more prominent in UK.

[Place Table V about here]

V. 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 IV.B 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.

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 real credit in the UK.²⁴ Unfortunately, in the US the broadest measure of money published is M2. Thus, we only run this empirical exercise using UK data.

We expect the real credit shocks to have sizable effects on macroeconomic variables and QE shocks to have negligible bearing on lending. More precisely, the two tests we run are: 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 3 about here]

Figure 3 shows the impulse responses to a 2-unit broad money shock identified as per Section III.B.²⁵ Just as hypothesised, such a loosening of monetary policy would indeed have a significant and permanent impact on the macroeconomy as the reaction of inflation indicates. However, we detect no significant effect on asset prices. Furthermore, the fact that the output response

²⁴. With the term ‘real credit’ we refer to lending towards investments and consumption that would be captured by real GDP measures

²⁵. The complete set of IRFs is available on request.

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 1 and 3 in terms of magnitude, we note that the ratio between the size of a QE shock to the response of inflation is around 50, whereas the proportion of the M4 shock to price levels is around 4. 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 much more modest enlargement of the central bank balance sheet than a QE-like policy.

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).²⁶ 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 4 about here]

Looking at the monetary aggregate IRF in Figure 4, we find that the 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.

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, inflation, 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 III dropping all the additional variables (stock market and liquidity) and only including the four variables used in GHP, which allows a direct comparison.

[Place Figure 5 about here]

Figure 5 reports the results of this analysis. Our estimates indicate that once equity prices are excluded from the model, QE shocks would have a positive and significant effect on inflation in

²⁶. See, for instance, ECB (2011).

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.²⁷ 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 monetary 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.²⁸ 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.

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.

VI. Robustness tests

We examine two classes of robustness tests to the baseline model in 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, ii) altering the ordering of the variables in the Cholesky decomposition, positioning the monetary policy variable last, iii) identifying the structural shock by sign restrictions, and iv) estimating the model over the QE period only.

Appendix A reports the IRFs of these alternative specifications. Figure 6 provides support to the

27. 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 previous literature.

28. Using Forni, Gambetti, and Sala (2014) 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*”.

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 7 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.

In Appendix C we describe a different approach to identifying the QE shock, 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 (2013) and Joyce et al. (2012), we restrict the contemporaneous impact of equity prices to be negative. The response of volatility and liquidity is left unrestricted. In order to augment the identification power of this methodology, we attempt to identify other structural shocks. Figure 12 presents the effects of QE shocks, which are comparable to our main findings. In both economies, output does not appear to be influenced, whereas price levels show a modest increase in the medium term. The stock market shows a clear upward trend after the instantaneous negative response, while volatility is reduced after about 7 to 10 months. However, the consequences of QE for liquidity and volatility cannot be determined due to the large standard error bands around zero.

As a final model variation we estimate a VAR 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, this 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. Estimation details are included in Appendix D. What we find is that our baseline results are robust to this model variation. The IRFs displayed in Figure 13 supply more evidence of little macro economic 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 a post 2008 period, indicates that our model is able to capture economic dynamics even at the ZLB and the results are not driven by pre-QE observations.

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 III: 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 presented in Appendix B, display virtually no meaningful differences

compared with our baseline findings. Figure 8, 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. As Harari (2016) demonstrates, productivity stagnation after the Great Recession has been of key interest among UK media and policy makers since it propels long-term economic growth. Thus, regulators should consider policies that directly address the possible causes of productivity decline, such as limited investment on equipments, 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 9 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 on 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 inflation. 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 10 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 bonds 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 Cholesky 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 11 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 et al., 2011; D’Amico and King, 2013). The responses of the other US macro and financial variables is qualitatively similar to our findings in Section IV. 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 11, since 10-year UK yields show no significant decline after an unconventional monetary policy shock.

VII. 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, inflation, 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 studies. Unlike other studies (e.g. Kapetanios et al., 2012; Pesaran and Smith, 2012), our framework does not rely on the impact estimates of the yield curve and its linkages with the stock markets. On the contrary, QE enters in our model directly as a variable on its own, thereby allowing for other possible transmission channels. Before turning to estimating the impact of unconventional monetary policy, we run a model validation analysis based on comparing the 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. We find that exogenous QE shocks only have a meaningful impact on financial variables. More specifically, the estimates suggest no significant effects on UK output and inflation and US price levels, whereas US output only increases significantly with a 12-month lag.

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 in Britain, which

is a small open economy.

The two economies' stock market reactions are found to be 'V' shaped: markets respond adversely in the few months following the announcement but subsequently regain the losses and increase even further. Stock market volatility paints the opposite picture as it displays a positive reaction following a QE shock before it becomes negative. 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. Lyonnet and Werner, 2012) 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. More precisely, we argue that the expansion of the central bank balance sheet was not channelled into credit creation for investments and consumption. The consequence of this was an evident increase in equity prices not followed by 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, should be preferable.

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Tables and Figures

Table I

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

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

Table II

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

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

Table III

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 IV

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.

Table V

		Short-run effect	Long-run effect
UK	Output	Briefly positive	Insignificant effect
	Inflation	Insignificant effect	Insignificant effect
	Stock market	Negative on impact	Positive
	Volatility	Positive	Negative
	Liquidity	Negative	Insignificant effect
US	Output	Insignificant effect	Positive
	Inflation	Insignificant effect	Insignificant effect
	Stock market	Negative on impact	Positive
	Volatility	Positive	Negative
	Liquidity	Negative	Insignificant effect

Summary of main findings. Short and long-run effects of QE shocks.

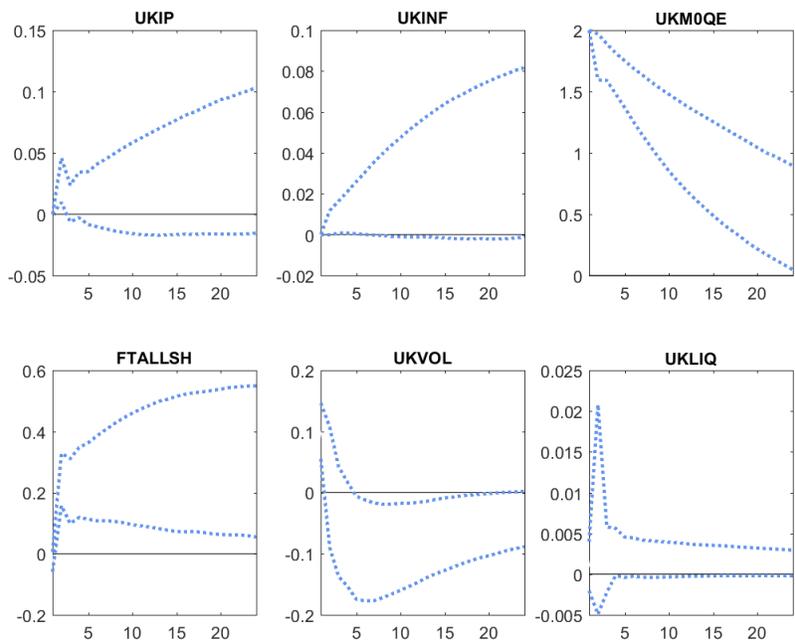


Figure 1. UK baseline model Impulse response functions. IRFs to QE shocks, 16th and 84th quantiles reported.

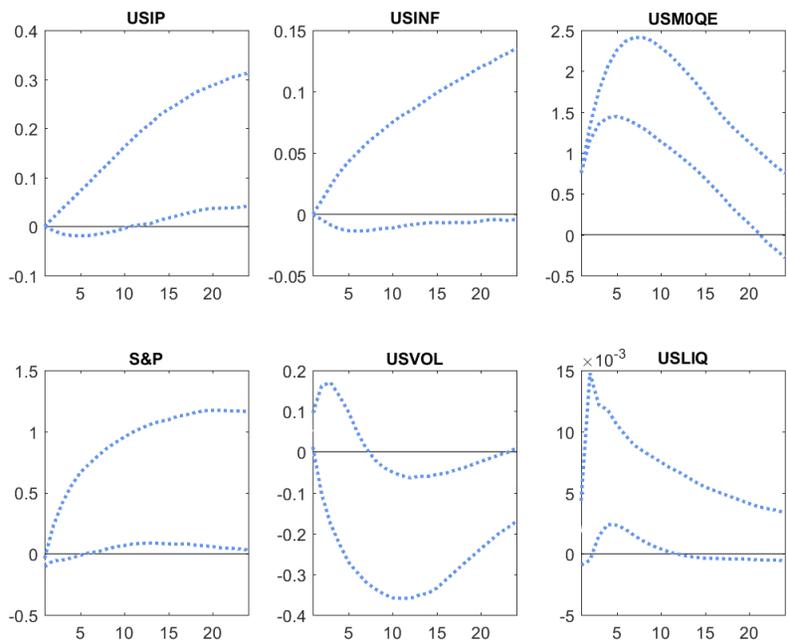


Figure 2. US baseline model Impulse response functions. IRFs to QE shocks, 16th and 84th quantiles reported.

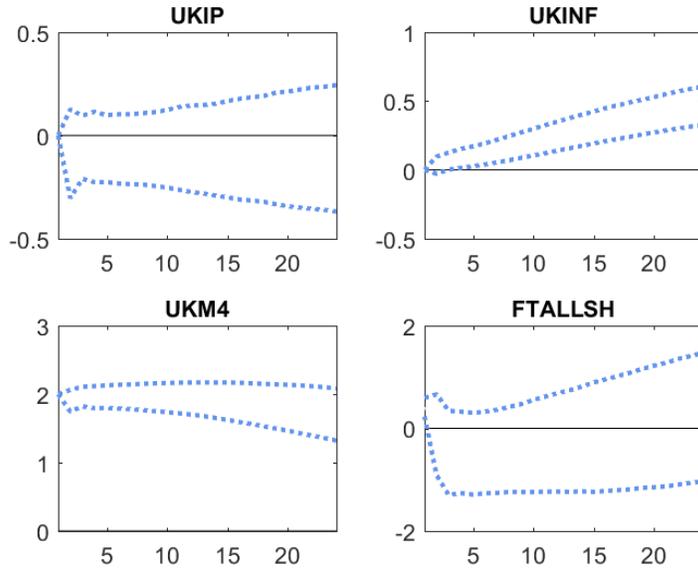


Figure 3. UK extended model Impulse response functions. IRFs to broad money (M4) shocks, 16th and 84th quantiles reported.

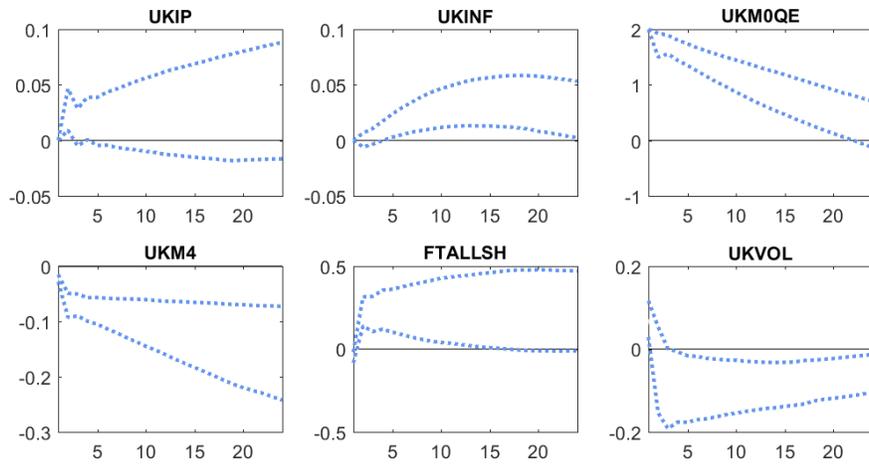
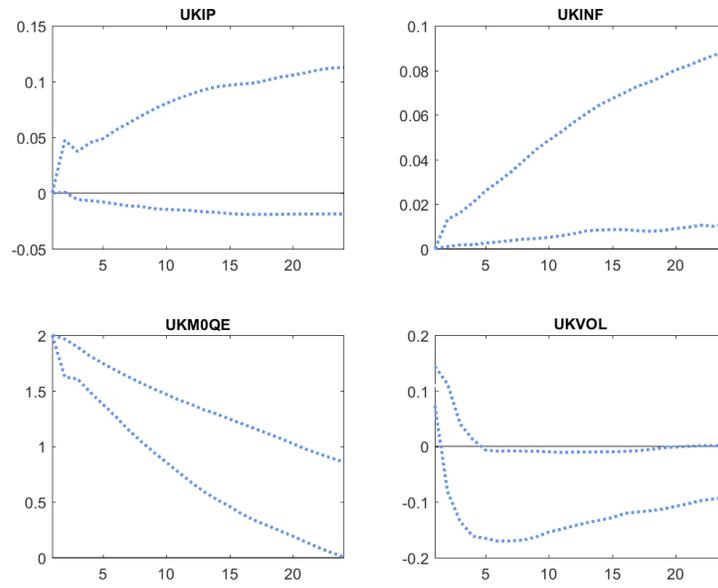


Figure 4. UK extended model Impulse response functions. IRFs to QE shocks, 16th and 84th quantiles reported.

(a) UK



(b) US

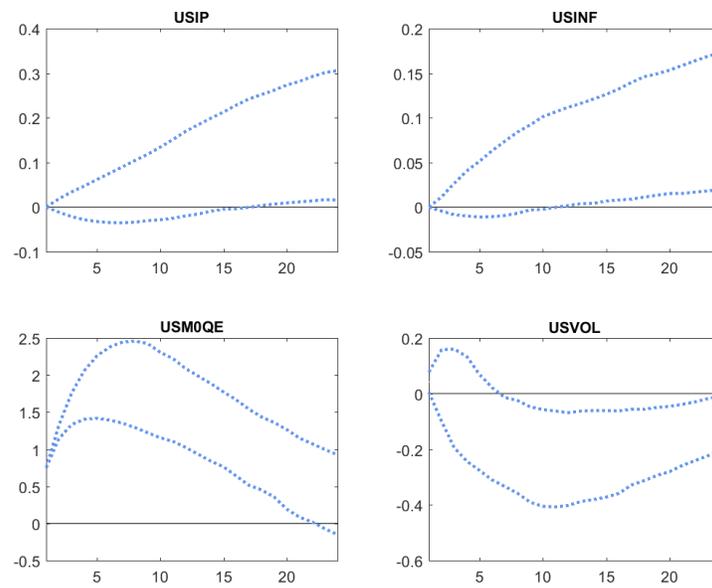
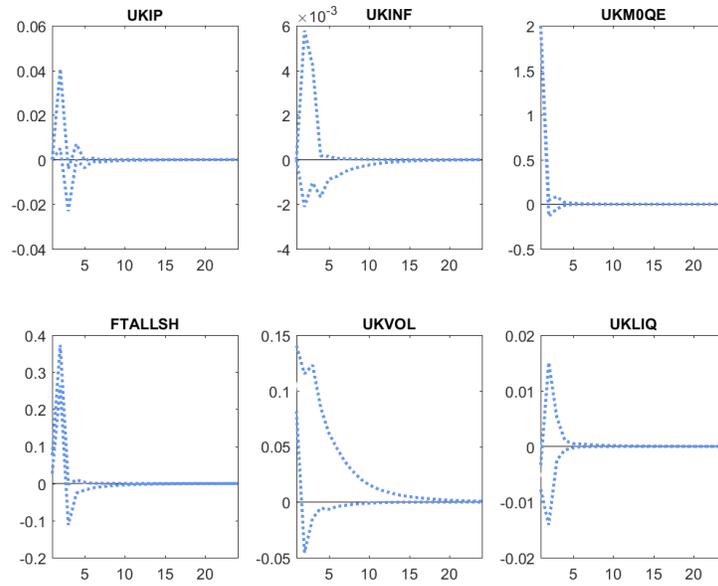


Figure 5. Reduced models Impulse response functions. IRFs to QE shocks, 16th and 84th quantiles reported.

Appendix A. Model variations

(a) UK



(b) US

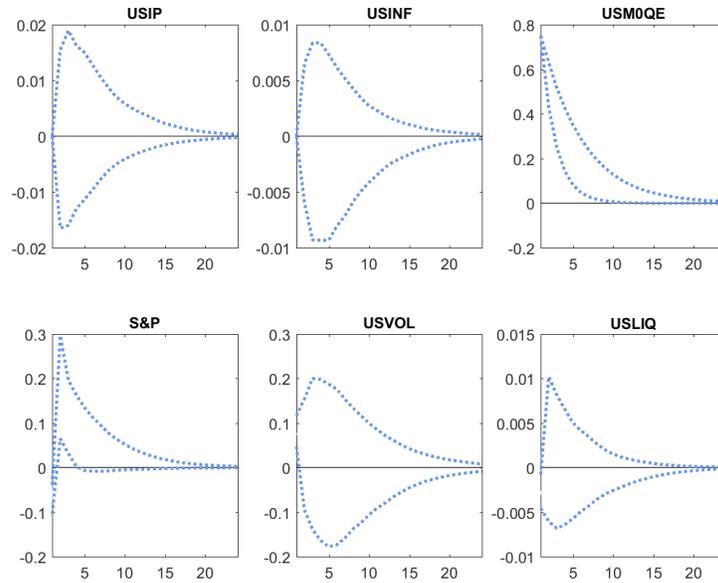
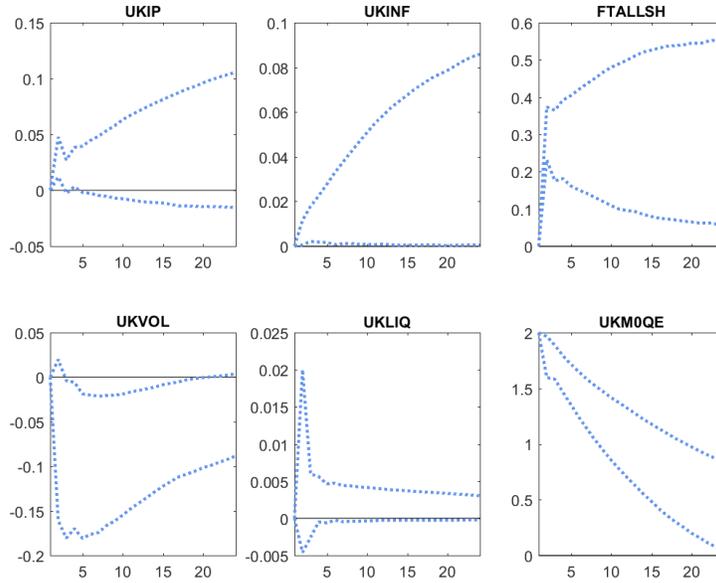


Figure 6. Models in first differences. IRFs to QE shocks, 16th and 84th quantiles reported.

(a) UK



(b) US

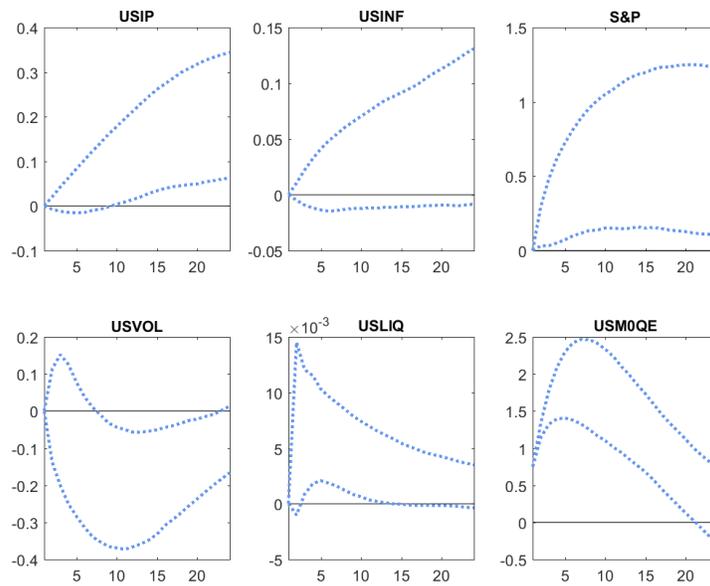
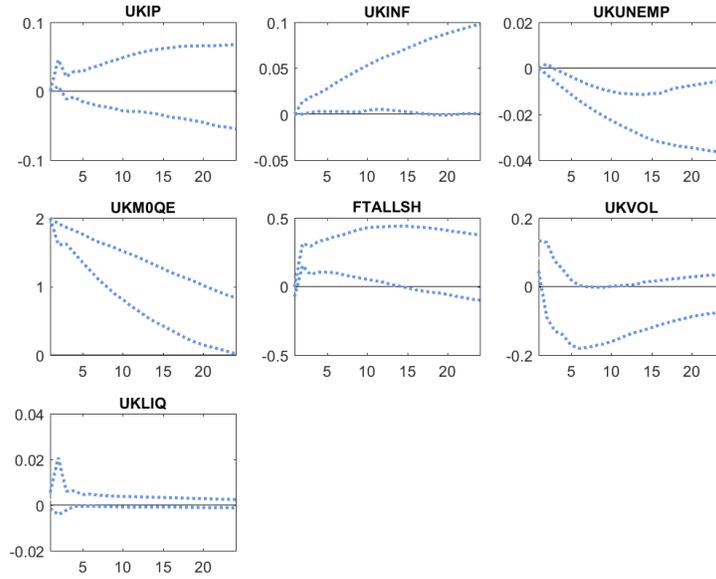


Figure 7. Altered cholesky ordering. IRFs to QE shocks, 16th and 84th quantiles reported.

Appendix B. Model extensions

(a) UK



(b) US

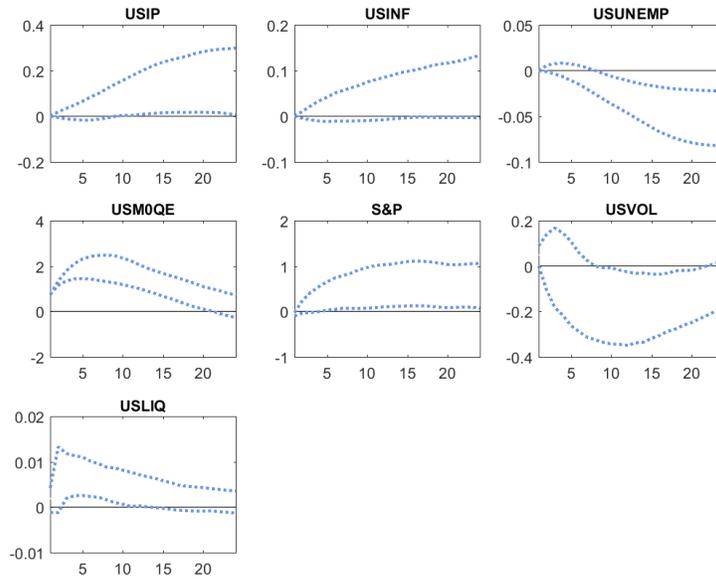
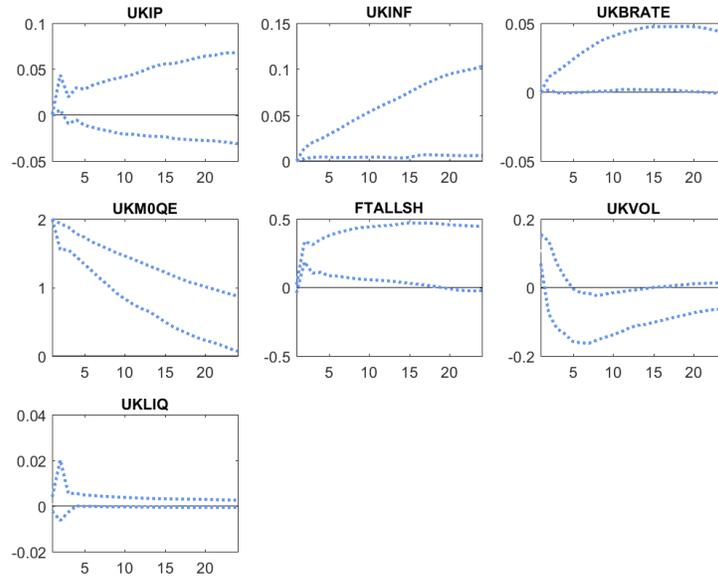


Figure 8. Adding unemployment. IRFs to QE shocks, 16th and 84th quantiles reported.

(a) UK



(b) US

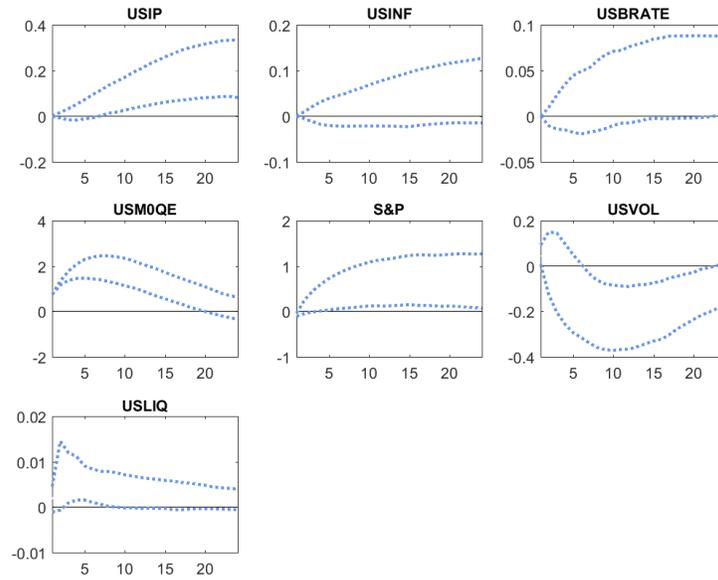
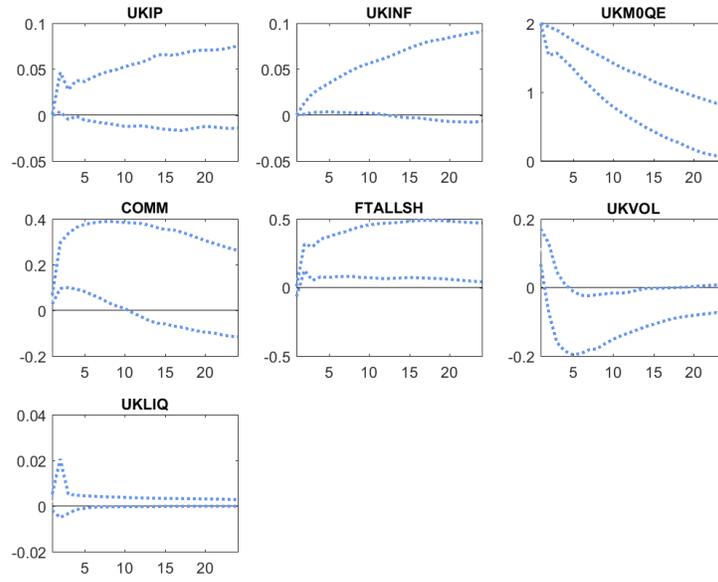


Figure 9. Adding Central Bank base rate (BRATE). IRFs to QE shocks, 16th and 84th quantiles reported.

(a) UK



(b) US

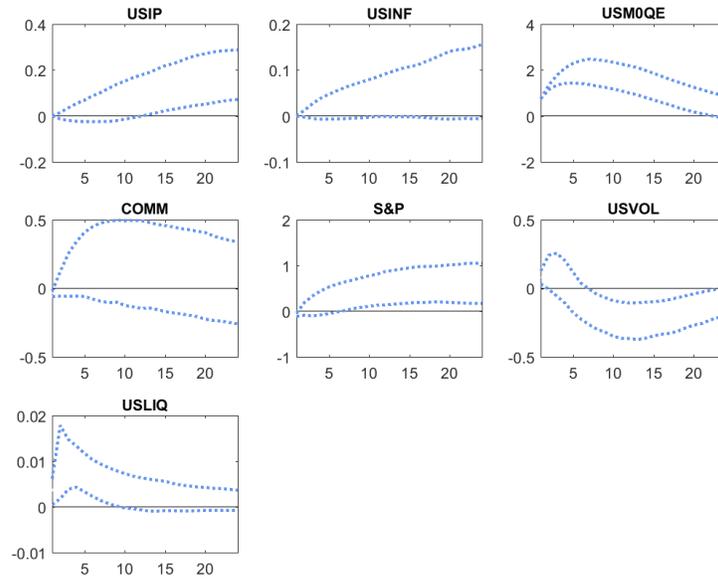
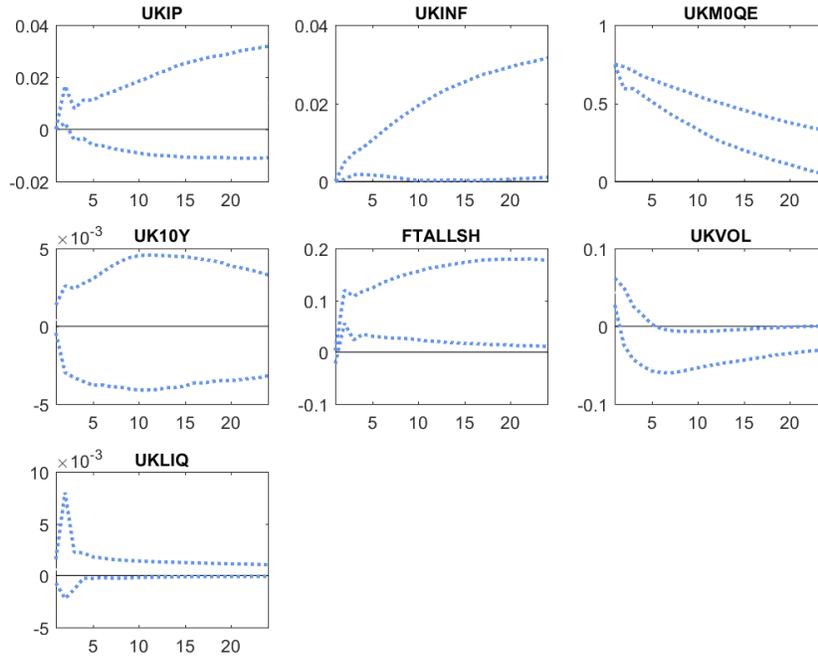


Figure 10. Adding Commodities (COMM). IRFs to QE shocks, 16th and 84th quantiles reported.

(a) UK



(b) US

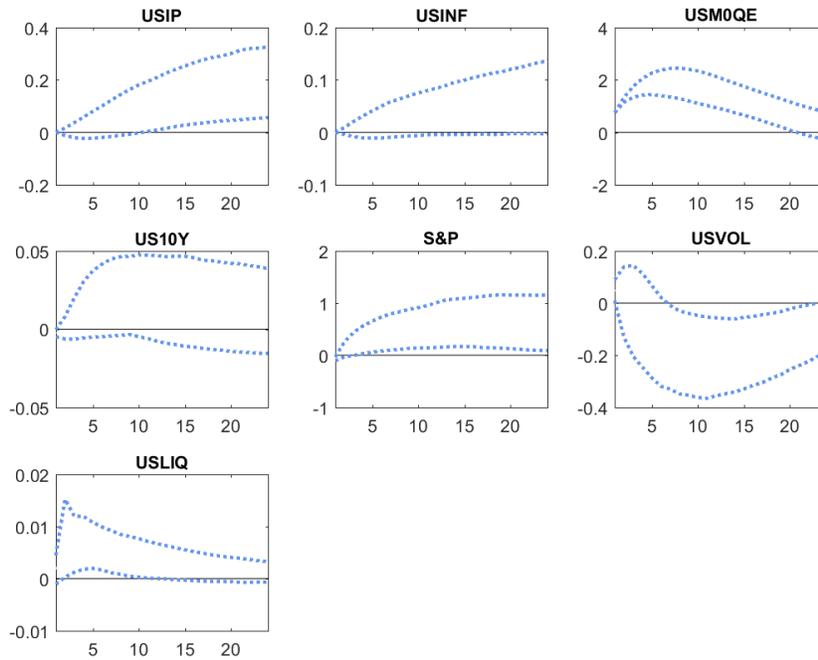


Figure 11. Adding Long-term yields (US/UK10Y). IRFs to QE shocks, 16th and 84th quantiles reported.

Appendix C. Sign restriction identification

As a further robustness check we tested an identification strategy of the monetary policy shock by combining sign and short run restrictions. In principle, restricting signs seems less strict than imposing exclusion restrictions, but this is not the case as Kilian (2011) argues. For the short run restrictions we assume that the two macro variables (output and inflation 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, C , of the variance-covariance matrix, Σ_ε , of the error term ε_t in Eq. 1, such that $\varepsilon_t = C\eta$. The candidate structural shocks w_t are computed as

$$w_t = C'Q \quad (C1)$$

where Q is a 6×6 matrix, such that $Q'Q = I_6$ and $\varepsilon_t = CQQ'C' = CQw_t$. There exists an infinite set of structural shocks w_t that satisfy the above condition, however we restrict the set of candidate solutions by imposing zero and sign restrictions to the structural impact multiplier matrix CQ . 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

$$Q = \begin{bmatrix} I_2 & 0 \\ 0 & q \end{bmatrix} \quad (C2)$$

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 can be mathematically summarised as:

$$\begin{pmatrix} \varepsilon_t^{IP} \\ \varepsilon_t^{CPI} \\ \varepsilon_t^{QE} \\ \varepsilon_t^{SM} \\ \varepsilon_t^{VOL} \\ \varepsilon_t^{LIQ} \end{pmatrix} = \begin{bmatrix} > 0 & 0 & 0 & 0 & 0 & 0 \\ < 0 & > 0 & 0 & 0 & 0 & 0 \\ * & * & \geq 0 & * & * & * \\ * & * & < 0 & > 0 & < 0 & < 0 \\ * & * & * & * & > 0 & * \\ * & * & * & * & * & > 0 \end{bmatrix} \times \begin{pmatrix} w_t^{AS} \\ w_t^{AD} \\ w_t^{MonetaryPolicy} \\ w_t^{Stockmarket} \\ w_t^{Uncertainty} \\ w_t^{Liquidity} \end{pmatrix} \quad (C3)$$

where ‘*’ means unrestricted. We iterate the sign-restriction procedure until we have accepted 1000 draws.²⁹

The impulse responses reported in Figure 12 display a number of similarities with our baseline model results. For instance, the shape of responses of the QE variables is similar and in both economies the response seems to be fades away after two years. The reaction of volatility, albeit

29. On average, we accept 1% of draws from both countries.

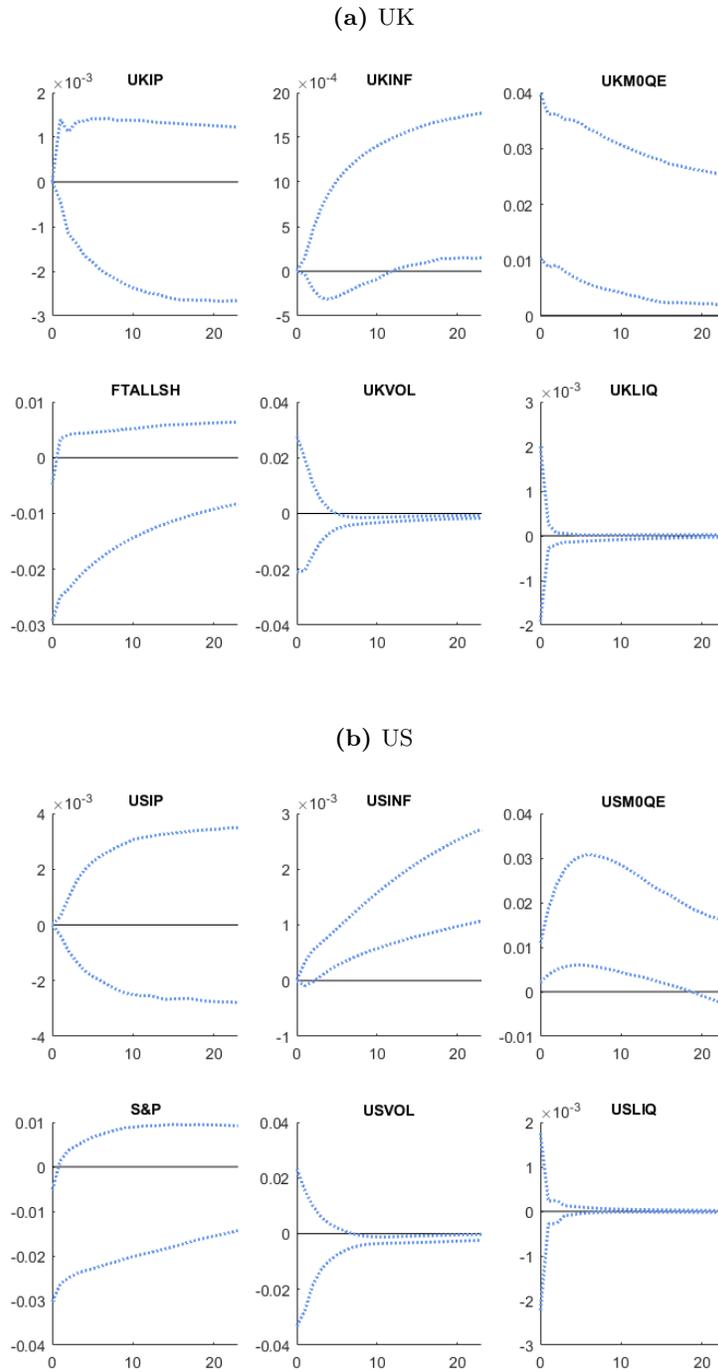


Figure 12. Sign restrictions identification. IRFs to QE shocks, 16th and 84th quantiles reported.

it is not well identified in the very short term, is significantly negative after about five months in the UK and seven months in the US. Sign restriction identification suggests a neutrality of stock market liquidity to QE, which is at slightly at odds with our cholesky identification findings and

with the literature on bond market liquidity. Lastly, moving to the macroeconomic analysis, our main conclusions on the neutrality of QE on output are strengthened as the error bands of the responses of industrial production are centred around zero. However, Figure 12 presents some evidence on a positive effect of inflation following a QE shock, starting in the very short term for the US and after around one year in the UK.

Appendix D. Monetary aggregates and QE

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 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:

$$\begin{aligned}\beta|\Sigma &\sim N(b, \Sigma \otimes \Omega) \\ \Sigma &\sim IW(\Psi, d)\end{aligned}\tag{D1}$$

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

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

δ_i is set to 1 for variables believed to be highly persistent (the ones 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:

$$\begin{aligned}Y^+_{n \times n} &= \text{diag}\left(\frac{Y_0}{\mu}\right) \\ X^+_{n \times (1+np)} &= \begin{bmatrix} 0 & Y^+ & \dots & Y^+ \end{bmatrix}\end{aligned}$$

where Y_0 is an $n \times 1$ vector of averages of the first p observations and the hyperparameter μ is set to 1.

For internal consistency, we plot the 16th and 84th percentiles of the impulse responses densities

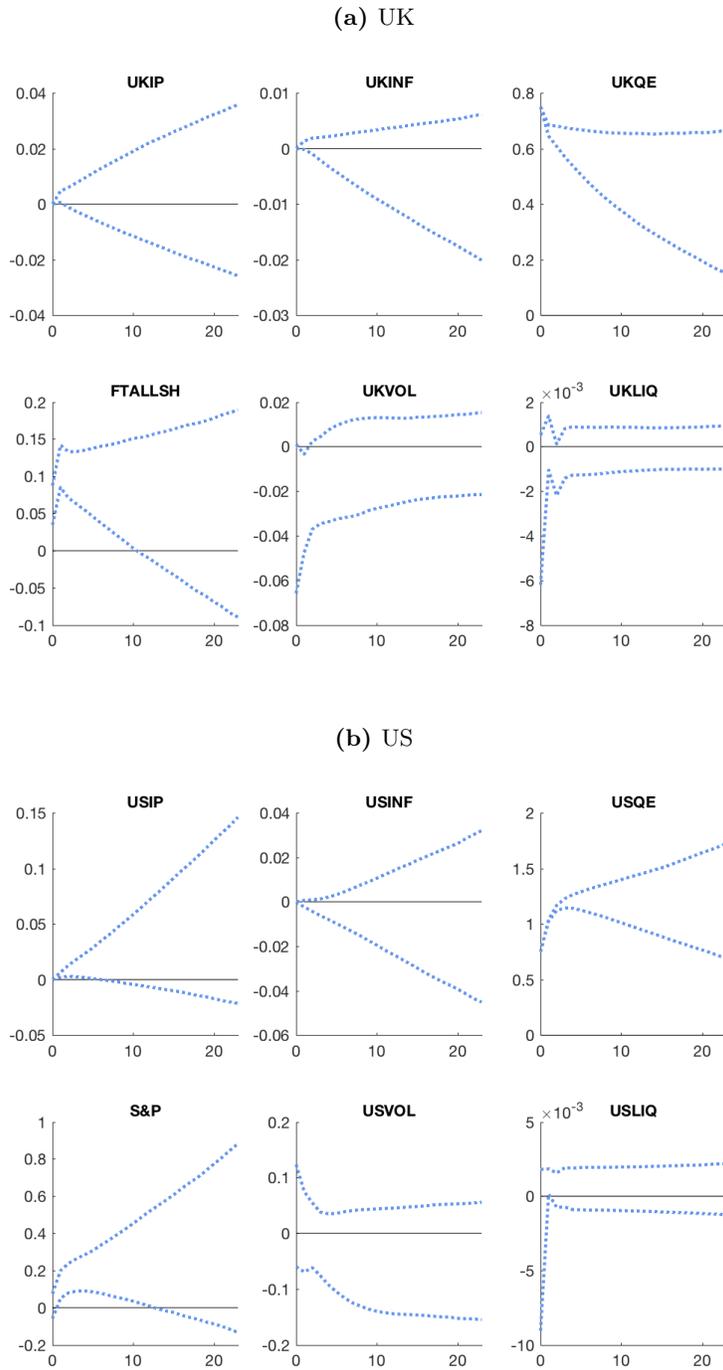


Figure 13. BVAR model, QE period. IRFs to QE shocks, 16th and 84th quantiles reported.

(computed with a direct sampling MCMC algorithm) to a 2-unit shock to UK QE and 0.75-unit shock to US QE, identified as per Section III.B. Figure 12 shows that our main results are qualitatively robust. In fact, the conclusions on the impact of QE on the macroeconomy are even stronger and the stock markets still display a rise. Finally, market volatility is reduced on

impact in the UK and only after 3 to 4 months in the US whereas (il)liquidity shows a negative contemporaneous response to the QE shock.