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ESTIMATING THE EFFECT OF MONETARY POLICIES ON LONDON'S RESIDENTIAL PROPERTY PRICES: A VECTOR AUTOREGRESSIVE ANALYSIS

Abstract

In the last decades, London's property prices have experienced an unprecedented appreciation associated with a great credit expansion. The current high liquidity and low-interest-rate environment has significantly diminished the cost of debt for Londoners and fueled the demand for housing. Historically, large asset appreciations fostered by an increase in household leverage were followed by substantial price adjustments. Therefore, motivating this research to investigate the extent to which monetary policies contributed to the residential property price appreciation in London from 1996 to 2017. To investigate this relationship, I hypothesize that a contractionary monetary policy shock is negatively associated with property prices in London. To verify this claim, I employ the Vector Autoregressive Model (VAR) with Cholesky decomposition to trace out the effects of a monetary policy shock on property prices over two years. It results that a contemporaneously uncorrelated increase in the policy rate is significantly associated with a decrease in house prices and that monetary policies account for 7.7 percent of the variation in property prices in London in the long-run.

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INTRODUCTION

300 million Americans, their lending institutions, their government, their media, all believed that house prices were going to go up consistently (…) Lending was done based on it, and everybody did a lot of foolish things

Warren Buffet (CNBC, Charlie Rose Interview, 1st October 2008).

The decade of expansionary monetary policies initiated by the collapse of the US housing market in 2007 saw central banks around the globe compelling policy rates to zero and embarking on controversial monetary policies to stimulate economic growth. These policies have harshly penalized world's savers and created incentives to seek for yields in riskier and less liquid asset classes, with potentially alarming consequences on our financial and economic system (BlackRock, 2015). This low-interest-rate and low-yield environment has fueled the demand for housing in London, as households have leveraged up to purchase dwellings and asset managers have sought for assets with higher returns and lower correlation with their portfolios (consult the Appendix for a cost and benefit analysis of London's real estate from a portfolio management perspective, Figure 1 and 2).

The low-interest-rate and liquid environment has substantially decreased the cost of debt for Londoners. According to data from the Bank of England (BoE), the effective mortgage rate decreased from 5.9 percent in 2008 to 3.1 percent in 2015 (Figure 3 Appendix). Correspondingly, this resulted in a credit expansion in London where the total stock of mortgage debt increased from £21 billion to £23 billion from 2009 to 2013 (Office for National Statistics, 2015). Furthermore, the growth of the amount of mortgage debt outstanding in London has far outpaced the one of Londoners' disposable income. In fact, the aggregate household mortgage debt to disposable income ratio increased from 2.82 in 2009 to 3.2 in 2013 in London (Office for National Statistics, 2015). According to Marsden, the low costs of credit have supported high prices in London and may expose the local economy to the risk of a price adjustment (2015). To illustrate, between 2009 and 2017 London's property prices grew at an annual rate of 8.1 percent, compared with the national average of 4.4 percent (Land Registry, 2017). As Figure 4 in the Appendix displays, this gap is even more pronounced when one looks at different boroughs of London. Moreover, the recent growth in house prices has far exceeded the one of Londoners' earnings. According to data from the Office for National Statistics and Land Registry, mean property prices to median earnings in London increased from 9.2 in 2009 to 15 in 2014, while the ones of England grew from 7.2 to 9.6. This gap between affordability and valuation is especially enhanced in Central London where the range increased from 32.8 to 64.8 in the same time period (Figure 5 in the Appendix).

The value of living in London and of the access to its job market has increased substantially since the mid-1960s, as London has gone through a major economic transformation from manufacturing city to leading international financial, business and broadcasting center (Hamnett, 2001). However, it is hard to tell whether the recent rise in real estate valuations is due to the effect of monetary policies or due to an increase in the fundamental value of London's property market. Historically, large asset appreciations fostered by an increase in household leverage were followed by substantial price adjustments. Crowe, Dell'Ariccia, Igan and Rabanal (2013), Borio and Lowe (2002), and Davis and Zhu (2011) provide evidence that the coincidence between a large increase in house prices and rapid credit expansion appear to increase the probability of financial crisis in a specific country. Therefore, it is relevant to bring to light whether the Bank of England (BoE) has influenced the recent appreciation of London's buildings. This motivates me to investigate the following research question:

> *"To what extent have monetary policies contributed to the residential property price appreciation in London from 1996 to 2017?"*

This research is addressed to residential property prices as there is a limited availability of data on corporate property prices. In addition, I only measure monetary policies with policy rate changes. However, the BoE purchased £200 billion of long-term securities to stimulate the economy from March 2009 to January 2010 (Joyce, Tong, & Woods, 2011). The research question is answered with the following hypothesis: a contractionary monetary policy shock is negatively associated with property prices in London. To investigate this relationship a Vector Autoregressive (VAR) method is used on policy rate, exchange rate, equity returns, inflation, credit, London's residential house prices, and economic activity. The VAR was first introduced by Sims (1980). Sims was awarded the Nobel Prize in 2011 because of the introduction of the VAR and other advancements in macroeconometrics. A large body of literature has identified a causal relationship between monetary policies and property prices (Iacoviello, 2005, Del Negro & Otrok, 2007, Vargas-Silva, 2008, Eickmeier & Hofmann, 2013). However, to my knowledge, there is no paper in the current literature that has investigated the effect of monetary policies on London house prices with this methodology.

Researching the relationship between monetary policies and residential real estate prices in London has considerable economic and social implications. First, this evidence may warn market participants of a higher probability of financial instability in London. As stated previously, the economic literature provides evidence that a large increase in house prices that comes along a rapid credit expansion increases the probability of financial distress in an economy (Crowe, Dell'Ariccia, Igan & Rabanal, 2013, Borio & Lowe, 2002, & Davis, Zhu, 2011). Second, this result may inform local policymakers of the severity of this potential crisis. As Crowe, Dell'Ariccia, Igan and Rabanal show, asset depreciations tend to be more costly for society when these assets are financed through credit and leveraged institutions (2013). This occurs because when assets depreciate, borrowers' financial conditions deteriorate rapidly. As more players defaults on their liabilities, the banking system weakens and the supply of money in the economy decreases impacting the real economy (Davis and Zhu, 2009). This phenomenon is also known as debt-deflation. Third, London's property wealth, which accounts for 40 percent of total wealth among the richest 20th percentile in London (Marsden, 2015), may decrease sharply when the interest rate will rise and quantitative easing programs will be terminated.

The rest of this paper is organized as follows. In the first part of this paper, the theories and empirical findings of the existent literature that are relevant to this research are analyzed. In the second part, the data and the variables used in this investigation are discussed. In the third part, I elaborate on the econometric methodology used to reach this paper's conclusion. In the fourth part, the results of the econometric investigation of this research are illustrated. Finally, I interpret the results and discuss the limitations of this paper.

THEORETICAL FRAMEWORK

Several papers in the previous literature have investigated the effect of monetary policies on the housing market.

Iacoviello in 2005 developed a macroeconomic model with frictions in which endogenous variations in the balance sheet of the corporate sector amplify the business cycle. This new-Keynesian model was first introduced by Bernanke et al. (1999). To this framework, Iacoviello adds nominal debt contracts and collateral constraints tied to housing values. This model is employed by the author to perform a quantitative policy analysis resulting in the two following conclusions. First, monetary policies yield to inconsiderable gains in terms of inflation and gross domestic product. Second, debt-deflation significantly amplifies demand shocks, but interestingly stabilizes supply shocks, improving the output-inflation variance trade-off in an economy. This paper contributed to this research as Iacoviello used a VAR to document key macroeconomic relationships that he integrated into his model. This VAR is composed by detrended real GDP, change in the log of GDP deflator, detrended real house prices, and Fed Funds rate. To investigate the causal relationship between monetary policies and house prices, Iacoviello traced out the effects of a monetary policy shock in his VAR analysis. He performs this with the use of an impulse response analysis with Cholesky decomposition. The order of the variables that he assumes is the following: Fed Fund, inflation, house prices and output. I elaborate more on the Cholesky ordering in the methodology of this paper. Iacoviello's analysis is performed in the US with a sample from 1974 to 2003. The author proved a negative response of inflation, real housing prices and GDP to contractionary monetary policies; a small negative response of real housing prices to an increase in inflation; and a positive comovement of inflation and output in response to a shock in housing prices.

Del Negro and Otrok (2005) use a dynamic factor model via Bayesian methods to separate the common component in the movement of US housing prices from local shocks. The sample used for this paper consists of quarterly data from 1986 to 2005 in the US. They discovered that the national component in the US house prices played an important role between 2001 and 2005, increasing its explanatory power from 11 to 34 percent. However, most of the variation in the sample was explained by the local component. Del Negro and Otrok implement a Structural VAR with sign restrictions to estimate the effect of monetary policies on the variance of house prices explained by the national component. The VAR is employed using four lags of the house factor, total reserves, CPI inflation, GDP growth, the 30-year mortgage rate and the Federal Funds rate. All the variables are in growth rates, except for Fed Funds rate that is first differenced. As compared to Iacoviello (2005), the authors control for changes in mortgage rate and reserves rate. In addition, Del Negro and Otrok use a sign restriction based on the work of Uhlig (2005). According to this identification, contractionary monetary shocks are defined as an increase in the policy rate, a decrease in total reserves, a decrease in the price level, and a non-positive growth in GDP. The responses of the house factor and the mortgage rate are left unrestricted. Del Negro and Otrok discover that monetary policies can impact house prices, as found in Iacoviello (2005), and monetary policies shocks describe 13 percent of housing price variance. Vargas-Silva (2007) implement a similar methodology, but he highlights that the magnitude of the impact of monetary policies is sensible to the assumption on the horizon of the sign restrictions.

Eickmeier and Hofmann (2013) research the role of monetary policy in property prices and credit markets imbalances. To this purpose, they use a factor-augmented vector autoregressive model (FAVAR), proposed by Bernanke et al. (2005). This methodology extends to the VAR a set of factors summarizing more than 200 financial variables and contributes extensively to the existing literature by providing a more comprehensive characterization of the transmission of monetary policy shocks. Similarly to Del Negro and Otrok (2005) and Vargas-Silva (2007), Eickmeier and Hofmann (2013) use sign restrictions and contemporaneous zero restrictions. The FAVAR is composed of quarterly data of real GDP growth, GDP deflator, effective Federal Funds rate, 69 property prices, 62 stock market indices, 50 interest rates, 2 monetary aggregates, and 49 series of non-financial firms' balance sheet. The sample period is from 1987 to 2007. The results of this research are that monetary policy shocks have a significant and large effect on property prices and significantly contributed to the house price appreciation and credit market expansion occurred between 2001 and 2006.

As Iacoviello (2005) did, this research uses a structural VAR model with Cholesky decomposition to investigate a causal effect between monetary policies and house prices in London. Contrary to Del Negro and Otrok (2005), Vargas-Silva (2007), Eickmeier and Hofmann (2013), I do not use sign restrictions on the residuals and I identify a monetary policy shock simply with an increase in the policy rate. Similarly to the papers discussed in the theoretical framework, a measure of inflation and economic activity is included in this model to control for the correlation of these - otherwise - omitted variables with the residuals. My work differs from the previous literature in the following ways. First, residential house prices are residential and not both corporate and residential house prices. Second, changes in house prices are investigated in London and not in the United States. Third, the effect of monetary policies on house prices is analyzed on a metropolis and not on a country level, perhaps providing new insights on the dynamic of property markets in large cities.

DATA

To estimate the effect of monetary policies on the property prices in London this research uses an unrestricted VAR with the following variables: Bank Rate, the UK Effective Exchange Rate, the FTSE 100 equity index, total loans to individuals, all-item Consumer Price Index (CPI), London residential house prices, and unemployment rate. The sample period ranges from February 1996 to January 2017 with a monthly frequency.

The Bank Rate is the official policy rate of the BoE and it is used to influence other interest rates in the economy by the Monetary Policy Committee (MPC). Specifically, the Bank Rate is the rate of interest that the BoE pays on reserve balances that commercial banks hold. This rate was retrieved from FRED, the economic research database of the Federal Reserve Bank of St. Louis, and it can be found under the ticker BOERUKM. The Effective Exchange Rate is used to measure the overall change in the exchange value of the pound sterling. This rate is computed by taking the weighted average of the appreciations and depreciations of the British pound, where the weights are assigned based the trade flows between the relevant countries. This time series can be found on the BoE's website under the ticker XUMABK82. The FTSE 100 is a market index of the 100 public companies with highest market capitalization in the United Kingdom. A limitation of this index in measuring equity returns is that it does not take into account dividends and it does not cover mid cap and small cap valuations. This series was retrieved using The Bloomberg Terminal under the ticker UKX Index. Total loans to individuals were used as a proxy of household credit in London. This variable represents the total amount outstanding of lending to individuals excluding student loans. The use of this time series introduces a limitation. Namely, it describes the credit condition of the United Kingdom and not of London. Thus, it is implicitly assumed that London and the United Kingdom have similar credit conditions. However, this not true, as the aggregate debt to income ratio in London is 3.18, while in the rest of the United Kingdom is 2.27 (Office for National Statistics, 2015). This series was retrieved in the BoE's collection of historical macroeconomic and financial statistics for the UK and it can be found with the ticker LPMBZ2A. All-Item CPI was used as a proxy for inflation in the United Kingdom. This series is a good proxy for changes in price levels in an economy. However, it has a considerable limitation. In fact, it is a price index that measures the prices of a basket of consumer goods and thus it does not consider changes in prices for producers. A better estimate of inflation would be GDP deflator, as it considers changes in price levels in both consumer and producers. However, this figure is only available at a quarterly frequency and it cannot be used in this analysis. The time series was retrieved in the UK Office for National Statistics. Residential London house prices were estimated using the data from the Land Registry Association. This house price index is created based on residential housing transactions occurred in a certain month. The commercial transactions were not included in this dataset. This database was also used to compute illustrative statistics on each borough of London. The indicated index is particularly suitable for this research as it excludes transactions from the corporate sector, allowing this paper to accurately research residential house prices. Unemployment Rate was integrated into this model as a proxy for economic activity. This choice was inspired by Brooks and Tsolacos (1999) who used unemployment as an indicator of general economic activity in their paper researching the effect of macroeconomic variables on UK housing prices. The aforementioned variable was retrieved from the Office of National Statistics. I could not use GDP in this analysis as it is not available on a monthly base. In addition, I could not use the Manufacturing and Service Index PMI as a proxy of economic activity because this figure was not available for a sample longer than two years in the databases available to this research.

This research performs two main transformations. First, total loans to individuals and London house prices are transformed from nominal to real variables, by dividing each series with the All-Item CPI index with the base year in 2014. Second, the series are rendered stationary, *id est* all the series in this analysis have a constant mean, variance, and autocovariance. I did so by taking the first difference of the unemployment rate and bank rate and computing the returns of the equity index, the Effective Exchange Rate, London residential house prices, All-Item CPI, and total loans to individuals. It is then tested whether the resulting series are stationary with the Augmented-Dickey Fuller (ADF) test, and all the series results to be stationary at a 95 percent confidence interval (see Figure 6 in the Appendix). The Dickey-Fuller test's null hypothesis is that β_1 is unit root and the alternative hypothesis is that β_1 is smaller than one, therefore a stationary process. Specifically, H_0: $\partial = \beta_1 - 1 = 0$ and H_a: $\beta_1 - 1 < 0$.

$$DF_{test} = \frac{\hat{\partial}}{SE(\hat{\partial})}$$

The extension of this framework to *p* lags is known as the Augmented-Dickey Fuller test (Dickey & Fuller, 1979).

METHODOLOGY

In this research, I am interested in measuring the effect of monetary policies on London residential house prices. Specifically, I want to test whether this effect ($\beta_{6,t}$) is different from zero and measure its magnitude and sign with a 95 percent confidence interval.

To estimate this parameter, the vector autoregressive model (VAR) is used:

$$\begin{pmatrix} y_{1,t} \\ y_{2,t} \\ \vdots \\ y_{k,t} \end{pmatrix} = \begin{pmatrix} \beta_{0,1} \\ \beta_{0,2} \\ \vdots \\ \beta_{0,k} \end{pmatrix} + \begin{pmatrix} \beta_{1,1}^1 & \beta_{1,2}^1 & \cdots & \beta_{1,k}^1 \\ \beta_{2,1}^1 & \beta_{2,2}^1 & \cdots & \beta_{2,k}^1 \\ \vdots & \vdots & \ddots & \vdots \\ \beta_{k,1}^1 & \beta_{k,2}^1 & \cdots & \beta_{k,k}^1 \end{pmatrix} \begin{pmatrix} y_{1,t-1} \\ y_{2,t-1} \\ \vdots \\ y_{k,t-1} \end{pmatrix} + \dots + \begin{pmatrix} \beta_{1,1}^P & \beta_{1,2}^P & \cdots & \beta_{1,k}^P \\ \beta_{2,1}^P & \beta_{2,2}^P & \cdots & \beta_{2,k}^P \\ \vdots & \vdots & \ddots & \vdots \\ \beta_{k,1}^P & \beta_{k,2}^P & \cdots & \beta_{k,k}^P \end{pmatrix} \begin{pmatrix} y_{1,t-p} \\ y_{2,t-p} \\ \vdots \\ y_{k,t-p} \end{pmatrix} + \begin{pmatrix} \epsilon_{1,t} \\ \varepsilon_{2,t} \\ \vdots \\ \epsilon_{k,t} \end{pmatrix}$$

Where *k* is the number of variables and *t* is the number of lags.

The VAR is a system in which each variable is regressed on a constant, its lags, and the lags of other variables. This construction allows each variable to be endogenous and to influence other variables in the model with a distributed lag. This dynamic model was preferred to a simple linear regression as the latter allows only for contemporaneous relationships between variables Sims (1980). However, intuitively, I expect that a change in a macroeconomic factor does not affect housing prices instantaneously and in a single month, but rather with a lag and over multiple months. Moreover, the VAR includes the dynamic structure of all the variables in the model, thereby allowing this research to model the information contained in the past values of each variable and solving the problem of autocorrelated error terms. To determine the lag length of this model, the multivariate version of the Akaike Information Criterion (AIC) is used, which includes a penalty for the degrees of freedom that the model loses by including an additional lag and a premium for decreasing the sum of squared residuals (RSS) in the model.

$$MAIC = \log(\hat{\Sigma}) + \frac{2k'}{T}$$

Where $\hat{\Sigma}$ is the variance-covariance matrix of the residuals, k' the number of regressors in all equations, and *T* the number of observations.

Another contribution of the VAR to this research is that it allows to examine the relationship of multiple variables, therefore providing this research with the ability to control for variables that are both correlated with the dependent variable and the independent variables. Controlling for these omitted variables is very important for this analysis, as one of the assumptions of the OLS method is that the independent variables are non-stochastic, meaning that they are not correlated with the error term at any lag, $corr(x_{k,t}, \epsilon_{k,t}) = 0$. If this assumption is not respected, the coefficient $\beta_{6,t}$ would be inconsistent and therefore biased.

In this model, besides London's residential house and policy rate, the Effective Exchange Rate, equity returns, inflation rate, and economic activity are included. The selection of these variables is justified by both previous literature and economic rationale. As Iacoviello (2005) and Del Negro and Otrok (2007) did, I quantify monetary policy shocks using the policy rate, measure housing prices using a house price index, and control for economic activity and inflation. However, I also include in the model equity valuations, Effective Exchange Rate, and Total Individual Lending. The reason for this decision lies in the empirical fact that the Effective Exchange Rate and equity prices are highly correlated with house prices and policy rates in this sample (see Figure 7). The economic rationale that justifies the inclusion of the Effective Exchange Rate is that 49 percent of the buyers in prime central London, 20 percent in Inner London, and 7 percent in Outer London were foreign buyers in 2013. (Knight Frank, 2013). While the reason for including equity prices is that households in the UK own 12 percent of the quoted shares, totaling 206 billion of wealth (Office for National Statistics, 2014). Therefore, the performance of the equity market may substantially determine the ability to participate in the property market for UK households.

To interpret the result of the VAR, it is not practical to look at single t-tests, as there are 438 parameters. Because of this large number of parameters, this research may commit a Type I Error, *id est* rejecting the null hypothesis that the effect of a parameter is zero when in reality it is equal to zero. Therefore, the F-test is used to estimate the significance of the joint effect of the independent variables on the dependent variable. The null hypothesis of the F-test is that $\beta_0 = \beta_1 = \cdots = \beta_k = 0$ and it is tested with the following formula:

$$F - test = \left(\frac{RRSS - URSS}{URSS}\right)\left(\frac{T - k}{m}\right)$$

Where URSS is the sum of squared residual of the unrestricted regression, RRSS is the sum of squared residuals a regression in which β_k are imposed to be equal to zero, *m* the number of restrictions, *T* the number of observations, and *k* the number of regressors in the unrestricted regression. If RRSS and URSS are not very different from each other I cannot reject the null hypothesis. Although the F-test is a good test statistic to estimate the presence of a correlation, it does not tell us much about the direction of this correlation. To gain an insight on which variable significantly forecasts another variable I use the Granger Causality test. Even though the name of the test may hint that I am testing for causality between two variables, I am not. This test simply provides an insight on the direction of a correlation. It was named "causality" test because if x causes y the direction of the correlation must be from x to y, but correlation does not imply causation.

The F-test and Granger Causality are sufficient to assess whether monetary policies are significantly correlated with residential housing prices. However, they are not sufficient to estimate a causal relationship between two variables, as the error terms are contemporaneously correlated (see Figure 8). In addition, these two tests do not tell us anything about the sign, the length, and the magnitude of the impact of monetary policies on housing prices. To better analyze the effect of monetary policies on house prices, I simulate in the VAR a monetary policy shock that is contemporaneously uncorrelated with all the other variables and trace out the effect of this shock in the dynamic model. This methodology is known as *impulse response analysis*. It is noteworthy to emphasize that to perform this analysis correctly the residuals must be contemporaneously uncorrelated, otherwise, I would model a common component that could potentially be wrongly attributed to changes in the Bank Rate. Thus, I apply a transformation to the innovations such that they become uncorrelated, $E[\epsilon_t, \epsilon_t{}'] = I$. To orthogonalize the impulse, the Cholesky factor is used. A limitation of this methodology is that a different order of the variables leads to different results, and there is no statistical method to identify the correct order. The identification implemented is the following: policy rate, exchange rate, equity returns, inflation, credit, London's residential house prices, and economic activity. The order policy rate, inflation, house prices, and economic activity is the same used by Iacoviello (2005). I put exchange rate and equity returns before all the other variables because they are financial variables and, therefore, I assume that they are more responsive than other macro variables; and I place credit after inflation, as I assume households account for inflation when deciding how much leverage to take. To further analyze the nature of the relationship between monetary policies and residential house prices in London I perform the *variance decomposition* analysis. The variance decomposition allows me to quantify the variance of house prices in London caused by uncorrelated changes in the Bank Rate. In the *variance decomposition* analysis, I also orthogonalize the residuals using the Cholesky decomposition and assume the aforementioned order of the variables.

The VAR is estimated using the OLS method and therefore the estimator $\beta_{6,t}$ must respect all five assumptions of the OLS to be the best linear unbiased estimator (BLUE). First, the average value of the error term $\varepsilon_{k,t}$ has to be equal to zero, $E(\varepsilon_{k,t}) = 0$. This assumption is necessary for the coefficient $\beta_{6,t}$ to be unbiased and in this model it holds as the constant $\beta_{0,t}$ is integrated. Second, the variance of the errors must be constant $var(\varepsilon_{k,t}) = \sigma^2 < \infty$, *id est* the error terms need to be homoscedastic. This assumption is not necessary for the coefficient to be unbiased and consistent, but if it does not hold $\beta_{6,t}$ is not BLUE. I test for heteroscedasticity with the use of the VAR Residuals Heteroscedasticity test, which is an extension of White's (1980) test. The null hypothesis is that there is no heteroscedasticity and this test is performed by regressing each cross product of the residuals on the cross products of the regressors and testing for joint significance. Third, the covariance of the error terms over time has to be equal to zero, meaning that the error terms should not be serially correlated. The consequence of breaking this assumption is that the coefficient $\beta_{6,t}$ is still unbiased, but it will be inefficient. In this paper, I account for the autocorrelation of the residuals by visualizing the residuals and using the LM test. The LM test statistics' null hypothesis is that there is no serial correlation. Four, there should be no omitted variable correlated with both the dependent variable (house prices), and the independent variable (monetary policy), as the coefficient $\beta_{6,t}$ would capture not only the effect of monetary policies but also the effect of these omitted variables. This assumption is taken into account by integrating variables that I believe significantly capture the correlation between the error term and the dependent variables, $corr(x_{k,t}, \epsilon_{k,t})$. Five, the error terms $\varepsilon_{k,t}$ must be normally distributed. This assumption is required to conduct hypothesis tests on the coefficients of this econometrics analysis. the Jarque-Bera normality test is performed to assess the validity of this assumption. This test compares the moments of the distribution of the residuals (mean, standard deviation, skewness, and kurtosis) with the ones of the normal distribution.

RESULTS

The AIC statistical analysis is implemented to choose the best lag order for this model, see Figure 9. The lag that minimizes the AIC is the 12th lag. Hence, this is the lag order that maximizes the tradeoff between lower RRS and more degrees of freedom in this model. Once the VAR is identified, its stability is checked by running the Inverse Roots of AR Characteristic Polynomial graph, see Figure 10. This figure shows that all the roots are smaller than one, and therefore the VAR is stationary and stable.

Before estimating the VAR, I need to check if the residuals of the VAR are serially correlated, normally distributed, and homoscedastic. If one of these misspecification is present, the estimators are still consistent and unbiased, but they are inefficient, meaning that they do not minimize the standard errors of the parameters. To assess whether the residuals are autocorrelated, the residuals are plotted to check if there is any pattern suggesting the presence of autocorrelation (see Figure 11 in the Appendix). This first visual analysis hints that the residuals are white noise. To confirm this conclusion quantitatively a Serial Correlation LM test is performed (Figure 12). The result of the Serial Correlation LM test is that the there is significant autocorrelation up to the lag number 12. To test whether the residuals are normally distributed the Jarque-Bera residual normality test is performed. Sadly, the result is that the residuals of the Bank Rate, the exchange rate, and credit are not normally distributed (see Figure 13 in the Appendix). In addition, the null that the residuals are jointly normally distributed in this VAR is rejected. To further investigate the nature of the distribution of these variables, I perform histograms of the residuals of the non-normal variables (see Figure 14 in the Appendix). After a visual inspection of these distributions, strong outliers are identified. These may be the reason why the residuals of these variables are not normally distributed. Finally, heteroscedasticity is tested with the White Heteroscedasticity test, Figure 15 in the Appendix. This test suggests that this paper cannot reject the null hypothesis that the residuals are homoscedastic.

Now that I am confident that the VAR is stable and that it is well specified, I compute VAR estimates. As stated in the methodology, checking for the significance of single parameters is not practical and may lead to Type I Error as there are too many parameters. Therefore, the significance of this model is assessed with the F-test. The result of the F-test is that all the variables in the model have a significant joint effect on London residential house prices. Surprisingly, also for all the other equations, there is a significant joint effect of all the other variables and their lags.

Equation	Parms	RMSE	R-sq	chi2	P>chi2
policyrate_dif	85	0.13	0.61	397.04	0.0000
exc_ret	85	1.86	0.42	184.20	0.0000
equity_ret	85	3.94	0.35	134.47	0.0004
cpi_ret	85	0.22	0.74	729.74	0.0000
credit_ret	85	0.66	0.66	480.47	0.0000
london_ret	85	1.00	0.60	374.27	0.0000
unempl_dif	85	0.08	0.57	340.20	0.0000

Figure 16: *VAR's output summary. Number of parameters, Root mean squared deviation, R-squared, Chi2 statistics, and F-test p-*

From a first analysis, the model seems promising. The R-squared for London housing prices returns is 60 percent, meaning that this VAR explains more than half of the variation in London's house prices. Additionally, the R-squared for all the equations is rather high. This result is to be expected as the VAR models not only the structural relationships between the variables that I would consider in a regular cross-sectional setting, but also the autocorrelations of each variable with its past observations and the past observations of all the other variables included in the model.

To investigate the nature of the correlations of residential house prices and other variables, this research performs a Granger Causality test. In this sample, it appears that all variables significantly

Granger-cause residential house prices in London, except for unemployment rate. This evidence suggests that this model is particularly suitable for forecasting and it increases the chances to find a causal relationship between monetary policies and the real estate market in London. (Consult the appendix to see an in-sample forecast analysis of this model, Figure 17).

Equation	**Excluded**	**chi2**	**Df**	**P value**
london_ret	policyrate_dif	40.673	12	0.000
london_ret	exc_ret	39.602	12	0.000
london_ret	equity_ret	23.411	12	0.024
london_ret	cpi_ret	49.001	12	0.000
london_ret	mfi_ret	26.214	12	0.010
london_ret	unempl_dif	14.53	12	0.268
london_ret	**ALL**	**200.4**	**72**	**0.000**

Figure 18: *Granger Causality test of policy rate first difference, exchange rate returns, inflation returns, credit returns, and unemployment rate first difference on London house prices returns.*

At this stage I am confident of the existence of a correlation between house prices and monetary policies and that the direction of this correlation goes from the policy rate to London residential house prices. However, it is not possible to identify a causal relationship at this point because I did not isolate the effect of a monetary policy shock with the Granger Causality test. To investigate if monetary policies cause residential house prices appreciations or depreciations in London, I use the *impulse response analysis*. An accumulated *impulse response* is run over a time period of two years with the Cholesky decomposition to eliminate any contemporaneous relationship between the error terms in the VAR. The confidence interval of the innovations is determined by ±2 standard errors.

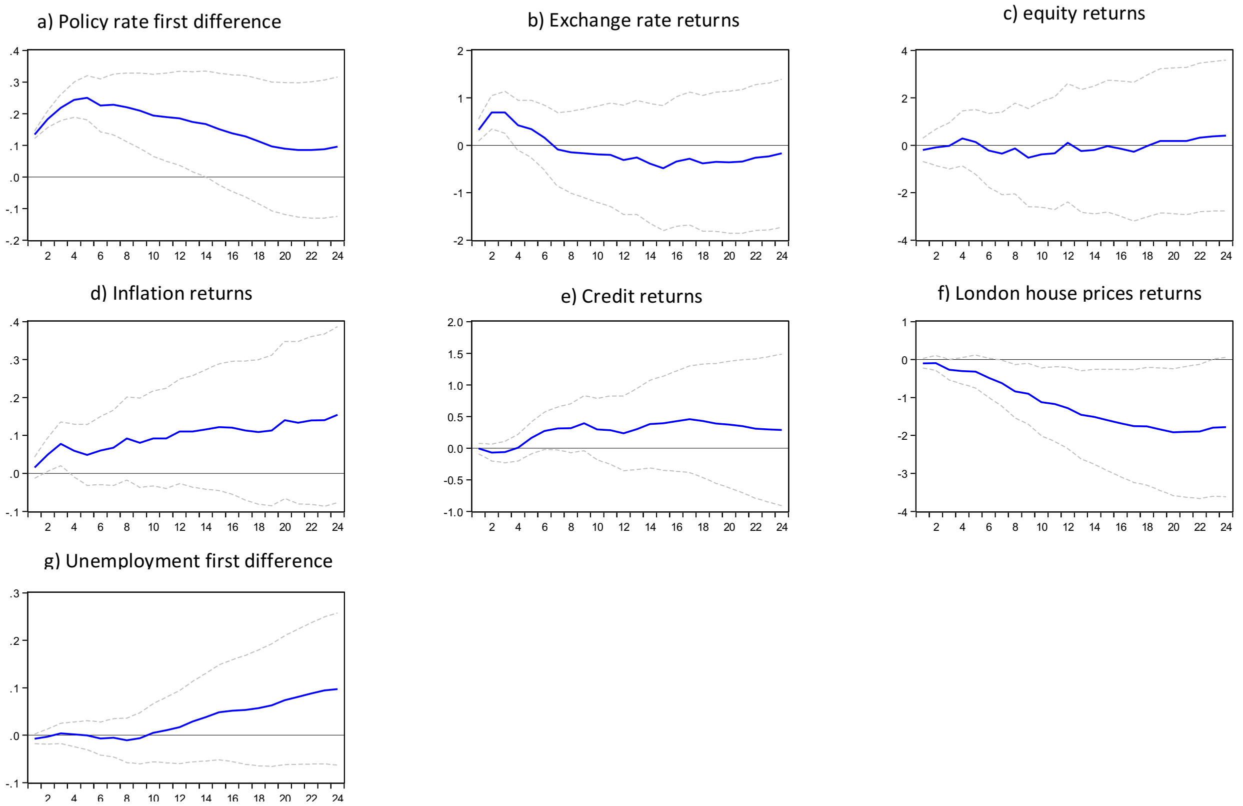


Figure 19: *Accumulated impulse response analysis with Cholesky decomposition. Impulse variable: policy rate first difference. Response variables: policy rate first difference, Exchange rate returns, Equity returns, Inflation returns, Credit returns, London house prices returns, Unemployment first difference*

As the impulse response analysis shows in quadrant (f), an increase in the Bank Rate is associated with a significant decrease in London's residential house prices over time. Therefore, under a great number of limitations and assumptions, I can infer the existence of a causal relationship between monetary policies and house prices in accordance with Iacoviello, 2005, Del Negro & Otrok, 2007, Vargas-Silva, 2008, and Eickmeier & Hofmann's 2013 findings. Furthermore, the monetary policy shock resulted in the following effects on the other variables in the VAR. First, an increase in the policy rate causes a temporary appreciation of the British pound, but I cannot reject the null hypothesis that the effect of the monetary policy shock is equal to zero after approximately 3 months (see quadrant b). Second, a monetary policy shock does not have a significant effect on equity valuations (see quadrant c). Third, a contractionary monetary policy causes a temporary significant increase in inflation in the economy (see quadrant d). This result is known as the *Prize Puzzle*. This empirical finding is described as a *puzzle* because we would expect a fall in price levels when the central bank raises interest rates. A similar result was found by Iacovello (2005) and Sims (1992). The *Price Puzzle* was overcome by Del Negro & Otrok (2007), Vargas-Silva (2008), and Eickmeier & Hofmann (2013) by identifying a contractionary monetary policy shock with an increase in the policy rate, a lower inflation, and lower economic activity. Fourth, contrary to what economic intuition would suggest, I cannot reject the null hypothesis that the policy rate does not have an effect on lending activity (see quadrant e). Finally, an increase in the policy rate does not significantly cause an increase in the unemployment rate (see quadrant f).

To further understand how monetary policies contributed to the property appreciation in London, I perform a variance decomposition analysis. This analysis illustrates what proportion of the total variation of a variable is explained by a monetary policy shock.

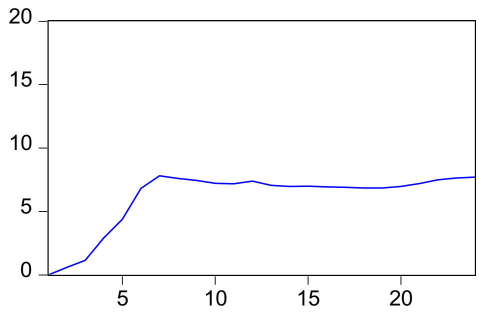


Figure 20. *Variance decomposition analysis with Cholesky decomposition. Impulse variable: policy rate. Reponse variables: policy rate first difference, Exchange rate returns, Equity returns, Inflation returns, Credit returns, London house prices returns, Unemployment first difference.*

From this sample, it results that a monetary policy shock explains up to 7.81 percent of the variance in house prices in London. To see a detailed table with the variance decomposition of all the variables due to a monetary policy shock consult the Appendix (figure 21). Additionally, after 24 months a monetary policy shock explains 56.2 percent of the variation in the policy rate, 6.7 percent of the variance in the exchange rate, 16.8 percent of the variation of equity valuations, 6.6 percent of the variance in inflation, 3.2 percent of the variation on households' lending, 7.7 percent of the variance of residential house prices, and 2.8 percent of the variance of the unemployment rate.

CONCLUSION

In this paper, I estimated the effect of monetary policies on London's residential property prices from 1996 to 2017. To perform this analysis a Vector Autoregressive Model (VAR) with Cholesky decomposition is employed similarly to Iacoviello (2005) who researched the same relationship on the United States from 1974 to 2003. This research contributes to the existing literature as it studies the behavior of property prices of a metropolis and investigates the monetary policies' contribution to the recent property price appreciation in London. From this analysis, it resulted that a monetary policy shock has a persistent and significant effect on residential property prices in London. This finding is in accordance with Iacoviello (2005) Del Negro and Otrok (2007) Vargas-Silva (2008), Eickmeier & Hofmann's (2013) findings. Secondly, it appears that residential property prices in London do not change immediately because of a monetary policy shock, but they respond with a delay of approximately seven months. Thirdly, the effect of a contractionary monetary policy on property prices prolongs for approximately two years since the date of the shock. Fourthly, an increase in the Bank Rate explains up to 7.81 percent of the variation in property prices after approximately six months and 7.7 percent in 24 months from the shock. Similarly, Del Negro and Otrok (2007) discovered that monetary policy shocks explain 13 percent of the variation in house prices in the United States with a decline to 8 percent in the long-term using the sign restriction approach.

As the Cholesky decomposition is used to render the residuals contemporaneously uncorrelated for the *impulse response* and *variance decomposition* analyses, the effect of a monetary policy shock on London's house prices were isolated in this research. Thus, this paper is able to infer the existence of a causal relationship between monetary policies and residential house prices in London. In the light of this analysis' result, there is enough evidence to claim that the BoE's monetary policies have significantly contributed to the London's residential properties appreciation from 1996 to 2017. In this research, I interpret causation as a tendency, *id est* as an effect that holds *certeris paribus*. This interpretation of causation was introduced by the philosopher John Stuart Mill (1843) in his masterpiece *System of Logic*.

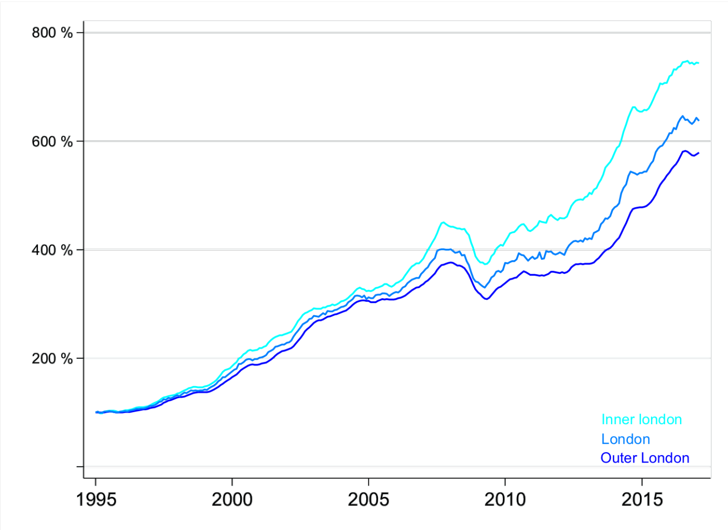
This conclusion is sensible to several limitations. First, I may have omitted variables that are both correlated with the Bank Rate and the residential property prices in London. The omission of one of these variables would lead to the estimation of an inconsistent coefficient. This means that I might have wrongly concluded the existence of a significant effect of monetary policies on the property prices, while in reality it is not present or it is described by a completely different coefficient. The impulse response analysis suggests that this research may have omitted a relevant variable as it documents a *Price Puzzle*. Second, the proxies that I used for the monetary policies, credit, and economic activity can largely be improved as explained in the Data section of this paper. Third, I know for a fact that my model does not respect all the OLS assumption for the estimator to be BLUE, as the Jarque-Bera residual normality test rejects the null hypothesis that the residuals are jointly normally distributed in the VAR. However, after a careful evaluation of the distribution of the residuals (Figure 11 and Figure 12), I conclude that normality was rejected because of outliers in the Bank Rate, Effective Exchange Rate, and total amount of individuals' lending. These outliers could not be omitted as they occurred during the 2000 and 2007 financial crisis, and Brexit in 2016. The consequence of this misspecification is that the coefficients are inefficient and, therefore, they have larger standard errors. This may lead to a Type II Error, *id est* not rejecting the null hypothesis that a coefficient is equal to zero when in reality it is different from zero. Nevertheless, it is important to remind the reader that despite this misspecification, the coefficients are unbiased and consistent. Fourth, the VAR introduces several disadvantages that I did not discuss in the methodology. VARs are atheoretical, thus there is no theoretical explanation of the relationship of the variables that leads to a definition of a certain lag length. In addition, in this VAR analysis, there are 438 parameters. This large number of coefficients increases the probability of Type I Error and decreases the degrees of freedom in the model. The latter may cause larger standard errors thereby increasing the probability of Type II Error. Finally, the variables analyzed may have lost information on their long-run relationship because of the transformations applied to them. In fact, taking the first difference or computing the returns on variables that are used for a VAR analysis eliminates long-run relationships between variables. Nonetheless, I performed these transformations as the variables need to be stationary for this research to be able to use hypothesis tests on these results.

A suggestion to future researchers is to use a sign restriction and better proxies to estimate the effect of a monetary policy shock on London's residential house prices. This methodology may solve the *Price Puzzle* and increase the accuracy of the estimation of the coefficients. In addition, future research may be addressed to identify whether there is a break in the 2007 financial crisis, as this would provide policy markers with more precise information on the outcome of their policies. Moreover, to gain a more comprehensive understanding of London's housing prices, it would be useful to perform a similar analysis on London's corporate properties and compare the results found for residential house prices. Finally, it would be insightful to compare the effects of a monetary policy shock on house prices in the United Kingdom (excluding London) and London. This would provide a better understanding of the behavior of housing prices in metropolis compared to the rest of the country.

APPENDIX

COST AND BENEFIT ANALYSIS: A PORTFOLIO MANAGEMENT PERSPECTIVE

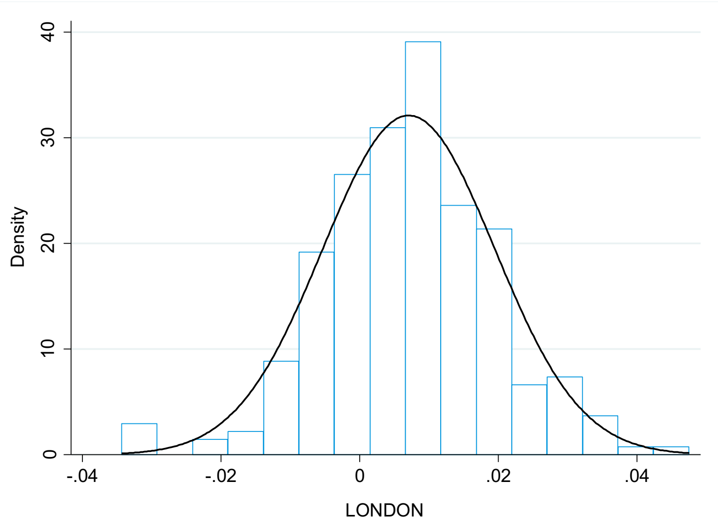
Figure 1. Cumulative Returns Inner London, London, Outer London from February 1995 to February 2017.



If one had purchased a house in London in February 1995 today on average he would have made 640 percent, 540 percent, and 480 percent only of capital returns in Inner London, London, and Outer London respectively. However, this simple figure is not sufficient for institutional investors to allocate their capital in this market. To understand the true nature of London's real estate as a financial product, one must analyze this asset from a portfolio management perspective.

To perform this task, I am interested in the distribution of the monthly returns of London real estate and its relation to a typical portfolio of a British investor. I estimate housing returns based on historical price changes in London's house prices. As a proxy of the returns of a typical UK portfolio, I use the FTSE 100 (UKX Index) capital returns. This methodology does not take into account returns derived from rents and dividends, but only capital gains, introducing a great limitation to this analysis. For both time series, I use observations from February 1995 to February 2017.

Figure 2. Return distribution of real estate in London excluding rents



	Mean Return (μ)	Std. dev. (σ)	Skewness	Kurtosis	Correlation	Beta
London Housing Market	0.70%	1.24%	-0.62	3.84	0.05	1.66
FTSE 100	0.40%	3.90%	-0.15	3.69	1	1

As the analysis above displays, in this sample, London housing market yielded a monthly average return of 0.7 percent (8.7 percent annualized) while the FTSE 100 offered a return of 0.4 percent (4.9 percent annualized). In addition, housing prices in London are much less volatile when compared to a typical UK long equity portfolio. From a two moment analysis the real estate market results to be more profitable and less risky when compared to UK equity. However, when one looks at the skewness and kurtosis of the distribution of these two assets, London housing market appears to be exposed to more frequent and larger outliers compared to equity. Skewness is a statistical measure of the asymmetry of a distribution from the normal distribution. A negative skewness suggests that there are larger negative outliers than positive outliers. Kurtosis is a measure of the tails of a distribution. The larger the kurtosis of a distribution the higher the frequency of outliers in a specific distribution. Thus, a negative skewness and large kurtosis seem to confirm the theoretical intuition that real estate is a cyclical market.

Another important measure that a portfolio manager considers before integrating an asset in her portfolio is the correlation of this asset with her portfolio. The lower the correlation of a specific asset with the portfolio of the fund, the higher the expected returns that can be achieved given a certain level of risk, measured by the standard deviation (Markowitz, 1991). Therefore, this particularly low correlation makes of housing a powerful tool to boost returns and reduce volatility in a long equity portfolio.

In conclusion, in this paper's view, London's housing market is a good investment that can highly benefit a portfolio from a risk-return perspective. However, this market is also highly cyclicality and exposed to great asset depreciations.

ANALYSIS OF LONDON PROPERTY PRICES AND CREDIT CONDITION

Figure 3. Effective Mortgage Interest rate, Base rate, Effective Floating rate, Effective Fixed rate. January 2004 - January 2015

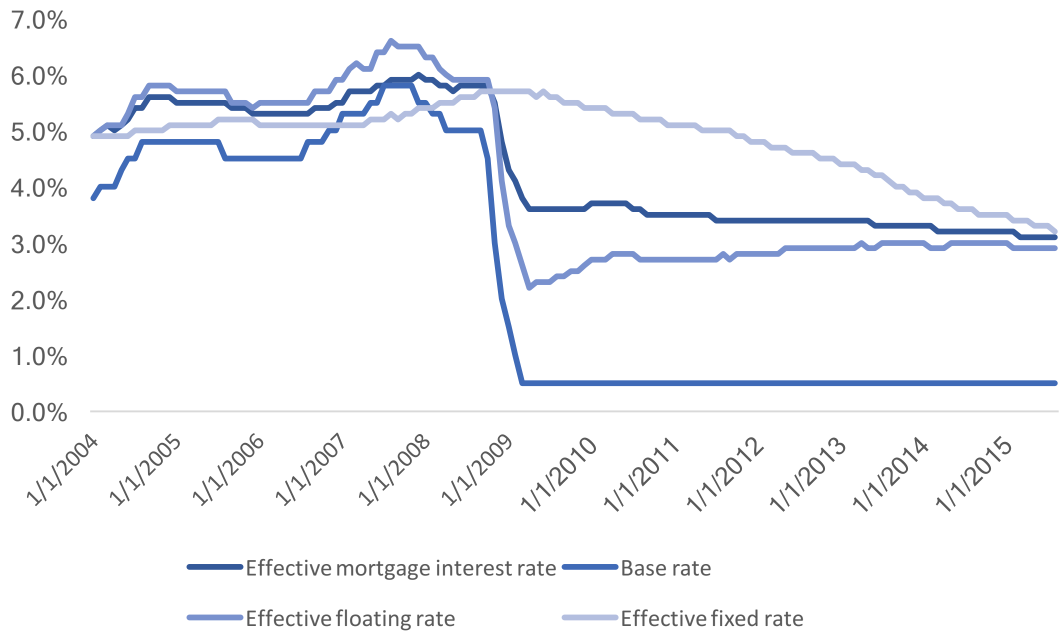
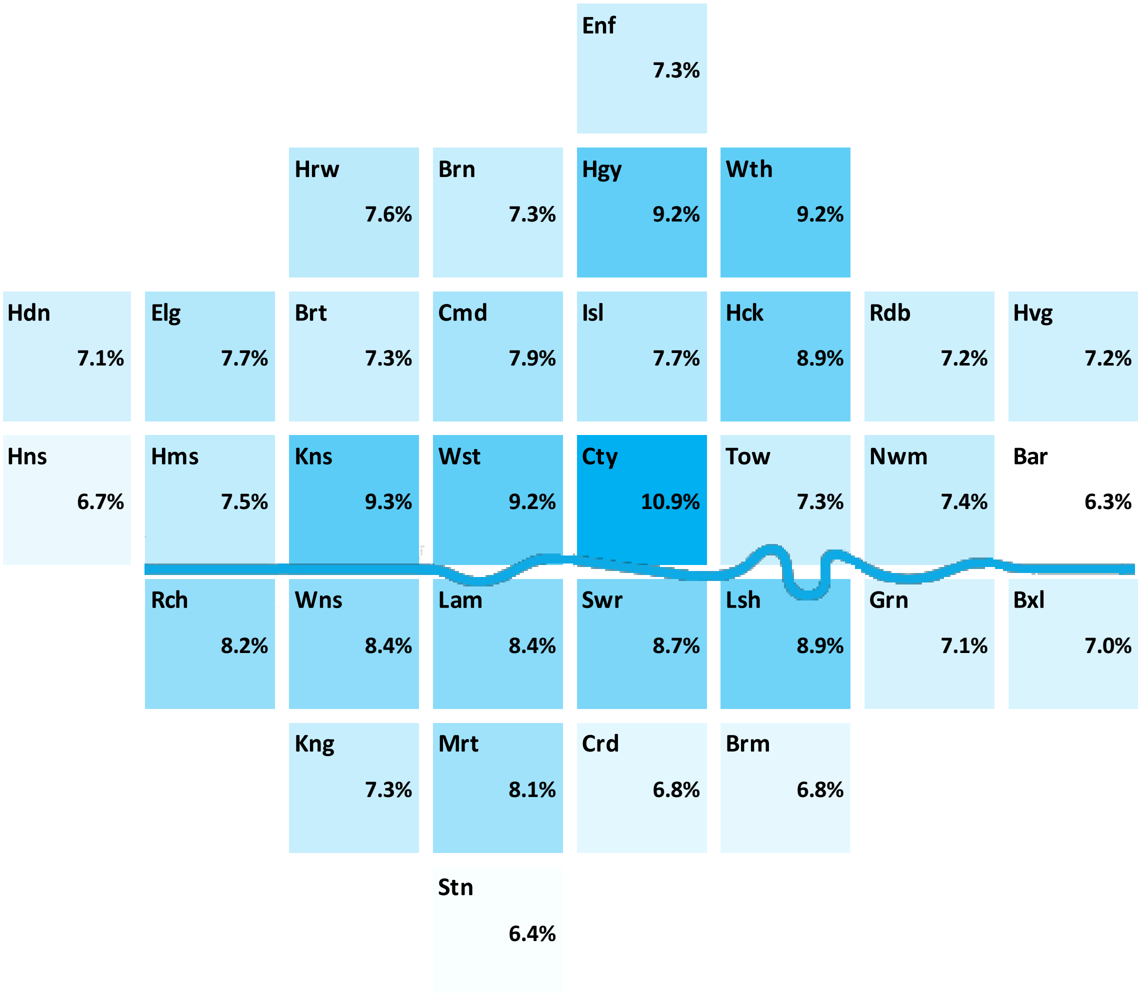
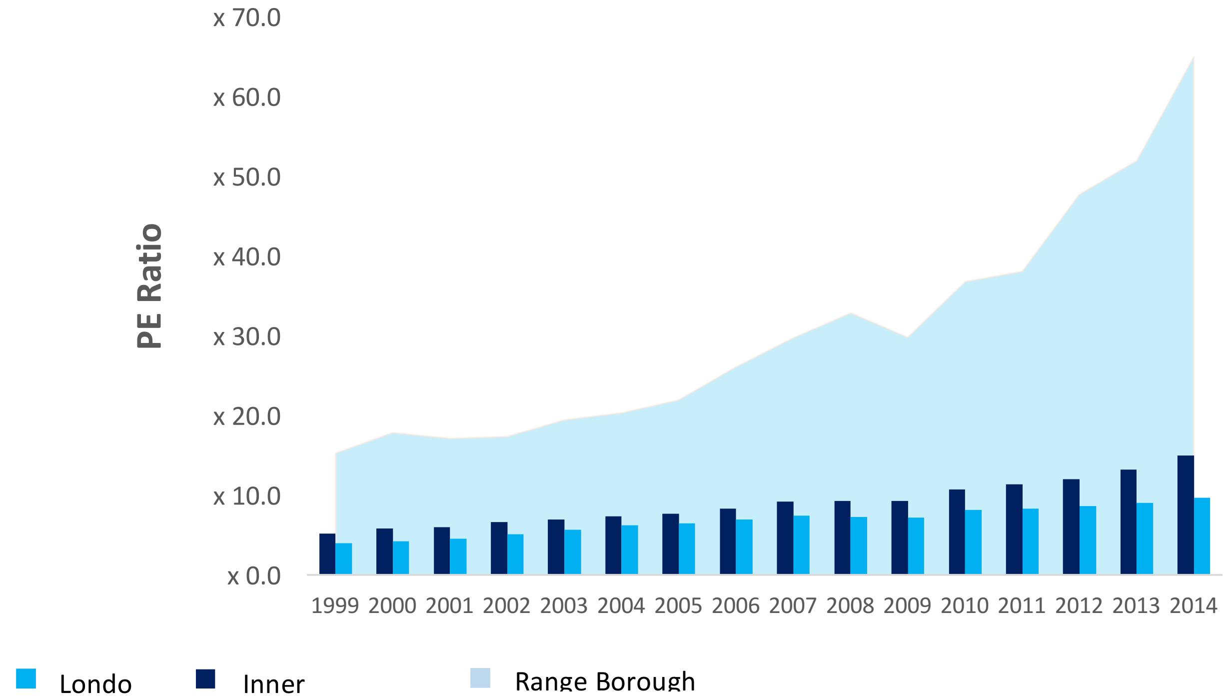


Figure 4. House Price Growth rates Jan 2009 Feb 2017



Annualized House Price growth rates from Jan 2009 to Feb 2017. To compute rates for each borough in London, I used monthly mean house prices from the Land Registry Database. The mean house price was preferred to the median as this database already exclude outliers: transactions below £1,000 and above £20 million. The template used was provided by the London Data Store https://data.london.gov.uk/dataset/excel-mapping-template-for-london-boroughs-and-wards.

Figure 5. House Price to Earnings ratio of London, England, and boroughs of London

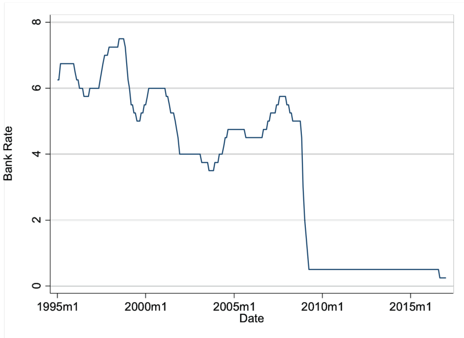


	2008	2009	2010	2011	2012	2013	2014
London	x 9.3	x 9.2	x 10.7	x 11.3	x 12.0	x 13.2	x 15.0
England	x 7.2	x 7.1	x 8.1	x 8.3	x 8.6	x 9.0	x 9.6
Range Borough	x 32.8	x 29.7	x 36.7	x 38.0	x 47.6	x 51.9	x 64.8

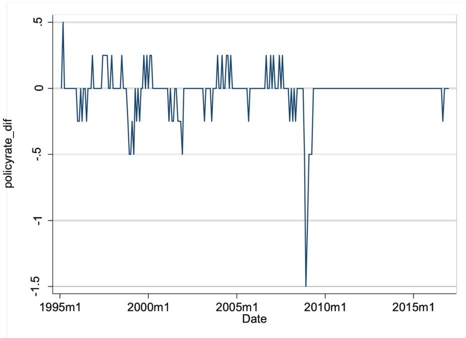
The price to earnings ratio for housing gives a perspective of the valuation of housing relatively to the earnings of its area. I use mean house prices from the Land Registry database. I use the work-based-on-location median gross earnings from the Office for National Statistics (ONS) to estimate earnings for London, England, and each borough. The earnings to price ratio that leads to such a high range for the boroughs of London is Chelsea. The second highest price to earnings ratio in 2014 is 39.1 in Westminster.

Operationalization and Specification of the VAR Model

Figure 6. Stationarity

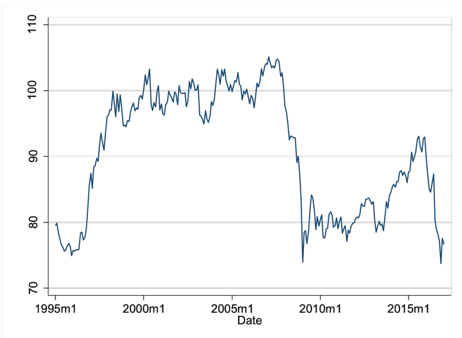


Bank Rate

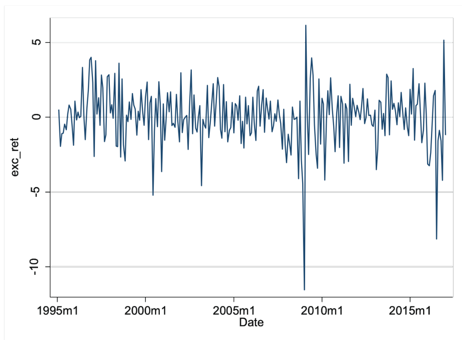


First Difference Bank Rate

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-8.655	-3.459	-2.879	-2.570

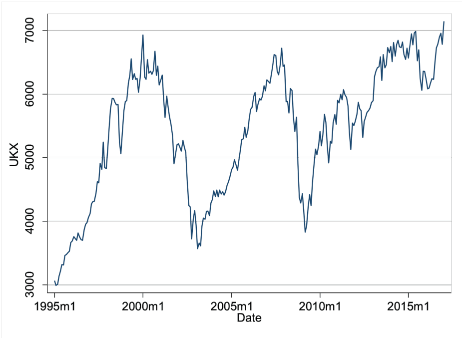


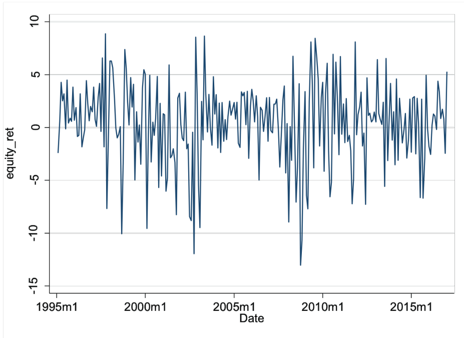
Effective Exchange Rate



Effective Exchange Rate Returns

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-16.997	-3.459	-2.879	-2.570

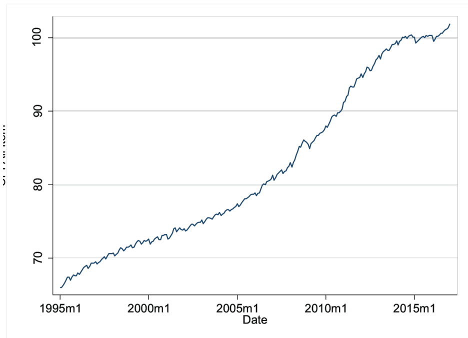


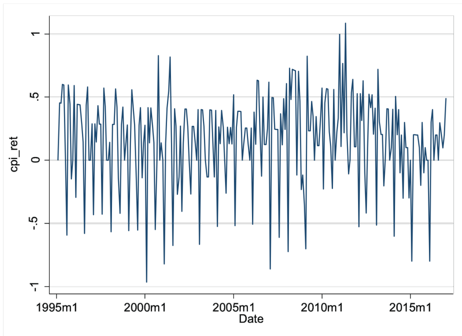


Equity Price

Equity Price returns

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-16.114	-3.459	-2.879	-2.570

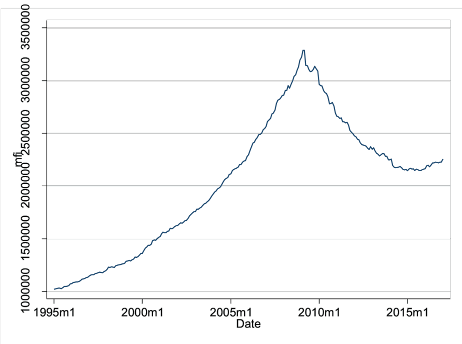




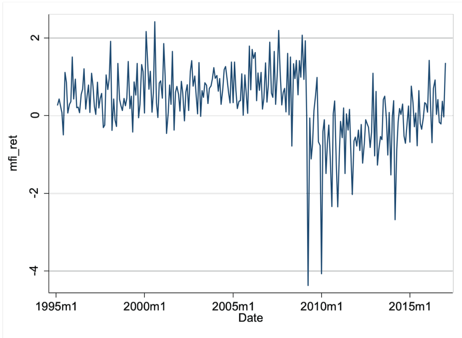
CPI All-Item Index

CPI All-items Index returns

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-17.485	-3.459	-2.879	-2.570

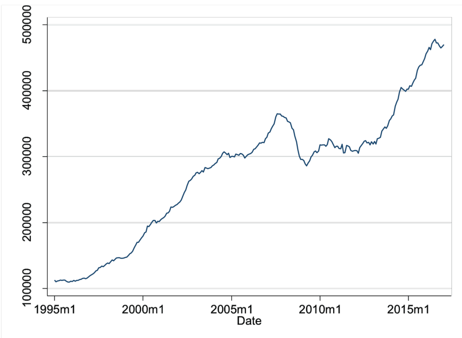


Household Credit

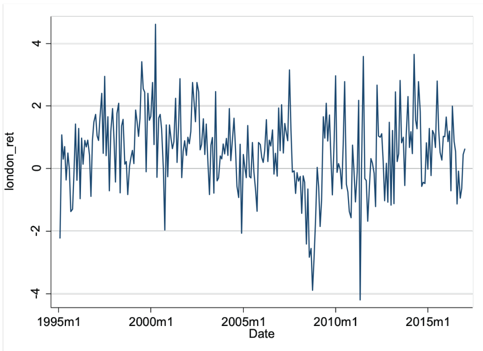


Household Credit returns

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-11.244	-3.459	-2.879	-2.570

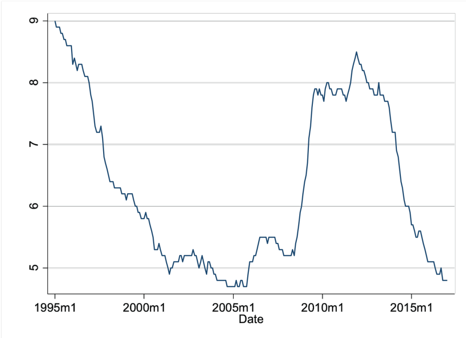


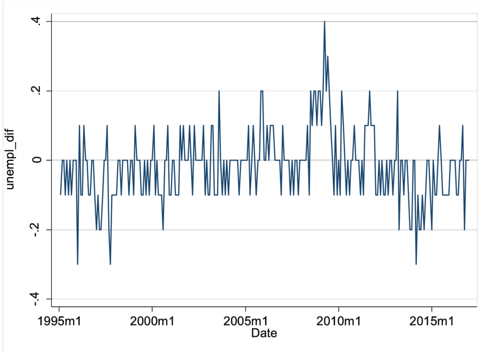
London Residential Property prices



London Residential Property prices returns

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-12.615	-3.459	-2.879	-2.570





Unemployment Rate

Unemployment Rate first difference

Augment Dickey Fuller Test Statistic	1 % critical value	5% critical value	10% critical value
-11.183	-3.459	-2.879	-2.570

Figure 7. Correlation matrix non-transformed variables

	policyrate	exchange rate	equity	cpi	credit	london	unemployment
policyrate	1.00						
exchange rate	0.51	1.00					
equity	-0.36	0.16	1.00				
cpi	-0.91	-0.41	0.59	1.00			
credit	-0.65	-0.14	0.32	0.67	1.00		
london	-0.76	-0.05	0.55	0.87	0.75	1.00	
unemployment	-0.19	-0.79	-0.29	0.07	-0.06	-0.35	1.00

Correlation matrix of the policy rate, exchange rate, FTSE 100 historical prices, All-item CPI, credit, London house prices and unemployment rate. The variables were not transformed from nominal to real and were not rendered stationary.

Figure 8. Correlation matrix of the residuals

	policyrate	exchange rate	equity	cpi	credit	london	unemployment
policyrate	1.00	0.17	-0.05	0.07	-0.01	-0.10	-0.10
exchange rate	0.17	1.00	-0.27	0.00	0.03	0.22	-0.06
equity	-0.05	-0.27	1.00	0.00	-0.04	-0.06	-0.10
cpi	0.07	0.00	0.00	1.00	-0.27	-0.39	0.08
credit	-0.01	0.03	-0.04	-0.27	1.00	0.16	-0.02
london	-0.10	0.22	-0.06	-0.39	0.16	1.00	-0.09
unemployment	-0.10	-0.06	-0.10	0.08	-0.02	-0.09	1.00

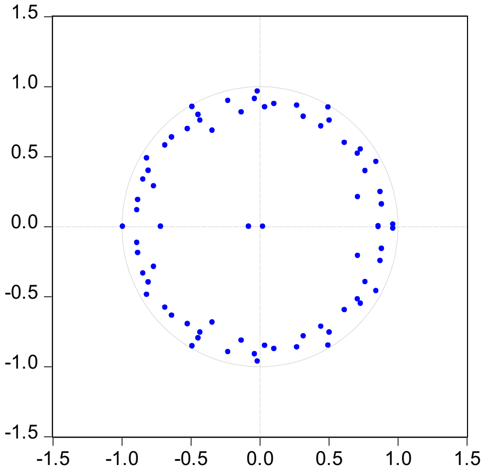
Correlation matrix of the residuals of the first policy rate first difference, Exchange rate returns, Equity Returns, Inflation returns, Credit returns, London house prices returns, Unemployment first difference.

Figure 9. Information criteria tests

Lag	Final Prediction Error	Akaike information criterion	Schwarz information criterion	Hannan-Quinn information criterion
0	2.0	17.7	17.8	17.8
1	0.9	17.0	17.6*	17.2*
2	0.8	16.8	17.9	17.3
3	0.8	16.8	18.5	17.5
4	0.9	16.9	19.0	17.7
5	0.7	16.7	19.3	17.7
6	0.6	16.5	19.7	17.8
7	0.6	16.4	20.1	17.9
8	0.6	16.6	20.7	18.2
9	0.7	16.6	21.3	18.5
10	0.7	16.7	21.9	18.7
11	0.8	16.7	22.4	19.0
12	0.6*	16.3*	22.6	18.8
13	0.6	16.4	23.1	19.1
14	0.7	16.5	23.7	19.4
15	0.8	16.5	24.3	19.6
16	0.8	16.6	24.8	19.9

The lag choice that minimized the Multivariate Akaike Information Criterion is the lag number 12.

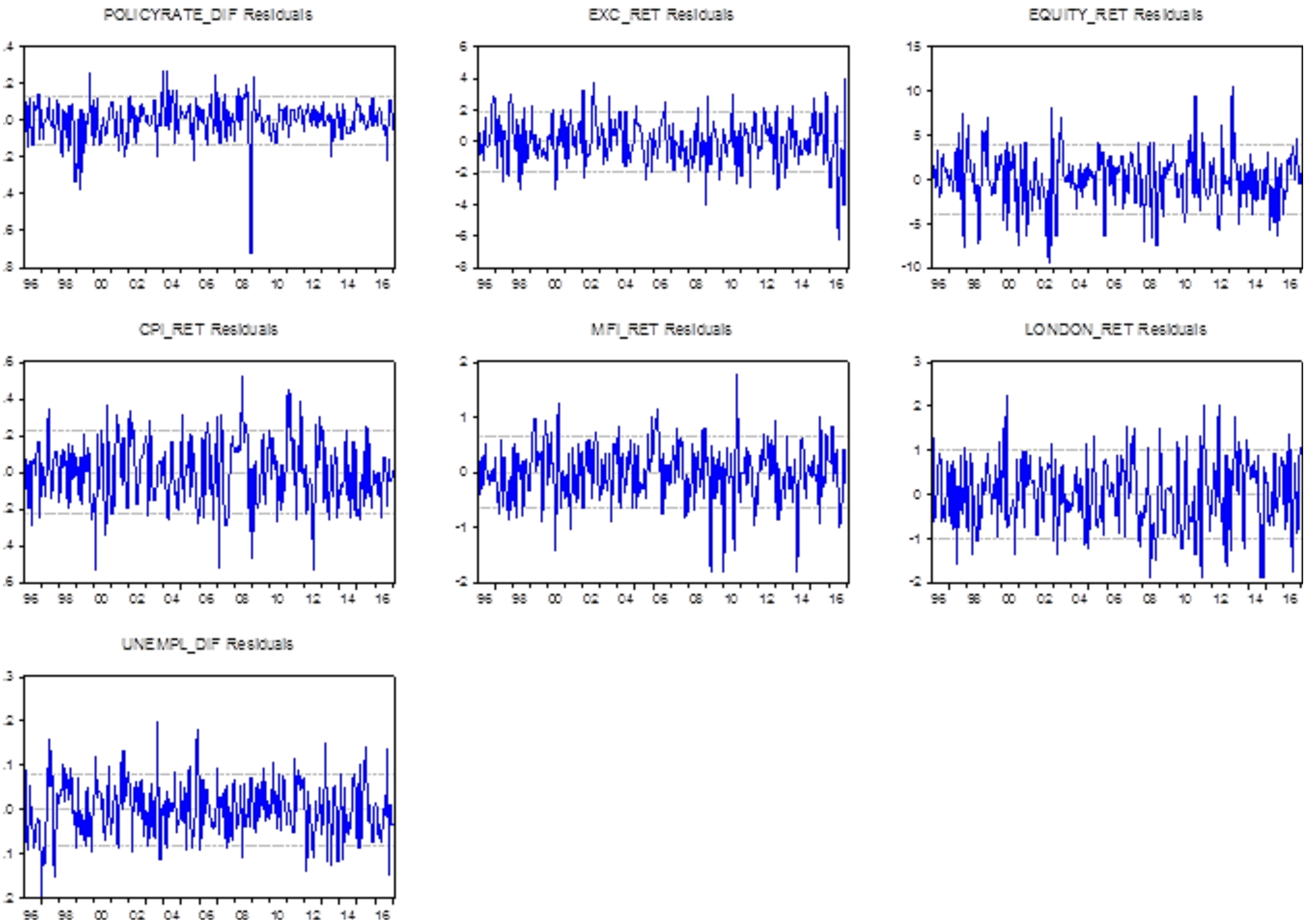
Figure 10. Inverse Roots of AR Characteristic Polynomial



All the roots lie inside the circle and therefore are smaller than 1. It might appear that two roots lie exactly on the circle, but once an inverse Roots of AR Characteristic Polynomial Table was performed I could confirm that the largest root is 0.98835. Therefore, the VAR is stable.

ANALYSIS OF THE ASSUMPTIONS

Figure 11. Plot residuals over time



The residuals of all the variables are plotted for the time period analyzed. All the series seem to not be serially correlated. However, there are several inconsistencies. First, during the financial crisis in 1999 and 2009, the policy rate exhibits outliers and perhaps autocorrelation. Second, the exchange rate in mid-2016 exhibits outliers and maybe autocorrelation. The outliers are explained by the massive depreciation of the British pound occurred in the months before and after the referendum to leave the European Union. Fourth, Inflation seems to exhibit autocorrelation from 2007 to 2009, and during financial and credit crises it exhibits outliers. Fifth, Total Individual Lending shows outliers during the financial crisis of 2008. Sixth, London's house prices seem to exhibit non-constant variance of the error terms, suggesting that the error terms might be heteroscedastic.

Figure 12. LM test for autocorrelation

Lags	LM-Stat	Prob
1	56.39322	0.218
2	58.26759	0.1712
3	49.28971	0.4615
4	49.97936	0.4342
5	61.52292	0.108
6	53.62552	0.3015
7	59.4277	0.1462
8	59.84219	0.1379
9	67.42502	0.0414
10	58.89973	0.1572
11	56.84785	0.206
12	58.34252	0.1695
13	66.29491	0.0504
14	45.57786	0.6127
15	35.74632	0.9213
16	71.88225	0.0183

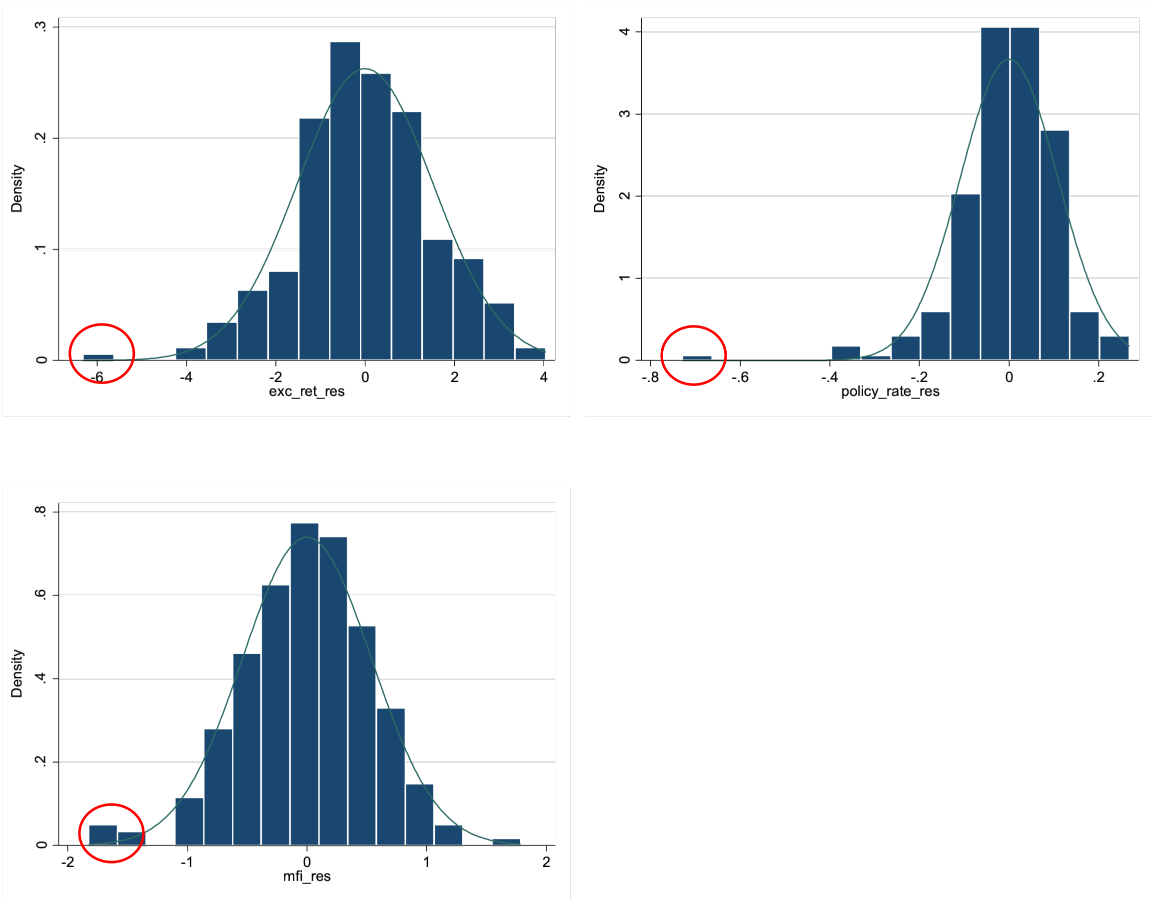
The LM test for autocorrelation was performed to test whether the residuals in this model are autocorrelated. For all the 12 lags included I cannot reject the null that the residuals are not autocorrelated with a 5 percent confidence level.

Figure 13. Jarque-Bera test for normality

Component	Jarque-Bera	df	Prob.
policyrate_dif	764.6293	2	0.000
exc_ret	10.43504	2	0.005
equity_ret	4.398807	2	0.111
cpi_ret	0.622666	2	0.733
credit_ret	21.71979	2	0.000
london_ret	1.870818	2	0.392
unempl_dif	1.342534	2	0.511
Joint	**805.019**	**14**	**0.000**

The Jarque-Bera test was used to assess whether the residuals of the variables are normally distributed. It results that I reject the null of normally distributed errors for policy rate, exchange rate, credit, and of the overall VAR.

Figure 14 Histogram residuals of non-normal residuals variables



A graphical analysis of the distributions of the non-normal variables suggests that there are large outliers influencing the distribution of the residuals. These outliers (circled in red) are negative and are probably caused by financial crises for the policy rate, credit crises for credit, and Brexit for the exchange rate.

Figure 15.

VAR Residual Heteroscedasticity Tests

Joint test:

Chi-sq	df	Prob.
4860.051	4704	0.055

Individual components:

Dependent	R-squared	F(168,83)	Prob.	Chi-sq(168)	Prob.
res1*res1	0.7865	1.81958	0.0013	198.1885	0.0555
res2*res2	0.6281	0.8344	0.8372	158.2816	0.6929
res3*res3	0.678	1.0402	0.4265	170.8529	0.4242
res4*res4	0.6776	1.03827	0.4303	170.7504	0.4264
res5*res5	0.8022	2.00306	0.0003	202.1422	0.0371
res6*res6	0.7255	1.30548	0.0872	182.8153	0.2056
res7*res7	0.7039	1.17429	0.2074	177.3747	0.2951
res2*res1	0.6163	0.79354	0.8948	155.3072	0.7499
res3*res1	0.7018	1.1625	0.2226	176.8438	0.3049
res3*res2	0.5974	0.73323	0.9535	150.5561	0.829
res4*res1	0.6758	1.02988	0.447	170.3034	0.4359
res4*res2	0.6903	1.1013	0.3145	173.9605	0.3603
res4*res3	0.7132	1.2283	0.1476	179.7149	0.2543
res5*res1	0.7019	1.16343	0.2214	176.8859	0.3041
res5*res2	0.7053	1.18214	0.1977	177.7244	0.2888
res5*res3	0.7052	1.18162	0.1983	177.7012	0.2892
res5*res4	0.6612	0.96434	0.5843	166.6319	0.5153
res6*res1	0.6562	0.94289	0.63	165.3573	0.5432
res6*res2	0.6466	0.90378	0.7111	162.9332	0.5959
res6*res3	0.6701	1.00335	0.5015	168.8556	0.4669
res6*res4	0.6889	1.09422	0.3265	173.6125	0.3673
res6*res5	0.7039	1.17427	0.2074	177.3741	0.2952
res7*res1	0.7205	1.27341	0.1091	181.5599	0.2246
res7*res2	0.7372	1.38618	0.0483	185.7846	0.165
res7*res3	0.6795	1.0476	0.412	171.2423	0.416
res7*res4	0.6739	1.02112	0.4648	169.831	0.446
res7*res5	0.7375	1.38772	0.0477	185.8387	0.1643
res7*res6	0.662	0.96766	0.5772	166.8255	0.5111

The VAR Residual Heteroscedasticity test is used to assess whether the residuals are constant or they vary over time. I can reject the null that they are heteroscedastic only for 0.05 percent confidence level. As this paper is based on a 5 percent confidence level I am not going to argue with this small margin. However, future researchers should account for the possibility of dealing with heteroscedastic errors when working on a different sample period or with different variables.

DYNAMIC AND STATIC FORECAST OF RESIDENTIAL PROPERTY PRICES

Figure 17. Forecast London house prices

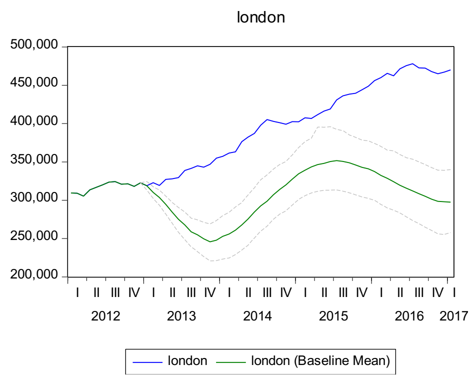


Figure (a): dynamic forecast
2 standard deviations confidence bands

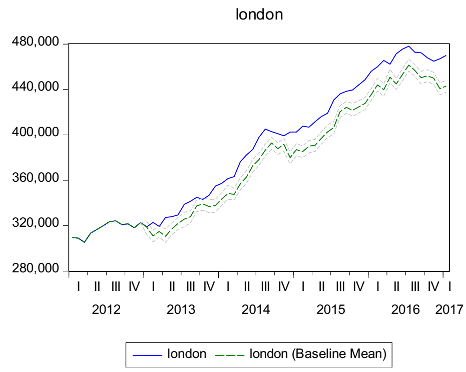


Figure (b): static forecast
2 standard deviations confidence bands

The two figures above show how well this model is able to forecast London average residential house price over four years. I performed an in-sample dynamic forecast and static forecast. In both figures the blue line is the actual value and the green line is the forecasted value.

Figure (a) forecasts the house prices in London starting from January 2013 up to January 2017. To predict the following lag it uses the predicted previous lag. Figure (b) forecasts the house prices in London starting from January 2013 up to January 2017. However, it is said to be static because it uses actual values when forecasting the next period's observation. Clearly, the VAR performs better in short-term forecasts rather than long-term forecast.

Variance Decomposition

Figure 21. VAR Variance Decomposition with Cholesky decomposition

Period	POLICYRATE_DIF	EXC_RET	EQUITY_RET	CPI_RET	MFI_RET	LONDON_RET	UNEMPL_DIF
1	100.00	0.00	0.00	0.00	0.00	0.00	0.00
2	91.63	0.00	5.34	0.11	0.07	0.59	2.26
3	86.68	0.04	9.89	0.10	0.10	1.14	2.05
4	82.63	0.42	11.83	0.17	0.13	2.92	1.91
5	78.89	0.52	12.49	0.82	1.03	4.39	1.87
6	71.46	0.49	16.28	2.19	0.99	6.82	1.77
7	67.77	0.47	16.32	3.37	2.08	7.81	2.18
8	65.85	1.42	15.93	4.82	2.02	7.61	2.35
9	63.82	2.66	15.39	6.34	2.00	7.45	2.33
10	62.07	4.11	15.21	6.60	2.35	7.22	2.43
11	61.16	4.34	15.65	6.83	2.41	7.18	2.43
12	60.32	4.83	15.90	6.77	2.38	7.39	2.40
13	57.93	5.93	17.14	6.90	2.51	7.06	2.55
14	57.31	6.36	17.46	6.82	2.56	6.97	2.51
15	57.23	6.53	17.47	6.74	2.56	6.99	2.49
16	57.16	6.70	17.34	6.68	2.71	6.93	2.48
17	57.06	6.66	17.28	6.65	2.86	6.90	2.60
18	57.10	6.60	17.12	6.59	3.00	6.85	2.74
19	57.11	6.69	16.94	6.54	3.08	6.85	2.79
20	56.88	6.66	17.02	6.51	3.16	6.97	2.80
21	56.76	6.64	16.97	6.49	3.15	7.19	2.79
22	56.51	6.62	16.91	6.50	3.17	7.50	2.79
23	56.34	6.62	16.86	6.56	3.16	7.63	2.81
24	56.24	6.65	16.80	6.63	3.15	7.72	2.81

Impulse variable: Bank Rate first difference. Response variables: exchange rate, equity returns, inflation returns, credit returns, London returns, unemployment first difference.

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