The Effect of Quantitative Easing on Investment in the US and UK: An SVAR Approach

by

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Introduction

Following the collapse of Lehman Brothers in 2008, the Federal Reserve (Fed) and the Bank of England (BoE) dramatically reduced interest rates to provide both financial and macroeconomic stability (Stone, Kenji, & Kotaro, 2011). However, both central banks quickly exhausted conventional policy tools as they approached the 'zero-rate lower bound' of their policy rates (IMF, 2013). Faced with this constraint, both the Fed and BoE turned to large-scale asset purchase programs. Later called Quantitative Easing (QE), these asset purchase programs were implemented to provide further liquidity to faltering markets, and to continue to place downward pressure on market interest rates. Theoretically, the higher asset prices and lower market yields induced by QE should have translated into a rise in aggregate wealth and lower market borrowing costs (Joyce, Lasaosa, Stevens, & Tong, 2010). Both of these effects are expected to have increased aggregate demand, and many studies have focused on the impact of QE on real GDP. In an effort to develop new insights into how QE affects the real economy, this paper will focus on estimating the effect of QE on real investment in the US and UK.

Studies of this nature help to evaluate QE as a policy tool for providing macroeconomic stability. In addition, contrasting the effects of QE on investment in the US and UK may reveal interesting differences in the operations of their respective financial markets. Pre-crisis data will be used to study the expected effects of QE on investment by using structural vector autoregression (SVAR) models of the US and UK economies. First, the historical relationship between bond yields and investment will be estimated by the SVARs. Next, using the SVAR results, the impact of QE on investment will be calculated for the US and UK from the cumulative announcement effects of QE on bond yields. For the US, the effects of LSAP 1, which extended from November 2008 to November 2009, will be compared with the effects of the UK QE program from February 2009 to February 2010. These periods were chosen because they are roughly the same length for both countries, and are the relevant periods studied in the Gagnon, Raskin, Remache, & Sack (2011) US event studies, and the Joyce et al. (2010) UK event studies.

However, to understand the econometric analysis, the relationship between QE, bond yields and real investment must first be understood. Thus, this paper is loosely divided into two halves. The first half will focus on establishing a theoretical background from which to analyze the effects of asset purchases on the real economy. This background will be supported by a brief review of previous estimates of the impact of QE on bond yields and real GDP. The second half of this paper will be devoted to developing and explaining SVARs of the US and UK economies. These SVARs will be used to estimate the impact of QE on investment with the changes in bond yields induced by the QE announcement effects.

Background: QE Design and Implementation in the US and UK

The Federal Open Market Committee (FOMC) listed two goals of the US QE program: "to provide greater support to mortgage lending and housing markets" and, "to help improve conditions in private credit markets" (Gagnon et al., 2011). The US program was unique because of its purchase of both government bonds of varying levels of maturity and agency mortgage-backed securities (MBS). Agency MBS were targeted because of their role in initiating the crisis, and supporting their prices was expected to be instrumental in bolstering market credit conditions and preventing fire sale spirals (IMF, 2013). The targets of the asset purchases were non-bank entities such as securities firms and money mutual funds. The first round of QE, called LSAP 1, ran from November 2008 to November 2009, and focused on treasury securities and agency MBS. LSAP 1 was effective in lowering yields on all purchased assets, as well as on other closely related asset substitutes (see Gagnon et al. (2011) results). Further rounds of QE were initiated after LSAP 1, and continued at the time this paper was submitted.

In the UK, after the interest rate was dropped close to its zero lower bound, the Monetary Policy Committee (MPC) at the BoE determined that nominal spending would be too weak to meet its 2% inflation target (Joyce & Tong, 2011). The MPC announced in early 2009 that it would begin a large-scale asset purchase program designed to lower market yields, and boost nominal spending by increasing market wealth and reducing borrowing costs. The asset purchases were overwhelmingly comprised of medium-to-long maturity UK government bonds, with a smaller number of commercial paper and corporate bonds purchased. The program was largely targeted towards non-bank financial institutions such as pension funds and insurance companies. In total, around £ 200 billion worth of bonds were purchased from March 2009 to January 2010, amounting to around 14% of annual GDP.

Theoretical Impact of Asset purchases

Economic intuition says that a fall in bond market yields should induce a rise in investment, *ceteris paribus*. The motivation for this is that *lower bond yields* imply *lower borrowing costs*, such that it is relatively cheaper to borrow to finance investment projects. While this is a simplistic representation of the relationship between bond yields and investment, it is the reasoning that motivates all subsequent analysis in this paper.

Therefore, understanding the results of the SVARs presented in this paper is conditional on an understanding of how QE affects yields in bond markets. A paper by the IMF (2013) lists three primary channels through which QE was expected to influence bond markets similarly in both the US and UK:

- **Signaling Channel:** Through this channel, the asset purchase programs were expected to validate the central banks' commitment to meeting inflation targets and keeping interest rates low.
- **Scarcity Channel:** As the central bank removed assets from the market, sudden asset scarcity was expected to bid up asset prices and reduce yields.
- **Duration Channel:** If longer-maturity assets were targeted in the asset purchase programs, it was expected that their removal from the market would decrease average portfolio duration. This reduction in sensitivity to interest rates was expected to induce a downward shift in the yield curve.

It has been hypothesized that QE signaled to both the US and UK financial markets of a conditional commitment to keeping interest rates low, and to continuing to meet inflation targets. Since bond yields are a function of expected future spot rates and the risk premium, lower interest rate expectations would immediately lower average bond yields. However, both Gagnon et al. (2011) and Joyce et al. (2010) reject that QE was important in influencing bond yields through the signaling channel in the US and UK, respectively. The authors instead suggest that both the Fed and BoE were careful in managing expectations by suggesting a rise in interest rates might be necessary in the future to combat inflationary pressures. Alternatively, Gagnon et al. (2011) and Joyce et al. (2010) suggest that a reason for the fall in market yields as a result of QE was because of a reduction in the risk premium. In particular, they say the fall in the risk premium was likely due to a drop in the term premium, which is the additional risk associated with holding debt over time. They suggest the reduction in the term premium came from the increased liquidity of the assets being purchased under the QE programs, and by the reduction in the duration of the market portfolio.

In addition to the signaling channel, QE was expected also to affect bond yields in both the US and UK through the portfolio rebalancing effect, which is seen as a combination of the scarcity and duration channels (IMF, 2013). To the extent that reserves are not perfect substitutes for the assets being purchased, there was expected to be some spillover effects of the bond purchase program as investors substituted towards other higher-risk assets (Woodford, 2012). This increased demand for other assets was expected to bid up market bond prices, and reduce market yields. This effect, known as the portfolio rebalancing effect, can be observed through the rising of asset prices over time as investors adjust the composition of their portfolios. As this spreads through the economy, Gagnon et al. (2011) suggest that overall private borrowing costs should be lowered. Both the US and UK QE programs were designed to exacerbate the portfolio rebalancing effects by targeting mostly smaller, non-bank financial institutions (Joyce & Tong, 2011; IMF, 2013). However, this effect is difficult to measure because it involves the gradual adjustment of portfolios over time, and cannot be completely captured in an event study (Joyce et al., 2010). Thus with respect to the portfolio rebalancing effect, event studies will tend to underestimate the effects of QE.

Event Studies and the Estimated Macroeconomic Effects of QE

Two widely known event studies for the US and UK QE programs were completed by Gagnon et al. (2011) and Joyce et al. (2010), respectively.

The event studies done by Gagnon et al. (2011) for the US concluded that the announcement effects of LSAP 1 amounted to a cumulative yield change of -91 bps for a 10 year US government bond, and a change of -67 basis points for an index of corporate bonds. Both a 10-year government bond variable and a corporate bond variable will be included in US SVAR in this paper. These two yield changes provided by Gagnon et al. (2011) will be used to predict the effects of LSAP 1 on investment in the US. The event study results from Gagnon et al. (2011) are displayed in figure 1.

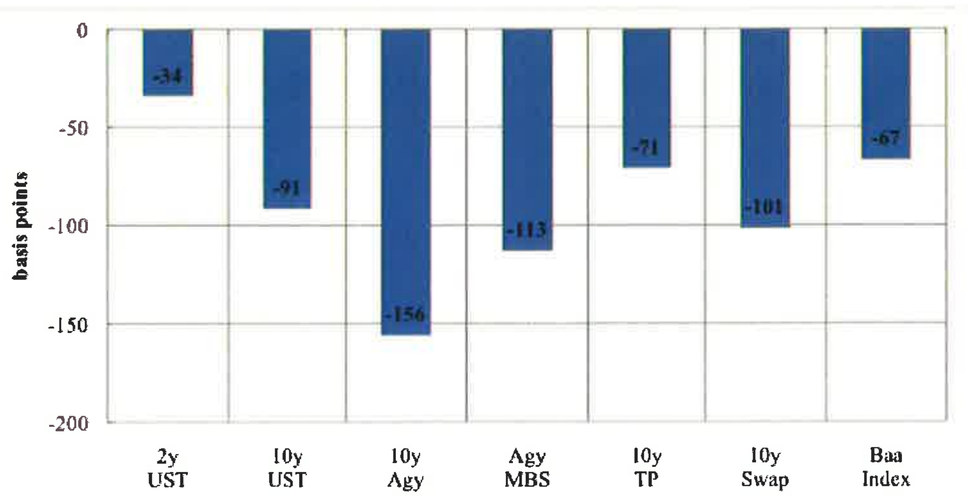

Figure 1: Cumulative Interest Rate/Yield Changes from Gagnon Event Studies, Source: Gagnon et al. (2011)

In the event studies done for the UK by Joyce et al. (2010), the announcement effect of QE was estimated to have induced a cumulative yield change of ~ -100 basis points on a 10-year government bond. A 10-year government bond yield variable will be included in the UK SVAR, and the result from Joyce et al. (2010) will be used to predict the impact of QE on investment. The results from the Joyce et al. (2010) event studies are displayed in figure 2.

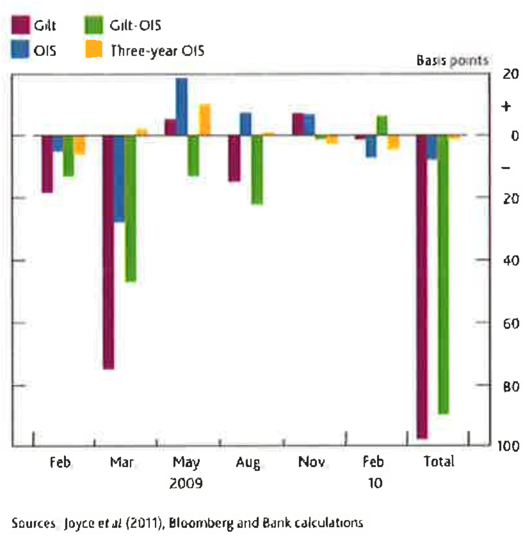

Figure 2: Cumulative announcement effects of UK QE, Source: Joyce et al. (2011)

In addition to these event studies, some work has been done to predict the effects of QE on GDP. While none of these studies will be reviewed in detail here, a brief summary of some of the results is displayed in table 1. Given its higher volatility, investment is expected to exhibit a larger response to yield changes than GDP, but the results displayed below will serve as a relevant benchmark with which the final results can be compared.

Table 1: Summary of the Empirical Work of effect of QE on GDP, Source: IMF (2013)

	Authors	%ΔGDP	Method	Sample Period
US	Baumeister and Benati (2010)	**2.4**	Time Varying SVAR	1965Q4-2009Q4
	Fuhrer and Olivei (2011)	**2.6**	SVAR	1987Q1-2007Q4
	Chung et al. (2011)	**2.4 - 3**	Fed Macro Model	N/A
UK	Baumeister and Benati (2010)	**2.4**	Time Varying SVAR	1965Q1-2009Q4
	Pesaran and Smith (2012)	**0.75 - 1**	VAR Counterfactual	1980Q3-2008Q4
	Kapetanios et al. (2012)	**0.28 - 0.72**	Markov-Switching SVAR	1963M2-2011M3

VAR and SVAR: Background

Now that a background for the US and UK QE programs has been established, the econometric methods used to analyze the impact of QE on investment in both countries must be discussed.

Vector autoregressions (VARs) are econometric models that allow for an analysis of the contemporaneous relationships of a system of economic variables. Mathematically, if y_t is an *nx1* vector comprised of the economic variables of interest that follows a p^{th}-order lagged VAR, then the system can be modeled as:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + u_t$$

In the above formulation A_i is the matrix of estimated coefficients for vector y_{t-i}, where *i* is the variable lag (Lutkepohl, 2004, pg. 88). However, without imposing restrictions on the VAR model derived from economic theory, it is difficult to assign any meaning to the estimated coefficients (Lutkepohl, 2004, pg. 159). In addition to this problem, it is unlikely that the residuals in the vector u_t are uncorrelated

(Lutkepohl, 2005, pg. 57-59). Thus, in terms of impulse response analysis, it is unrealistic to analyze the impact of a shock to a variable in y_t while assuming that no other shocks are triggered simultaneously. This makes it difficult to see how an economic shock is traced through the system of equations. It is obvious there exists a need to restrict the VAR model such that it can be better interpreted in an economic context.

Suppose that a vector of uncorrelated, orthogonal shocks is denoted as ε_t, and that restrictions are imposed on the VAR through matrices A and B. An SVAR has the form:[1]

$$Ay_t = A_1^* y_{t-1} + A_2^* y_{t-2} + \ . \ . \ . + A_p^* y_{t-p} + B\varepsilon_t$$

Where in this equation:

$$A_j^* = AA_j$$
$$u_t = A^{-1}B\varepsilon_t$$

The independence of the shocks in vector ε_t by construction allows us to understand how the system reacts to an exogenous shock to one of the variables, *ceteris paribus* (Lutkepohl, 2005, pg. 57). If a stable, single lag model is considered (that begins at some point in the finite past) then the evolution of the system after a shock can be shown succinctly in the moving average representation of the SVAR:[2]

$$y_t = \mu + \sum_{i=0}^{\infty} A_1^i B\varepsilon_{t-i}$$
$$where \ \mu = (I-A_1)^{-1}$$

For the sake of impulse response analysis it is assumed that the mean of the vector of variables is zero, making it easier to analyze the effects of a shock to the system. Thus, the set of equations can be re-written as:[3]

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[1] Lutkepohl, 2004, pg. 162
[2] Lutkepohl, 2005, pg.18
[3] Lutkepohl, 2005 pg. 58

$$y_t = \sum_{i=0}^{\infty} \Phi_i \, \varepsilon_{t-i}$$

$$\textit{where } \mu \textit{ set to } 0$$

$$\Phi_i = A_1^i B$$

With this formulation, Lutkepohl (2005, pg. 52) describes that "the jk-th element of Φ_i, , $\varphi_{jk,i}$, represents the reaction of the j-th variable of the system to a unit shock in variable k, i periods ago". Thus, the coefficients $\varphi_{jk,i}$ in matrix Φ_i can be thought of as:

$$\phi_{jk,i} = \frac{\partial y_{j,t}}{\partial \varepsilon_{k,t-i}}$$

The impulse response matrix Φ_i will be used to analyze the effects of QE on investment through its shock to bond yields.

General Model Methodology Used in the US and UK SVARs

Identification Strategy

The challenge in constructing an appropriate SVAR comes through the selection of matrices A and B, called identification (Christiano, 2012). The identification strategy should have some underlying economic meaning, and should impose the least number of assumptions on the model.[4] One construction of matrices A and B with the desired properties is obtained through recursive identification, setting matrix A as the identity matrix, and matrix B as a lower triangular matrix (Lutkepohl, 2005, pg. 362). This kind of identification is called a Cholesky decomposition. Shocks to monetary policy variables can cascade through a system with a recursive structure in a one-way causal direction without triggering simultaneous shocks (Lutkepohl, 2004, pg. 162). This property of the recursive structure makes it desirable for this SVAR study, as it can mirror a simple monetary policy transmission process. The largest weakness in using the Cholesky decomposition in this study is that it does not capture the nearly simultaneous impact on long

[4] Achieved through a "just-identified model", Christiano (2012).

rates of a shock to short rates. In addition, estimation using this identification strategy will produce different shock effects depending on the ordering of variables in the vector ε_t (Lutkepohl, 2004, pg. 167). However, a logical ordering in both the US and UK models was somewhat obvious, and the robustness of the SVAR was found to have a low sensitivity to the variable ordering.

Data, Stationarity and Stability

The largest difference between the US and UK datasets is the exclusion of a measure of corporate bond yields for the UK, since long-term datasets of UK corporate bond yields are not made publicly available. All variables were tested for stationarity using a dickey-fuller unit root test; however, the stationarity of all individual variables was not necessary for the stationarity of the underlying VAR process.[5] This is because, despite the inclusion of trending variables, the underlying US and UK VARs were found to satisfy the stability condition:[6]

$$det(I_k - A_1 z - \cdots - A_p z^p) \neq 0 \ for \ |z| \leq 1$$

A VAR(p) process that satisfies the stability condition is stationary (Lutkepohl, 2005, pg. 25). Thus, despite the inclusion of trending variables, the estimated coefficients in the stable US and UK VARs are consistent and asymptotically normally distributed (Guay & Pelgrin, 2006).

Lag-Order Selection

In terms of lag selection, there are three popular information criterions: Akaike's information criterion (AIC), the Hannan and Quinn information criterion (HQIC) and Schwarz's Bayesian information criterion (SBIC). All three criteria evaluate the optimal lag based on model fit. In a paper by Ivanov et al. (2001) at the Center for Economic Policy Research, it was shown that AIC is best when using monthly data, HQIC is best for quarterly data with many observations, (>120) and SBIC is best for quarterly data of all sizes. Given the small sample size for both countries in this study, the SBIC was used to select the number lags in each model.

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[5] Although the variables were not formally tested for cointegration, this result suggests strongly that the VAR process for both countries are cointegrated.

[6] The formal definition of the stability condition provided by Lutkepohl (2004) is "…[The process is stable if] the polynomial defined by the determinant of the autoregressive operator has no roots in and on the complex unit circle."

Initial Model Evaluation Tools

In both the US and UK models, granger causality was an important first screen to decide which variables were to be included in the final VAR and SVAR. However, there are weaknesses in using tests of granger causality that are important to acknowledge. In particular, as discussed by Lutkepohl (2005, pg. 48), it is problematic to interpret a lack of granger causality as the lack of a cause and effect relationship. A lack of granger causality between two random variables in the underlying VAR does not necessary imply that this will hold when a recursive relationship between the variables is imposed (as is done in this study). However, granger causality between two variables is necessary for an impulse in one variable to induce a response in the other (Lutkepohl, 2005, pg. 54). Although granger causality may not fully anticipate the results of the impulse response functions, it suffices as an initial model evaluation tool.

Country-Specific SVARs: Design and Results

The US SVAR Model

The following variables were included in the US SVAR:

- **Unemployment Rate, First Difference:**[7] First difference of the civilian unemployment rate, seasonally adjusted. Included as a cyclical variable to capture the effects of the business cycle on real investment.
- **Inflation Rate:**[8] Quarterly percent change in consumer price index for all urban consumers. Inflation rate is included in the model primarily to balance the effect of nominal variables such as the federal funds rate.
- **Federal Funds Rate:**[9] Quarterly average of the federal funds rate.
- **Ten-Year Government Bond Yield spread over the Federal Funds Rate:**[10] 10-year treasury bond constant maturity yield average, spread over the federal funds rate. This is expected to be one of the first mechanisms of transmission. Hereafter this variable is referred to as the "government bond spread".

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[7] US Department of Labor: Bureau of Labor Statistics. Release: Employment Situation.
[8] US Department of Labor: Bureau of Labor Statistics. Release: Consumer Price Index.
[9] Board of Governors of the Federal Reserve System, Release: H.15: Selected Interest Rates
[10] Board of Governors of the Federal Reserve System, Release: H.15: Selected Interest Rates.

- **Moody's Baa Corporate Bond Yield Index spread over the Ten-Year Government Bond Yield:**[11] Moody's seasoned Baa corporate bond yield average, spread above the 10-year Treasury bond constant maturity yield average. As the portfolio rebalancing effect occurs, this is expected to be a secondary mode of transmission from QE to investment. Hereafter this variable is referred to as the "Baa spread".
- **Log of Real Investment:**[12] Log of real gross private domestic investment, seasonally adjusted.

Initially, data for each variable was quarterly data that stretched from the first quarter of 1962 to the fourth quarter of 2006 (1962 Q1-2006 Q4). The initial unrestricted VARs run on this dataset satisfied the stability test, and showed encouraging levels of granger causality. However, before going further the data was tested for structural breaks. Since the exact time periods of potential structural breaks were unknown, a Quandt Likelihood Ratio (QLR) statistic was computed for the data from 1962-2006.[13] With the QLR statistic, breaks were observed in the government bond spread and inflation variables intermittently up to 1984 (see appendix C.1). This result agrees with the conclusions reached by Bagliano & Favero (1998) who identified breaks in US monetary data up to 1984. Bagliano & Favero (1998) suggest that the breaks are likely due to the large changes in monetary policy during the period 1966-1988 (see table 2). Therefore, the sample size was reduced to include only the data from 1988Q1-2006Q4.[14]

Table 2: US Monetary Policy Objectives from 1966-1988 (Bagliano & Favero (1998))

Period	Federal Reserve Monetary Policy Focus
1966-1972	Free Reserves Targeting
1973-1979	Federal Funds Rate Targeting
1979-1982	Non-borrowed Reserves Targeting
1982-1988	Federal funds rate-borrowed reserves targeting, pre-Greenspan era
1988-1996	Federal funds rate-borrowed reserves targeting, Greenspan era

With the reduced dataset, a VAR was again estimated and tested for granger causality, stability, and lag-order. The variables performed weakly in terms of granger causality, but the VAR was found to be stable. Based on results of Ivanov et al. (2001) the SBIC was used to select a lag-order of one. Given these

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[11] Board of Governors of the Federal Reserve System, Release: H.15: Selected Interest Rates.
[12] U.S. Department of Commerce: Bureau of Economic Analysis, Release: Gross Domestic Product.
[13] As is outlined in Stock & Watson (2011, pg. 568-561), the QLR statistic is calculated by taking the maximum of the Chow test statistics over the testing period. The middle 90% of the data was tested and all F-statistics were computed at a significance of 5% with q=3 restrictions for each variable (one constant and two lags).
[14] The reduced 1988 sample showed considerable improvement in residual homoskedasticity (reduced residual standard deviation) and in residual normality (Jarque Bera test statistic). No improvement in residual autocorrelation.

preliminary results, an SVAR was estimated for the six US variables from 1988-2006 using a Cholesky decomposition. The inflation and unemployment variables were placed first in the SVAR ordering to reflect the effect of these variables on the policy interest rate. To model a simple monetary policy transmission mechanism, the two bond spreads were placed after the federal funds rate. Since investment was the variable of interest, it was placed last in the ordering. Thus, the final US SVAR was identified as follows:

$$\begin{pmatrix} 1&0&0&0&0&0 \\ 0&1&0&0&0&0 \\ 0&0&1&0&0&0 \\ 0&0&0&1&0&0 \\ 0&0&0&0&1&0 \\ 0&0&0&0&0&1 \end{pmatrix}\begin{pmatrix} u_t^{\pi} \\ u_t^{u} \\ u_t^{FF} \\ u_t^{gb} \\ u_t^{Baa} \\ u_t^{I} \end{pmatrix} = \begin{pmatrix} b_{11}&0&0&0&0&0 \\ b_{21}&b_{22}&0&0&0&0 \\ b_{31}&b_{32}&b_{33}&0&0&0 \\ b_{41}&b_{42}&b_{43}&b_{44}&0&0 \\ b_{51}&b_{52}&b_{53}&b_{54}&b_{55}&0 \\ b_{61}&b_{62}&b_{63}&b_{64}&b_{65}&b_{66} \end{pmatrix}\begin{pmatrix} \varepsilon_t^{\pi} \\ \varepsilon_t^{u} \\ \varepsilon_t^{FF} \\ \varepsilon_t^{gb} \\ \varepsilon_t^{Baa} \\ \varepsilon_t^{I} \end{pmatrix}$$

Where: π = Inflation Variable
u = unemployment variable
FF = Federal Funds rate variable
gb = Government Bond Spread Variable
Baa = Moody's Baa Spread Variable
I = Investment Variable

Figure 3 shows the estimation results of the SVAR.

Figure 3: US SVAR Results

$$\begin{pmatrix} 0.3212*_{0.0262} & 0 & 0 & 0 & 0 & 0 \\ 0.0105_{0.0186} & 0.1605*_{0.0131} & 0 & 0 & 0 & 0 \\ 0.0649{*}{*}{*}_{0.0367} & -0.1747*_{0.0334} & 0.2614*_{0.0213} & 0 & 0 & 0 \\ 0.0247_{0.0383} & 0.0630{*}{*}{*}_{0.0379} & -0.1095*_{0.0365} & 0.3062*_{0.0250} & 0 & 0 \\ -0.0056_{0.0232} & 0.0643*_{0.0227} & -0.0748{*}{*}_{0.0212} & -0.0930*_{0.0188} & 0.1493*_{0.0122} & 0 \\ -0.0004_{0.0011} & -0.0044*_{0.0010} & 0.0023_{0.0009} & 0.0016{*}{*}{*}_{0.0009} & 0.0016{*}{*}{*}_{0.0009} & 0.0077*_{0.0006} \end{pmatrix}\begin{pmatrix} \varepsilon_t^{\pi} \\ \varepsilon_t^{u} \\ \varepsilon_t^{FF} \\ \varepsilon_t^{gb} \\ \varepsilon_t^{Baa} \\ \varepsilon_t^{I} \end{pmatrix}$$

Standard deviations are written as subscripts to the matrix entries and the markers *, **, * denote significance at 1%, 5% and 10% respectively.**

The SVAR residuals were then tested for serial correlation and normality (see appendix A). Using this SVAR formulation, the impulse response functions were calculated. The graphs of the responses of investment to impulses in each of the other five variables are displayed in appendix B.1. For the purposes of the analysis of the effects of QE, only the graphs of the government bond spread and the Baa spread are relevant. As is seen in figure 4, both of these variables induce statistically significant impulses in investment. The *largest statistically significant response* of investment to the impulses in the bond spreads was used in calculation of the effect of QE on investment from the results of the Gagnon et al. (2011) event studies (see figure 4). The estimated effect of LSAP 1 on investment is displayed in figure 5.

Figure 4: Summary of Impulse Response of investment to the Government Bond Spread and Moody's Baa Spread

US FINAL Results	Govt Spread	Baa Spread
Period of Significance (q)	3 - 20	0 - 8
Max % Investment Reaction to 1 bps Impulse (scaled)	**-0.0652**	**-0.0578**
Upper CI	-0.1068	-0.1094
Lower CI	-0.0235	-0.0063

Figure 5: US Impact of QE on Investment, final results

UNITED STATES FINAL RESULTS	Govt Spread	Baa Yield
Gagnon (2010) Event Study Results	-91	-67
% Investment Reaction to QE Impulse	**5.93%**	**3.88%**
Upper CI	9.72	7.33
Lower CI	2.14	0.42

With regards to the results obtained in figure 5, it must be kept in mind that the Baa spread variable was measured in the SVAR as a *spread above the government bond yield,* whereas Gagnon (2010) measured the movement in the *level* Baa corporate bond yield. Thus, the calculation of 3.88% above assumes that the government bond yield is static, which is not true. Therefore the prediction from the Baa spread is difficult to interpret.[15] Based on this problem, the 5.93% change in investment predicted by the government bond spread is more indicative of the actual effect of QE on investment. While the direct interpretation of the 3.88% predicted by the Baa spread is uncertain, at the very least it shows that the portfolio rebalancing effect was likely important in the transmission of QE to investment.

[15] To attempt to combine the percentages above and produce a single estimate of the percentage change in investment will prove difficult because a shock in one of the bond spreads above will influence the opposite spread.

With these caveats in mind, the effects of QE on investment predicted by the bond spreads provide an important starting point to help guide further thought on this topic. In addition, while other studies have shown the estimated impacts of QE on GDP to be around 2-3%, given that investment is a highly volatile component of GDP, the large estimates of its effect on investment seem highly plausible.

The UK SVAR Model

The following variables were included in the UK SVAR:

- **Federal Funds Rate:**[16] Quarterly average of the federal funds rate.
- **Exchange Rate:**[17] US dollars to one British pound, quarterly average. Included because of the highly open nature of the UK economy.
- **Inflation Rate:**[18] Quarterly percent change in consumer price index, aggregated by average. Inflation rate is included in the model primarily to balance the effect of nominal variables such as the BoE policy rate.
- **BoE Policy Rate:**[19] Quarterly average of official bank rate.
- **Ten-Year Government Bond Yield spread over the BoE Policy Rate:**[20] Quarterly average yield of British government securities, (10-year, nominal, zero coupon) spread over the average BoE policy rate. This is expected to be one of the first mechanisms of transmission. Hereafter this variable is referred to as the "government bond spread".
- **Log of Real Investment:**[21] Log of real gross fixed capital formation, seasonally adjusted.

The original UK dataset was quarterly data that extended from 1972Q1 – 2006Q4. However, similar to the US dataset, a structural break was detected prior to 1992 in the inflation variable using a QLR test statistic (see appendix C.2). Thus, the quarterly dataset was reduced to begin at 1992 Q1 in order to circumvent this structural break. This sample period is the same period used in the UK SVAR presented by Joyce & Tong (2011) on the effects of QE on GDP. However, initial VAR tests showed significant residual outliers in 1992 for the inflation and exchange rate variables (see figure 7). To better satisfy the assumption

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[16] Board of Governors of the Federal Reserve System, Release: H.15: Selected Interest Rates.
[17] Board of Governors of the Federal Reserve System, Release: H.10 Foreign Exchange Rates.
[18] OECD (2013), Main Economic Indicators Database, Consumer Prices.
[19] Bank of England, Quarterly Average of Official Bank Rate, Series ID: IUQABEDR.
[20] Bank of England, Series ID: IUQAMNZC.
[21] Office for National Statistics, Series ID: NPQT.

of residual normality, and given the bias in the estimators caused by these outliers, the dataset for all variables was reduced to include only quarterly data from 1993 Q1 – 2006 Q4.[22]

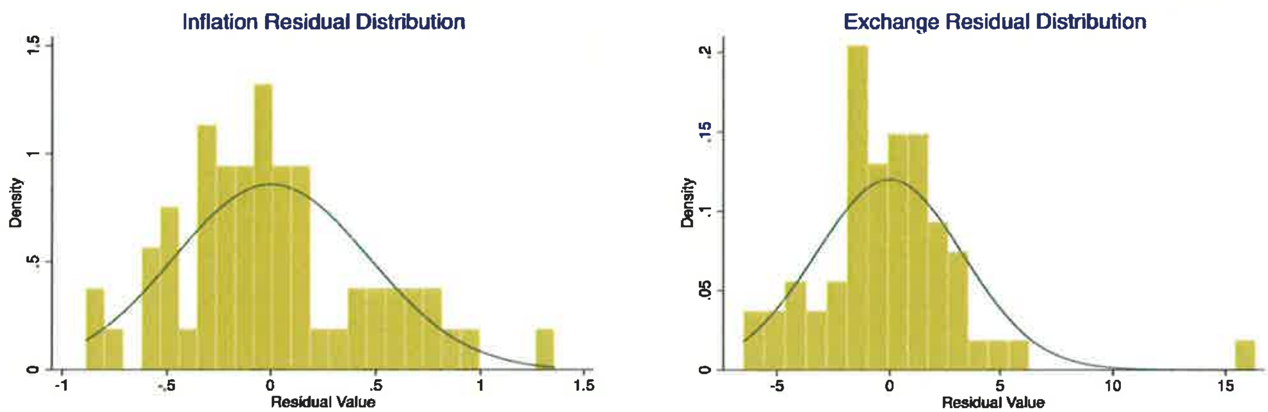

Figure 6: Residual Plots from a candidate UK VAR over sample period 1992 Q1 - 2006 Q4

Based on granger causality results, a large pool of variables was reduced to the variables introduced previously. However, some less significant variables were included, such as the US federal funds rate and the inflation rate. The US federal funds rate was included to take into consideration its influence on the BoE policy rate. The inflation variable was included to balance the inflationary effects of the nominal policy rate, and nominal exchange rate. After the variables were selected based on granger causality, the lag order was selected according to the SBIC (as suggested by Ivanov et al. (2001)), and one lag was chosen. The VAR was found to satisfy the stability condition, and was thus found to be stationary.

The residuals of the VAR model were than restricted by a Cholesky decomposition. The federal funds rate, the exchange rate and the inflation rate were all assumed to be variables important in setting the policy rate and were thus ordered ahead of the policy rate. To capture the simple monetary policy transmission mechanism desirable in the recursive identification strategy, the government bond spread was placed after the policy rate, followed last by investment.

The model identification strategy and ordering of the variables is shown below:

---

[22] The reduced 1993 sample showed considerable improvement in residual homoskedasticity (reduced residual standard deviation) and in residual normality (Jarque Bera test statistic). No improvement in residual autocorrelation.

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} u_t^{FF} \\ u_t^{e} \\ u_t^{\pi} \\ u_t^{i} \\ u_t^{gb} \\ u_t^{I} \end{pmatrix} = \begin{pmatrix} b_{11} & 0 & 0 & 0 & 0 & 0 \\ b_{21} & b_{22} & 0 & 0 & 0 & 0 \\ b_{31} & b_{32} & b_{33} & 0 & 0 & 0 \\ b_{41} & b_{42} & b_{43} & b_{44} & 0 & 0 \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} & 0 \\ b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & b_{66} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{FF} \\ \varepsilon_t^{e} \\ \varepsilon_t^{\pi} \\ \varepsilon_t^{i} \\ \varepsilon_t^{gb} \\ \varepsilon_t^{I} \end{pmatrix}$$

Where: FF= Federal Funds Rate Variable
e = Exchange Rate variable
π = Inflation Rate variable
i = Policy Rate Variable
gb = Gov't Bond Spread Variable
I = Investment Variable

The results of the SVAR using the recursive identification strategy are displayed in figure 9.

Figure 7: UK SVAR Results

$$\begin{pmatrix} 0.3405^{*}_{0.0325} & 0 & 0 & 0 & 0 & 0 \\ -0.0011_{0.0048} & 0.0358^{*}_{0.0034} & 0 & 0 & 0 & 0 \\ 0.0208_{0.0534} & 0.0018_{0.0534} & 0.3957^{*}_{0.0377} & 0 & 0 & 0 \\ 0.0943^{*}_{0.0322} & -0.0012_{0.0310} & -0.0354_{0.0308} & 0.2269^{*}_{0.0216} & 0 & 0 \\ -0.0322_{0.0481} & 0.0868^{***}_{0.0472} & 0.0608_{0.0461} & -0.2517^{*}_{0.0390} & 0.2278^{*}_{0.0217} & 0 \\ -0.0014_{0.0017} & 0.0015_{0.0017} & 0.0008_{0.0017} & 0.0032^{***}_{0.0017} & -0.0012_{0.0016} & 0.0122^{*}_{0.0012} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{FF} \\ \varepsilon_t^{e} \\ \varepsilon_t^{\pi} \\ \varepsilon_t^{i} \\ \varepsilon_t^{gb} \\ \varepsilon_t^{I} \end{pmatrix}$$

Standard deviations are written as subscripts to the matrix entries and the markers *, **, * denote significance at 1%, 5% and 10% respectively.**

The residuals of the SVAR were tested for serial correlation and normality. The results are displayed in appendix A. The high residual serial correlation detected for many variables is a source of concern in terms of robustness of the SVAR model.

The responses of investment to impulses in the five other variables were then calculated. The investment impulse response graphs can be found in appendix B.2. For the purposes of the analysis of the effects of QE, only the graph of the government bond spread is relevant. As is shown in appendix B.2, the government bond spread induced a brief statistically significant impulse in investment. Similar to the US methodology, the *largest statistically significant response* of investment to the impulse in the government bond spread was used in the calculation of the effect of QE on investment from the results of the Joyce et al.

(2010) event studies (see figure 8). The estimated effect of QE on investment in the UK is displayed in figure 9.

Figure 8: Summary of Impulse Response functions of the Government Bond Spread on Investment

UK FINAL Results	Govt Spread
Period of Significance (q)	0 - 5
MAX % Level Investment Reaction to 1bps Impulse (scaled)	**-0.0337**
Upper CI	-0.0640
Lower CI	-0.0034

Figure 9: UK Impact of QE on Investment, final results

UNITED KINGDOM FINAL RESULTS	Govt Spread
Joyce et al. (2010) Event Study Results	-100
% Investment Reaction to QE Impulse	**3.37%**
Upper CI	6.40
Lower CI	0.34

The 3.37% impact of QE on investment exceeds the GDP estimates presented in table 1 for the UK, as desired. Given that the UK QE program was smaller in relative size than the US program, the smaller reaction of investment to QE in the UK also seems fitting. However, comparing the two SVAR results, US investment is nearly twice as responsive to a basis point shock in the government bond spread than UK investment. While exploring the reasons behind this difference in historical yield sensitivity is outside of the scope of this paper, it is an interesting result, and may motivate future research.

Conclusion

Using an SVAR with a Cholesky decomposition, estimates of the effects of QE on investment were produced for the US and UK. In the US, deviations in the 10-year government bond yield suggested an impact of LSAP 1 on investment of 5.93%. In the UK, the deviation in the 10-year government bond yield suggested an impact of QE of only 3.37%. Moreover, both the US and UK results are statistically significant.

These results show that, given historical data, QE likely had a strong effect on aggregate demand through its effects on investment. However, markets do not respond in predictable manners during financial crises, and thus this result must be approached cautiously.

The 3.88% impact of QE on investment predicted by the Baa bond spread in the US is difficult to interpret because it assumes that the government bond yield was static during QE. Despite this, the significance of this result is useful in showing that the corporate bond market, and by extension the portfolio rebalancing effect, likely had an impact on real investment. However, the calculated effects for the US and UK are based only on the announcement effects provided by Gagnon et al. (2011) and Joyce et al. (2010) event studies and do not include any extended adjustment of yields over time. Therefore, to the extent that the full adjustment of bond yields in response to QE was not captured in the event studies, these estimates of the effect of QE on investment likely underestimate the true effect. The large difference between the US and UK investment sensitivity to government bond spread shocks is also an interesting result that requires further exploration. Taking into account the assumptions required to estimate the impact of QE on investment, the results in this paper should be viewed with caution, but will be useful to frame future thought on QE as a tool to provide macroeconomic stability.

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APPENDIX A: Summary of US and UK VAR Residual Characteristics

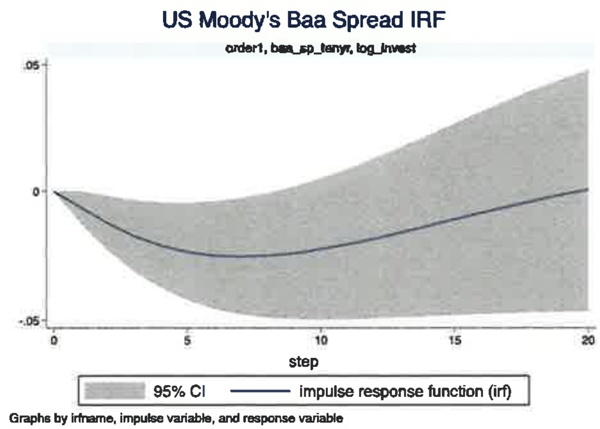
Satisfies Test, Satisfies Test Between 1-10% p-value, Does not satisfy

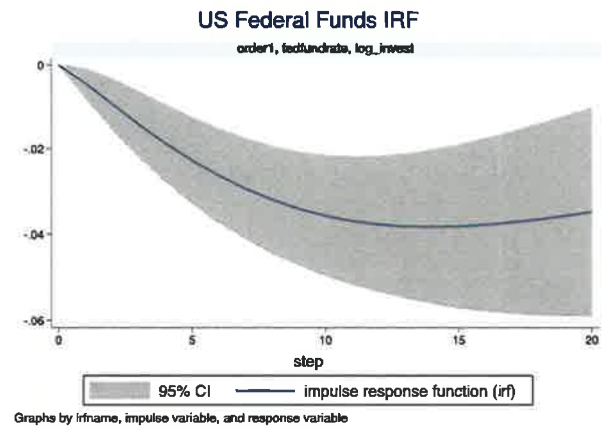
US VAR Data Characteristics	Inflation	Unemployment	Federal Funds Rate	Govt Bond Spread	Moody's Baa Spread	Investment	All
Portmanteau Residual Serial Correlation Test (p-value)[23]							
1988-2006 (Log of Inv)	0.2691	0.1096	0.0022	0.0000	0.9181	0.5988	-
Jarque-Bera Test of Normality[24] **(p-value)**							
1988-2006 (Log of Inv)	0.0044	0.4780	0.9657	0.6985	0.0085	0.4041	0.01757

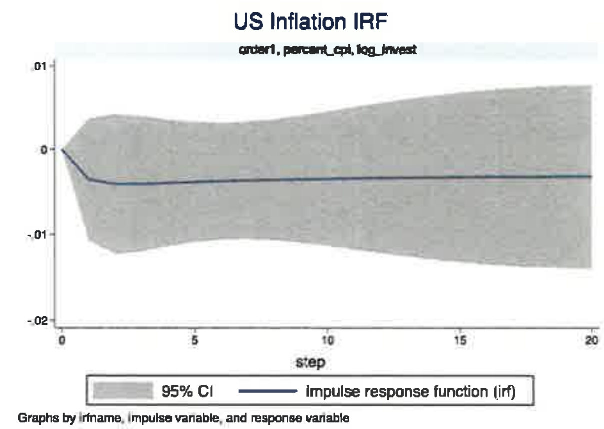
UK VAR Data Characteristics	Federal Funds Rate	Exchange Rate	Inflation	Policy Rate	Govt Spread	Investment	All
Portmanteau Residual Serial Correlation Test (p-value)							
1993-2006	0.0000	0.4180	0.0000	0.0000	0.0030	0.6002	-
Jarque-Bera Test of Normality (p-value)							
1993-2006	0.7955	0.8664	0.5813	0.0545	0.4511	0.2422	0.43958

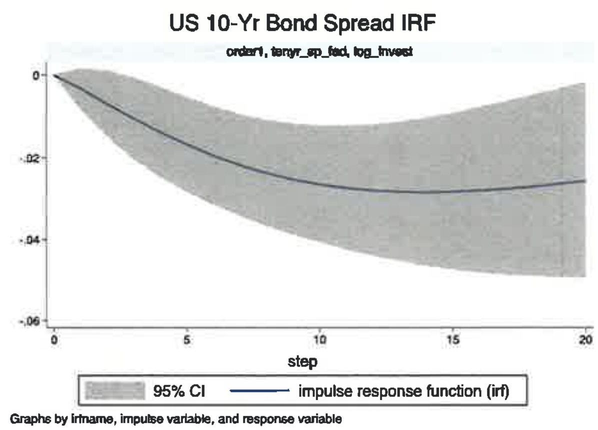
[23] The Portmanteau residual serial correlation test tests the null that the residuals have no serial correlations. See Lutkepohl (2004, pg. 127).
[24] The Jarque-Bera test tests the null that the residuals have a skewness and kurtosis resembling a normal distribution. See Lutkepohl (2004, pg. 129-130).

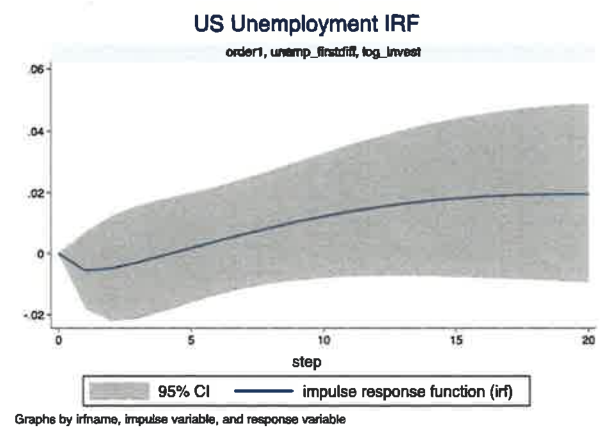
APPENDIX B.1: US Investment Impulse Response



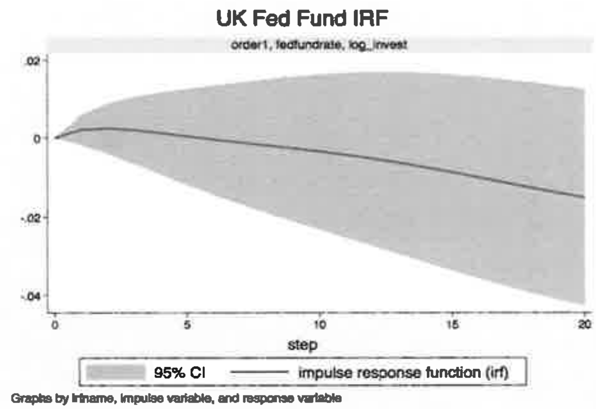


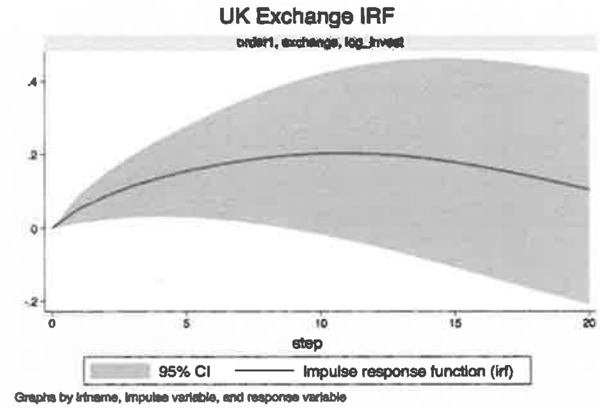


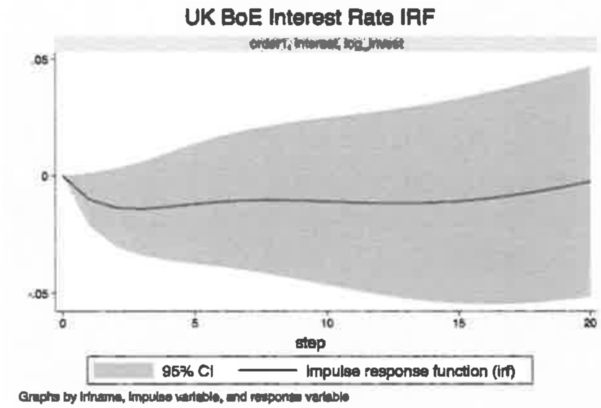


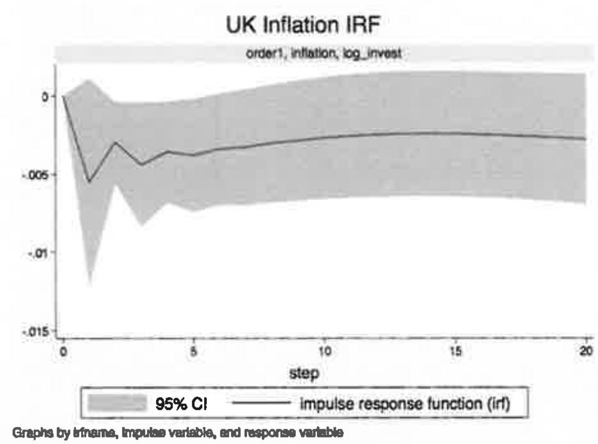


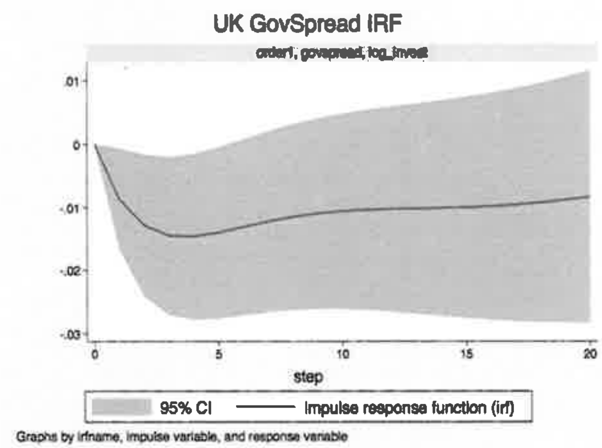
APPENDIX B.2: UK Investment Impulse Response



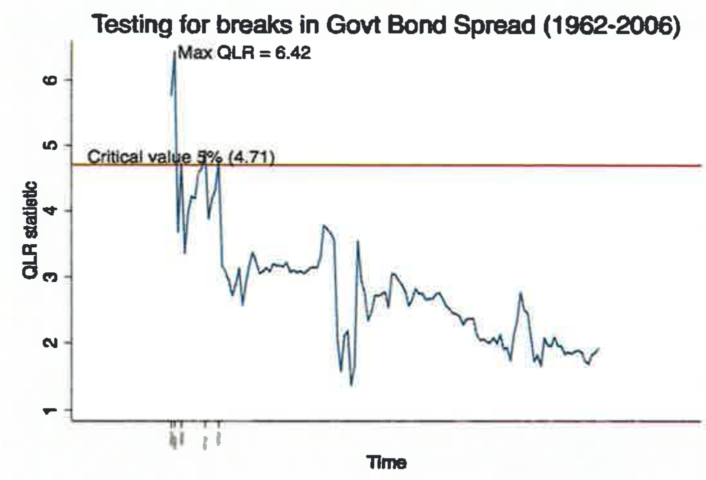


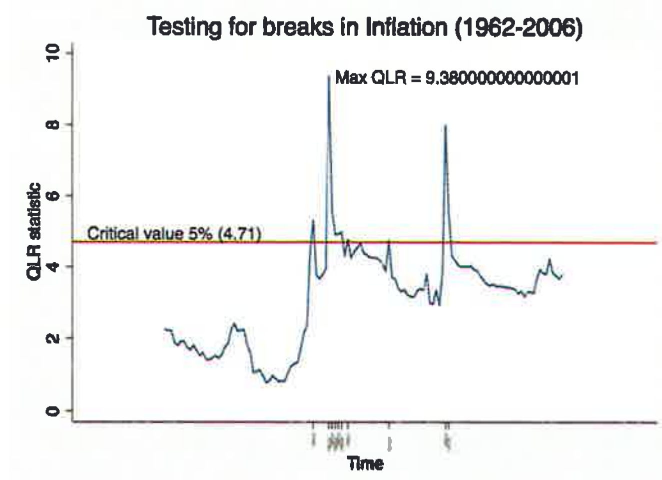




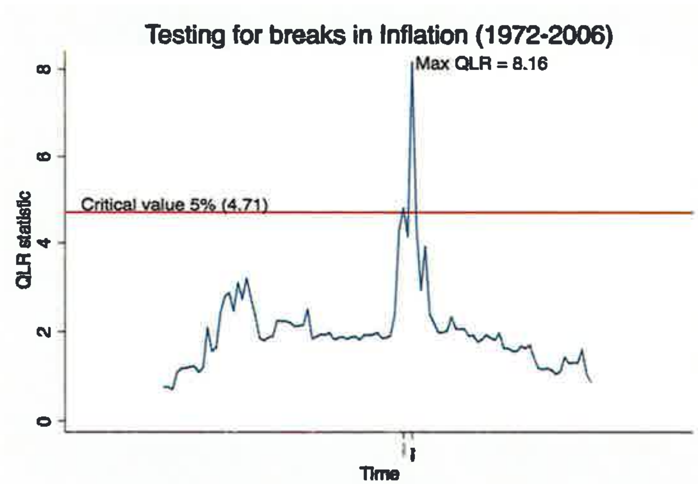


APPENDIX C.1: QLR Test Statistics for the US





APPENDIX C.2: QLR Test Statistics for the UK



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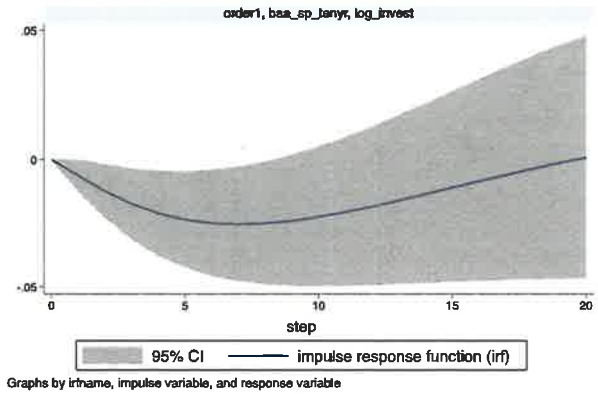
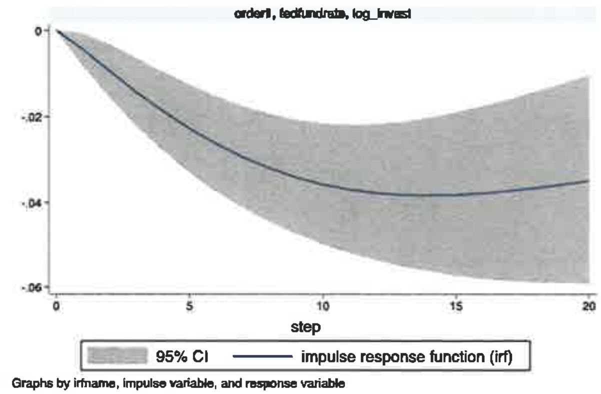
APPENDIX B.1: US Investment Impulse Response

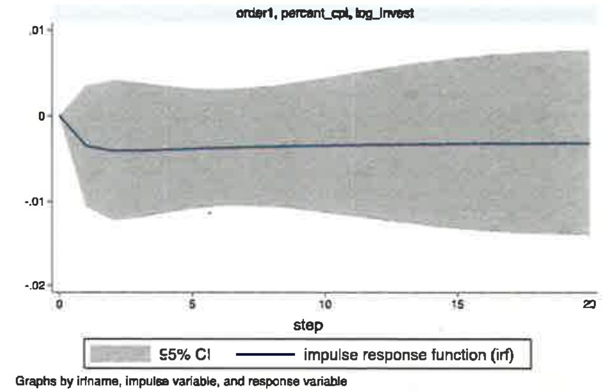
US Moody's Baa Spread IRF



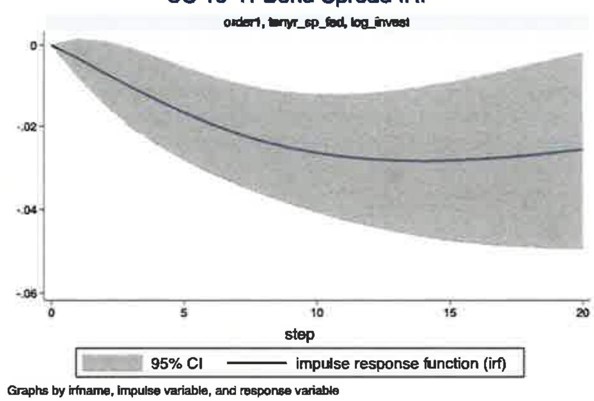
US Federal Funds IRF



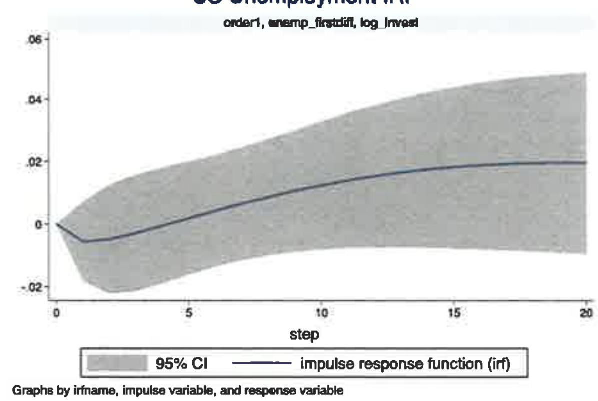
US Inflation IRF



US 10-Yr Bond Spread IRF



US Unemployment IRF



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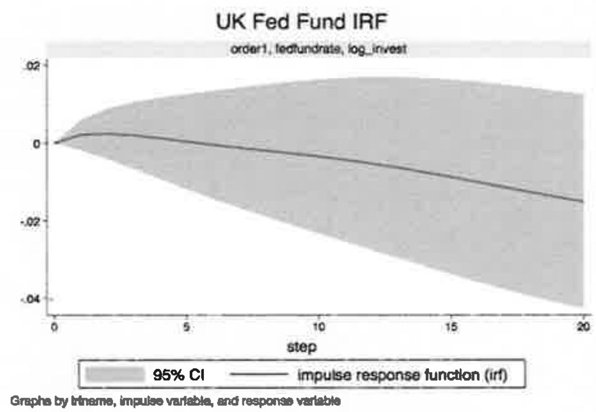

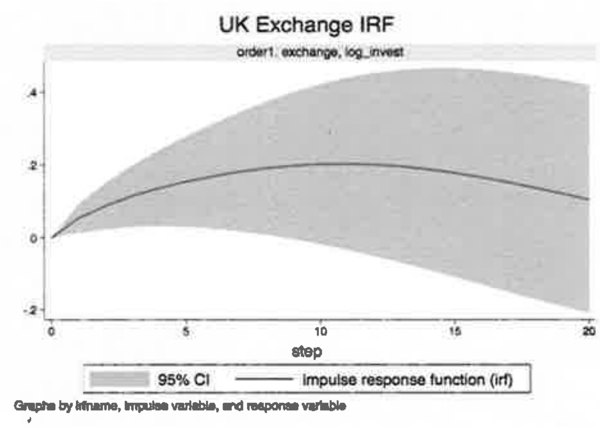

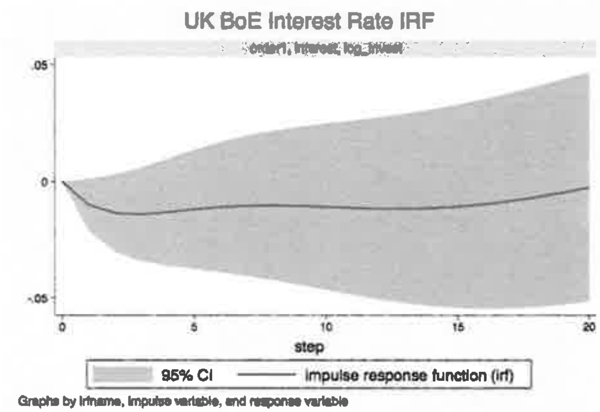

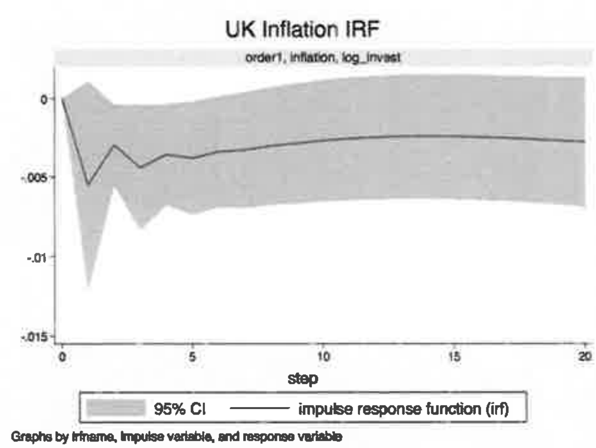

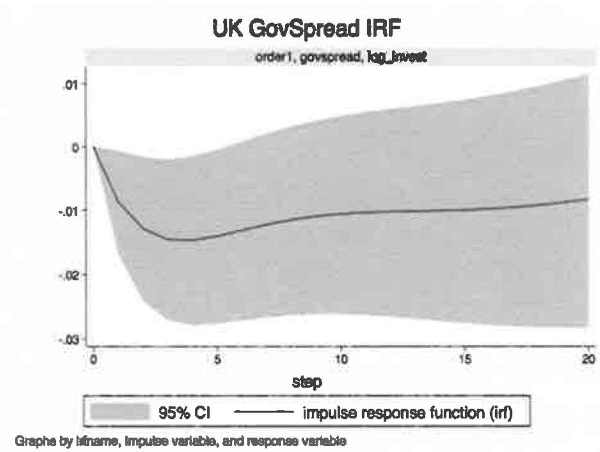

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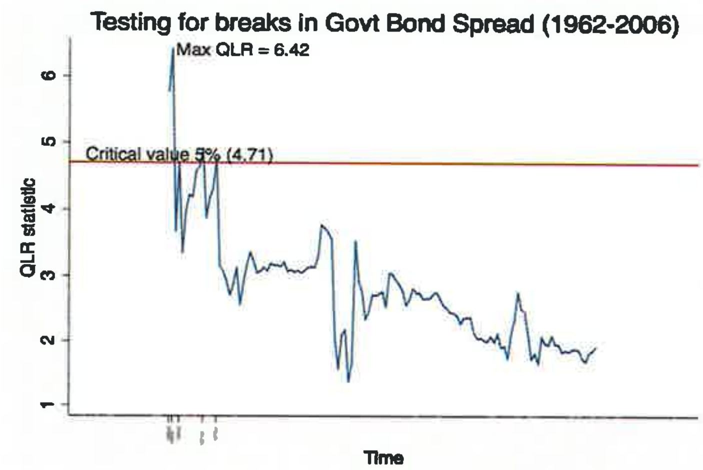

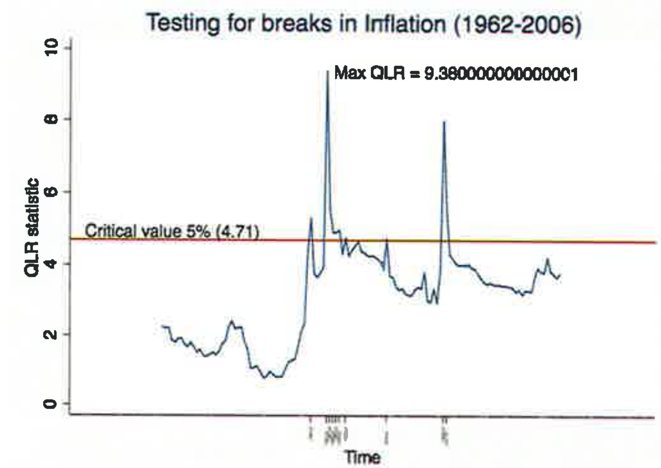

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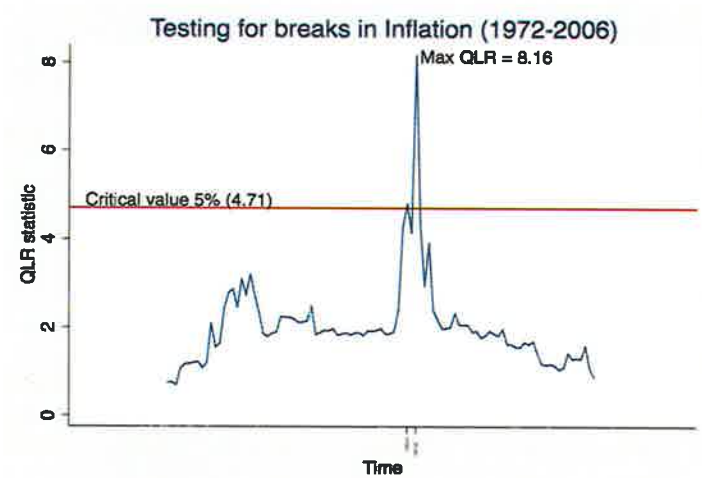

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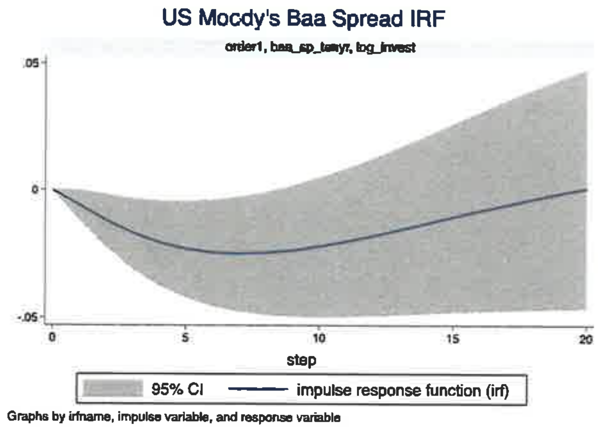
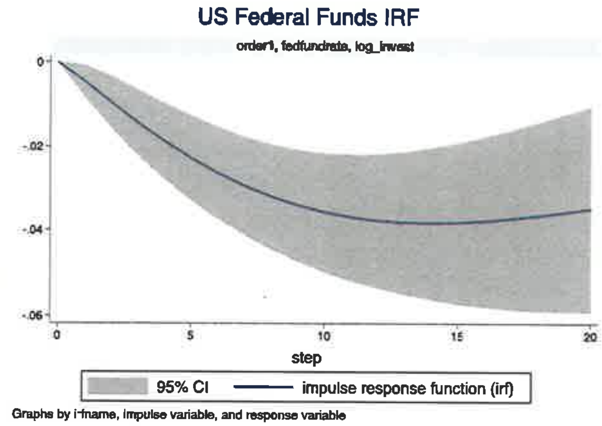
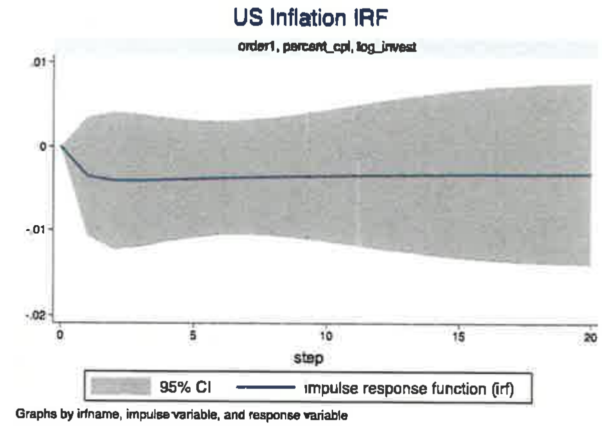
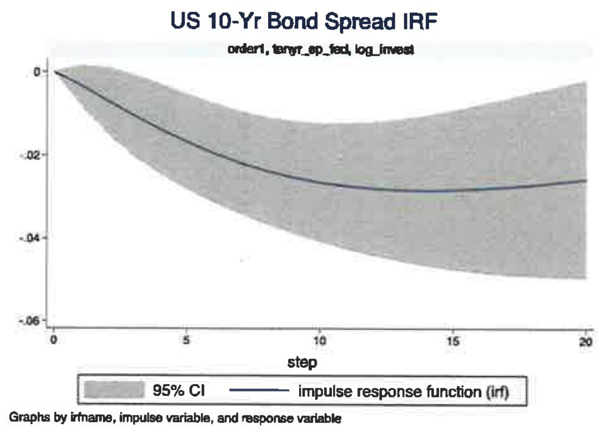
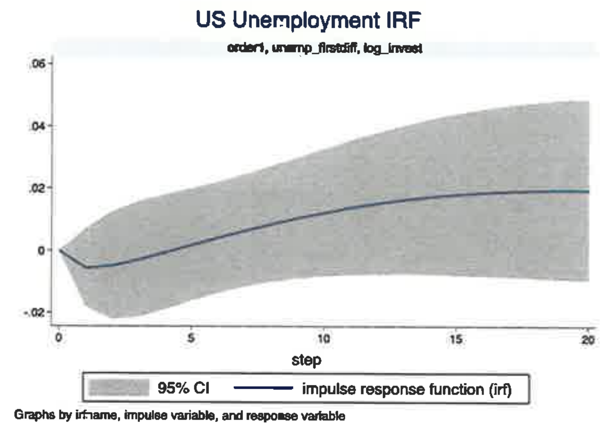


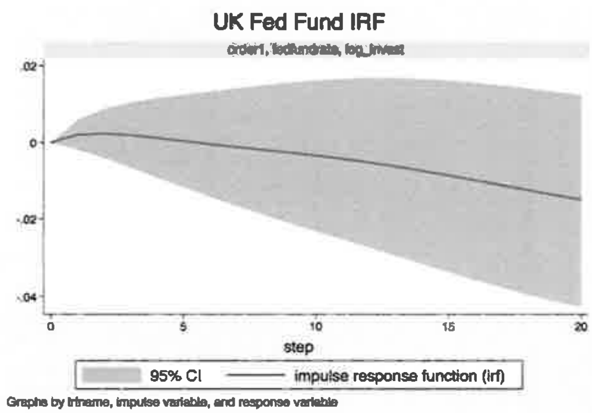


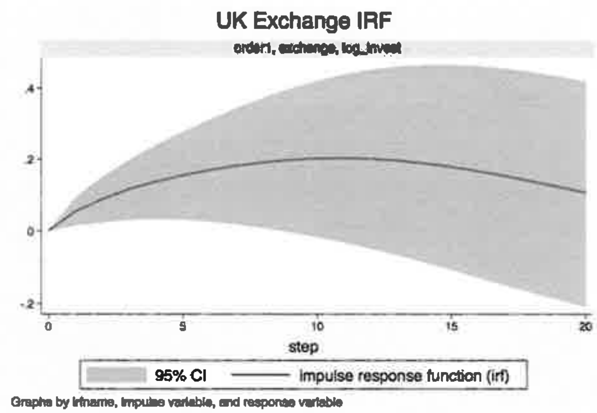


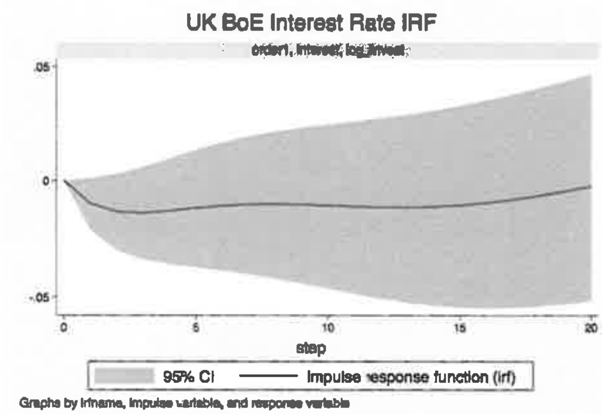


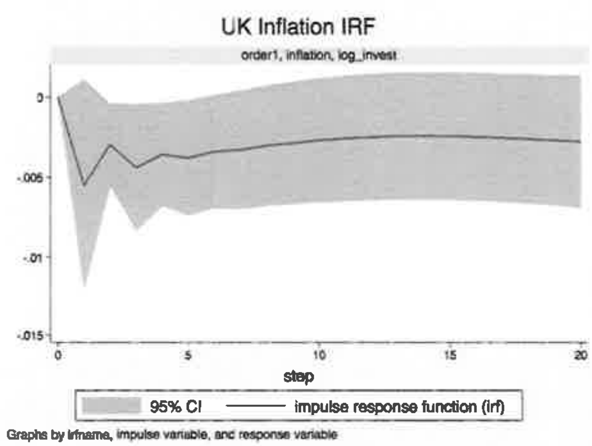


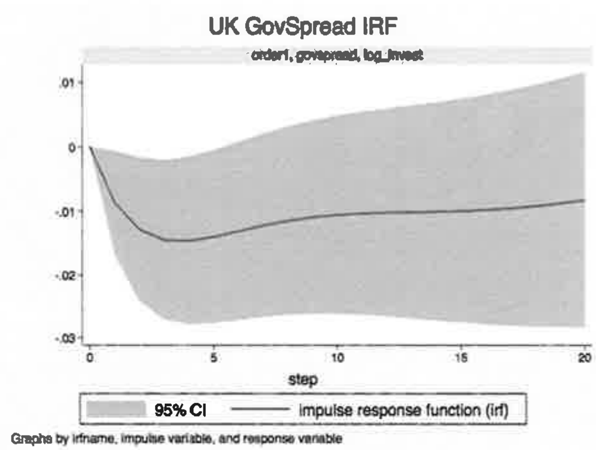
APPENDIX B.2: UK Investment Impulse Response



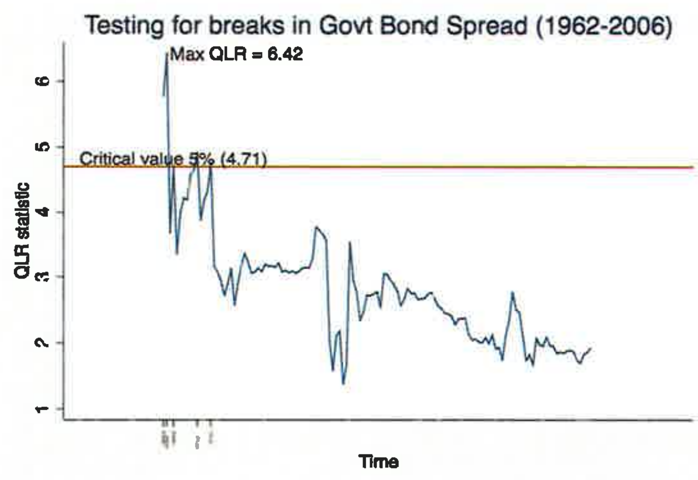


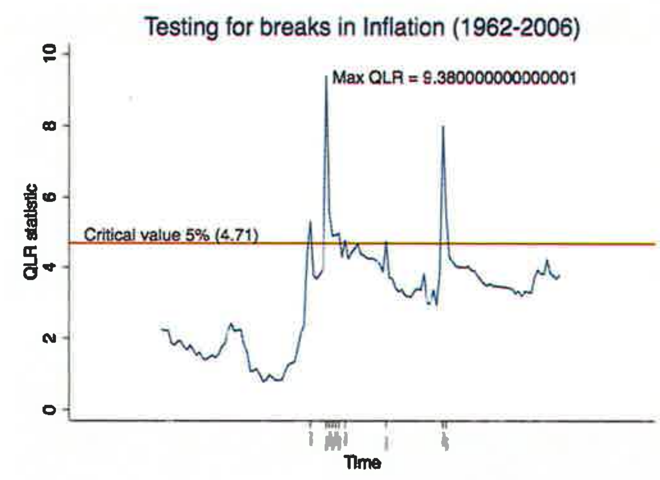






APPENDIX C.1: QLR Test Statistics for the US





APPENDIX C.2: QLR Test Statistics for the UK