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Monetary Policy Responses to the 2008 Financial Crisis: Quantitative Easing Evidence in the United Kingdom

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This paper analyzes responses to monetary policy tools during the United Kingdom's Quantitative Easing regime from March 06, 2009 to June 02, 2010 on a set of target variables: market index, foreign exchange index, investment grade and non-investment grade bond yield, and spots and forwards of different maturities for OIS, LIBOR and Nominal Government Yield. Results suggest that conventional monetary policy tools other than a zero-bound official bank rate may still be effective. Inclusion of one unconventional tool, the increase in government gilt holdings, has significant impact on most of the target variables.

JEL Key words: General Financial Markets, Financial Institutions and Services, Bond Interest Rates

JEL codes: G100, G280, G120

1. Introduction

Quantitative Easing refers to an expansionary monetary policy regime where a monetary authority is actively involved in large-scale asset purchase programs in order to inject additional liquidity into the economy as the official bank rate becomes an insignificant monetary tool because it has been reduced to a threshold level at or close to zero. During such policy regimes, asset purchase programs may engage a wide variety of financial assets from government short term treasuries and short term commercial paper and CDs to long term corporate bonds and government treasury notes and bonds.

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Recently, Japan was one of the developed economies that pursued a similar policy as the overnight lending rate reached the effective lowest bound of zero rates in February 1999. In March 2001, the Bank of Japan decided to supplement the zero-rate policy with a Quantitative Easing policy to provide further stimulus to the economy as price levels kept falling. The recent global financial crisis following the Lehman Brothers collapse in September 2008 forced monetary authorities in most countries around the world to initiate active monetary responses to stabilize the financial markets and support aggregate demand (Klyuev et al, 2009).

In this paper, we discuss Quantitative Easing (QE) monetary policy responses in the United Kingdom during the period of August 01, 2008 to June 02, 2010. We analyze how the conventional monetary policy tools—narrow money, broad money, and official bank rates—may impact financial markets and term structure during three sample periods; a) Overall Sample Period from 08/01/2008 to 06/02/2010, b) Pre-Quantitative Easing Period from 08/01/2008 to 03/05/2009, and c) Quantitative Easing Period from 03/06/2009 to 06/02/2010. Later we focus on analyzing the impact of non-conventional monetary policy tools—increasing the Central Bank asset-base through Gilt purchase and corporate bond sales and purchases—on increasing inflation expectations during the QE period.

We contribute to existing literature on monetary policy transmission in three different ways. First, we provide empirical evidence on monetary policy by using the United Kingdom dataset compared to the Japanese zero-bound interest rate literature. Second, we differentiate between monetary policy regimes for the pre-quantitative easing period and the quantitative easing period by dividing the sample period. Third, we include a large cross-section of different maturities of interest rates to analyze whether a long-run equilibrium or steady state exists between monetary policy tools and target variables. We follow the approach of Pedroni (2004) who presents a thorough discussion of issues in dealing with short time series variables and illustrates that, in the absence of any alternative to extend the time series, allowing more cross-sectional data may solve the short time span problem of structural co-integration tests.

1.1 Literature Review

Although the Japanese experience of Quantitative Easing is most frequently cited in the literature, evidence of Quantitative Easing can be traced back as early as 1932 in the U.S. when the U.S. Federal Reserve initiated a $1 billion purchase of government treasuries and maintained it until 1936 to mitigate deflationary trends during the Great Depression. However, the monetary impact of Quantitative Easing regimes is still a debated issue.

Recent studies in the Quantitative Easing literature focus on the Japanese experience beginning in February 1999 as the official bank rate effectively reached the zero-bound threshold. To provide further stimulus to the economy and avoid a deflationary trend, the Bank of Japan undertook Quantitative Easing as a supplement to its zero-rate policy in March 2001. Shirakawa (2002) discusses the Japanese experience of Quantitative Easing and delineates possible transmission channels of monetary policy during a zero-bound interest regime. He notes the similarity of the Japanese experience to the experiences of Sweden and the U.S. in the early 1930s. More recently, Shiratsuka (2010) compares the Quantitative Easing policy of the Bank of Japan during 2001 to 2006 to the U.S. Federal Reserve's policy. The U.S. Federal Reserve policy reactions aim at the asset side of its balance sheet whereas the Bank of Japan focuses on a target for the current account balances on the liability side.

Gauti and Woodford (2004) analyze the possible impact of Quantitative Easing as a supplement to a zero interest rate regime in a Neo- Keynesian framework. They argue that QE may fail to inject the desired level of stimulus to an economy if central bank policy cannot change expectations about future policy. That is, to ensure the desired effect, the central bank needs to make an explicit commitment about the future policy and such commitment needs to be credible. However, their interpretation is different from Auerbach and Obstfeld (2003) although both models are based on a similar framework. Unlike Gauti and Woodford (2004), Auerbach and Obstfeld (2003) assume that open-market operations may permanently increase the monetary base.

Later, Bernanke (2004) draws from the Japanese experience and discusses three monetary policy alternatives during a zero-interest regime that can provide additional stimulus to an economy. First, the central bank can

provide assurances that short-term rates will be kept lower in the future, to influence investor expectations. Second, a monetary authority may change relative supply through open market operations. Third, by increasing its balance sheet (QE), the central bank may keep the short-term rates at the zero-bound. Bernanke (2004) concludes that credibility of monetary policy will be pivotal in such policy regimes.

More recently, Klyuev et al (2009) elaborate on four possible alternative monetary actions central banks may take during a zero rate period, namely a) making an explicit commitment to maintain low policy rates, b) providing additional liquidity to financial institutions, c) affecting the long-term interest rates by purchasing government securities (QE), and d) actively intervening in specific credit markets. However, the impact of central bank actions may not be obvious because monetary transmission to the economy is complex. Later, Joyce et al. (2010) perform one of the few studies to analyze a Quantitative Easing experience other than Japan's. They analyze the impact of gilt purchases by the Bank of England on long-term interest rates by using multivariate GARCH model.

More recently, Ashraf et al. (2015) analyzes the QE experience in the United States and investigates the impact of unconventional monetary tools on the stock market reaction, with specific reference to the financial institutions.
This paper aims at providing empirical evidence to the much debated issue of the efficiency of conventional monetary policy tools during zero-bound official fund rate regimes. It also addresses another important research issue relevant to the existing literature, namely how unconventional policy tools such as asset purchase programs may impact the target interest rates vis-à-vis term structures.

2. Data & Methodology

2.1 Data

The Bank of England datasetprovides daily information on spot and forward rates of Overnight Index Swap (OIS), LIBOR rates, and inflation curves for fifty different maturities ranging from 6 months to 25 years at six-month intervals. QE regime asset purchase data are available following the formation of the Asset Purchase Facility Fund on January 30, 2009. Gilt purchase data are available on a ticker by ticker basis with

offer prices and yield information from the first gilt purchase date on January 26, 2010 to March 11, 2011. Corporate bond purchase and sales data begin on March 25, 2009 and January 08, 2010 respectively on a ticker by ticker basis with allocation volume and effective yield information.

2.2 Methodology

We analyze time series properties and the data generating process of the target variables. Then, we conduct pair-wise Granger causality tests for every possible combination of the target variables and conventional and non-conventional monetary policy tools. Later, we use Engle and Granger (1987) co-integration technique. We consider the following as the long-run equilibrium model:

$$y\_it= \alpha\_i+ \beta\_i.X\_it+ e\_it \quad (1)$$

where we assume a linear relationship exists among the UK stock market index, exchange rate index, and other target variables, (y_i), and conventional and non-conventional monetary policy tools (vectors of X_i). Although co-integration tests are commonly used by financial economists in analyzing the long-run equilibrium relationship of non-stationary variables, there are concerns about the low power of co-integration tests when applied to shorter span data.

3. Empirical Analysis

3.1 Descriptive Statistics

Following the global market collapse in September 2008, the Bank of England started reducing official bank rates on December 6, 2008 to increase liquidity and avoid a possible credit crunch. The bank further reduced the official bank rates five times between January 08, 2009 and February 07, 2009 by a total of 4 percent, from 5.50 percent to 1.50 percent. On March 05, 2009, the official bank rate was lowered to its threshold lowest level at 0.50. Subsequently, to increase liquidity and avoid deflation, the Bank of England undertook a Quantitative Easing policy regime that entailed active asset purchase participation of the bank during the near-zero bank rate era. On January 19, 2009 the Chancellor of Exchequer announced the decision to set up the asset purchase program.

Following the announcement, the Bank of England established an asset purchase facility on January 30, 2009 and started the first purchases of commercial papers and gilts on February 13 and March 09, 2009 respectively. By February 2010 the Monetary Policy Committee of the Bank of England had approved the purchase of £200 billion worth of securities, an amount equivalent to 14% of nominal GDP, mostly in UK government securities commonly known as gilts.

Panel 02 and Panel 03 of Table 01 suggests that, firstly, OIS (Overnight Interest Swaps) spots and forwards of lower maturities (one year and two year) show their rapid fall at the beginning of the financial turmoil that is consistent with the prevalent credit crunch. Other spot and forward rates however show the tendency to herd closely. Panel 02 and Panel 03 also depict a similar declining trend for other interest rates even after the official bank rate is lowered to the threshold limit. Second, OIS spots and forwards become more aligned with the other spots and forward rates with higher maturities as evident in Panel 04. Table 02 summarizes the descriptive statistics of the target variables and monetary policy tools. Panel 03 shows the most critical information that during the QE period the official bank rate is constant at 0.50% with a standard deviation of zero.

In Table 01, we present the time series plots of official bank rates in Panel 01. Panel 02 shows the time series plots of LIBOR spot and forward, OIS spot and forward, Nominal Govt. Spot and Forward for one year maturity. Other Panels such as Panel 03 through Panel 06 exhibit similar time series plots for 2 year, 5 year, 15 year and 20 year maturities.

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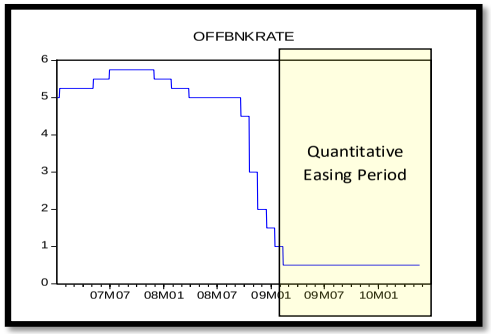
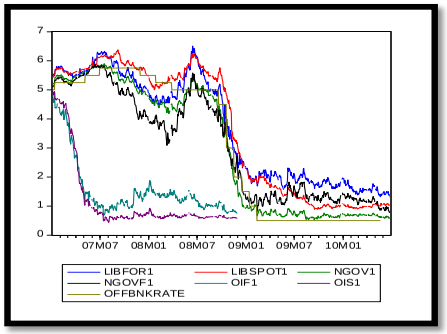
Table 1: Plots of Term Structure

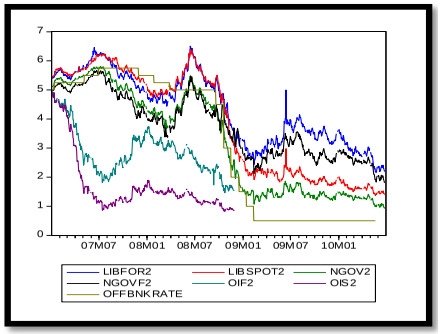
Panel 01: Official Bank Rates



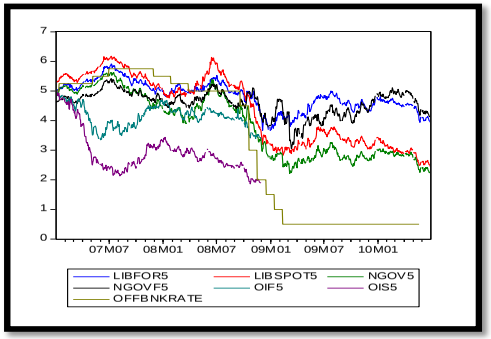
Panel 02: 1 yr Maturity spots and forwards



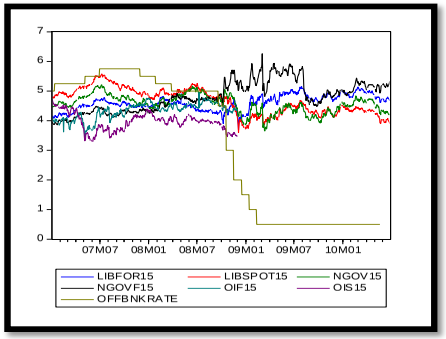
Panel 03: 2 yr Maturity spots and forwards



Panel 04: 5 yr Maturity spots and forwards



Panel 05: 15 yr Maturity spots and forwards



Panel 06: 20 yr Maturity spots and forwards

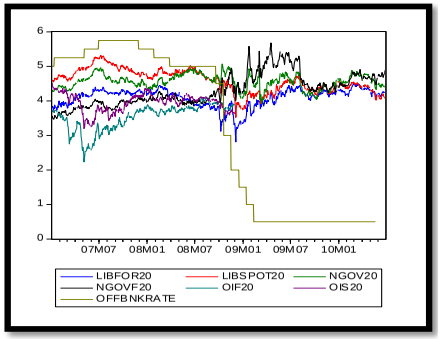


Table 2: Descriptive Statistics of Monetary Policy tools, Stock Market Index, Exchange Rate Index and Bond Yields

	Panel 01: Overall Sample Period				**Panel 02: Pre-QE Period**				**Panel 03: QE Period**			
	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
M1	53914.86	57121.00	50157.00	2056.76	51388.28	53201.00	50157.00	997.54	55135.12	57121.00	53201.00	1101.97
M2	98907.32	156405.00	27942.00	51903.97	38585.90	48367.00	27942.00	7180.54	128040.90	156405.00	39467.00	36880.14
M4	2007350.00	2208798.00	1776607.00	126820.50	1874059.00	1989966.00	1776607.00	67495.04	2071725.00	2208798.00	1977499.00	94435.88
Bank Rate	1.35	5.00	0.50	1.54	3.12	5.00	0.50	1.64	**0.50**	**0.50**	**0.50**	**0.00**
Govt. Gilt Holding	105156.20	125374.60	32677.68	32031.08	68939.70	125374.60	32677.68	34644.84	122647.80	125374.60	120130.50	1711.95
FTSE100	4806.63	5825.01	3512.09	591.25	4493.42	5636.61	3512.09	578.99	4957.90	5825.01	3753.68	535.80
EXGIND	81.68	93.28	73.75	4.14	83.89	93.28	73.75	6.02	80.61	85.26	75.69	2.11
Investment Grade Bond Yield	7.32	10.27	5.44	1.50	8.59	9.70	7.23	0.70	6.70	10.27	5.44	1.38
Non-Invest Grade Bond Yield	18.96	34.61	10.11	7.29	22.79	32.67	13.46	6.28	17.11	34.61	10.11	7.03
Sample Period		08/01/2008 to 06/02/2010				08/01/2008 to 03/05/2009				03/06/2009 to 06/02/2010		
No. of Observation		479				156				323		

We report the basic descriptive statistics (mean, maximum, minimum, and standard deviation) for Monetary Policy tools, Stock Market Index, Exchange Rate Index and Bond Yields for three sample periods; a) Overall Sample Period from 08/01/2008 to 06/02/2010 , b) Pre-Quantitative Easing Period from 08/01/2008 to 03/05/2009, and c) Quantitative Easing Period from 03/06/2009 to 06/02/2010 in Panel A, B and C respectively. M1, M2, M4 and Government Gilt Holding are in £ millions. Stock Market Index (FTSE100) and Exchange Rate Index (EXGIND) are in index and Official Bank Rate, Investment Grade Bond Yield and Non-investment Grade Bond Yields are in percentage.

3.2 Time Series Properties of Target Variables

We also analyze the ACF (Auto Correlation Function) and PACF (Partial Auto Correlation Function) for the target variables followed by the appropriate AR process based on the AIC (Akaike Information Criterion) and SBC (Schwarz Criterion) criteria, and conduct ADF unit root tests although that we do not report the results in the paper. Results show that for the majority of the spot and forward rates, the variables are I(1) processes; that is, the variables are non-stationary at their level but stationary at their first differences

Table 3: Unit Root Test for Market Index, Exchange Index, Monetary policy tools and Interest Rates at their Level and First Differences

Series	Panel 1: Market Index, Exchange Rate Index, Bond Yields					Panel 2: Conventional Monetary Policy Tools			
	Levels		First Diff.			Levels		First Diff.	
	Prob.	Lag	Prob.	Lag		Prob.	Lag	Prob.	Lag
LN_FTSE100	0.508	5	0.000	3	Official Bank Rate		0	0	0
EXGIND	0.062	0	0.000	0	Ln_M1	0.711	0	0.000	1
INV_GRD	0.948	0	0.000	0	Ln_M2	0.590	0	0.000	0
NON_INV_GRD	0.905	0	0.000	0	Ln_M4	0.687	0	0.000	0
					Ln_Gilt_Hldg	0.154	0	0.000	

	Panel 3: LIBOR swap curve, spot				Panel 4: LIBOR swap curve, forward				Panel 5: OIS curve, spot				Panel 6: OIS curve, forward				Panel 7: Inflation curve, Spot				Panel 8: Inflation curve, forward			
	Levels		First Diff.		Levels		First Diff.		Levels		First Diff.		Levels		First Diff.		Levels		First Diff.		Levels		First Diff.	
Series	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag	Prob.	Lag
0_5 yr	0.959	4	0	3	0.971	0	0	0	0.000	0	0	3	0.000	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1_0 yr	0.982	0	0	0	0.936	2	0	1	0.000	0	0	0	0.007	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2_0 yr	0.959	0	0	0	0.871	0	0	0	0.003	0	0	0	0.300	0	0	0	0.000	0	0	0	0.199	1	0	0
5_0 yr	0.961	0	0	0	0.716	0	0	0	0.098	0	0	0	0.253	0	0	0	0.560	2	0	1	0.073	1	0	0
10_0 yr	0.876	0	0	0	0.003	0	0	0	0.151	0	0	0	0.023	0	0	0	0.516	1	0	0	0.207	1	0	0
15_0 yr	0.700	0	0	0	0.023	0	0	0	0.154	0	0	0	0.192	1	0	0	0.278	1	0	0	0.264	1	0	0
20_0 yr	0.494	0	0	0	0.045	0	0	0	0.132	0	0	0	0.614	0	0	0	0.075	1	0	0	0.18	1	0	0

Table 3 reports Augmented Dickey Fuller test of Unit Roots for Market Index, Exchange Index, Monetary policy tools and various Interest Rates at their Level and First Differences for the overall sample period February 07, 2001 to April 15, 2011 with 2500 daily observations for each of the time series variables. Panel 1 shows the ADF statistics for the LSE Stock market index, Exchange Rate Index, Investment Grade Bond Yields and Non-Investment Grade Bond Yields and Panel 2 presents the test statistics for conventional monetary policy tools: official bank rates, M1, M2, M4, and gilt holding. Panel 3 to Panel 8 provide the ADF results for yields for different maturities for LIBOR swap spots and forwards, OIS overnight swap spots and forwards, and Inflation spots and forwards, respectively. For Augmented Dickey Fuller test, the null Hypothesis in each case is that the variable has unit root. A rejection of the null hypothesis means that the variable is otherwise stationary. Presented p-values are computed according to MacKinnon (1996) one-sided p-values.

Table 4: Granger Causality Tests

Panel A: Causality among Monetary Policy Tools			
	Obs.	F-Stat.	Prob.
LN_M2 does not Granger Cause LN_M1	323	0.031	0.969
LN_M1 does not Granger Cause LN_M2		0.054	0.948
LN_M4 does not Granger Cause LN_M1	323	0.008	0.992
LN_M1 does not Granger Cause LN_M4		1.874	0.155
LN_GILTHLD does not Granger Cause LN_M1	323	0.413	0.662
LN_M1 does not Granger Cause LN_GILTHLD		0.339	0.712
LN_M4 does not Granger Cause LN_M2	323	0.059	0.943
LN_M2 does not Granger Cause LN_M4		0.660	0.518
LN_GILTHLD does not Granger Cause LN_M2	323	0.010	0.990
LN_M2 does not Granger Cause LN_GILTHLD		0.465	0.629
LN_GILTHLD does not Granger Cause LN_M4	323	4.393	0.013
LN_M4 does not Granger Cause LN_GILTHLD		0.208	0.812

In Table 04 we report pair-wise Granger Causality analysis for the set of all possible combinations of explanatory variables and different maturities of different types of target interest rates and inflation rates in Panel A through Panel C. In Panel A, we present a pair-wise Granger Causality test among the Monetary Policy tools. In Panel B, we report the same for Monetary Policy Tools and different maturity spot and forward yields. Panel C shows the causal relations across the different maturities of spots and forwards that are the target of the monetary policy tools.

Table 4: Granger Causality Tests (continued)

Panel B: Granger Causality between Monetary Policy Tools and different maturity spot and forward yields													
		OIS		OIF		LIBORSPOT		LIBORFOR		IS		IF	
Null Hypothesis:	Obs	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.
LN_M1 does not Granger Cause 0_5yr	323	2.407	0.092	1.811	0.165	3.204	0.042	0.450	0.638	--	--	--	--
0_5yr does not Granger Cause LN_M1		0.223	0.800	0.294	0.745	0.036	0.965	0.049	0.952	--	--	--	--
LN_M2 does not Granger Cause 0_5yr	323	0.111	0.895	0.675	0.510	1.856	0.158	3.090	0.047	--	--	--	--
0_5yr does not Granger Cause LN_M2		1.428	0.241	0.996	0.371	0.431	0.650	0.139	0.870	--	--	--	--
LN_M4 does not Granger Cause 0_5yr	323	2.598	0.076	0.605	0.547	2.959	0.053	0.328	0.721	--	--	--	--
0_5yr does not Granger Cause LN_M4		0.011	0.989	0.068	0.934	0.940	0.392	1.236	0.292	--	--	--	--
LN_GILTHLD does not Granger Cause 0_5yr	323	1.112	0.330	0.610	0.544	1.165	0.313	0.330	0.719	--	--	--	--
0_5yr does not Granger Cause LN_GILTHLD		0.892	0.411	1.259	0.285	0.513	0.599	0.468	0.627	--	--	--	--
LN_M1 does not Granger Cause 1yr	323	1.093	0.337	2.661	0.071	0.342	0.711	8.153	0.000	--	--	--	--

1yr does not Granger Cause LN_M1		0.463	0.630	1.096	0.336	0.070	0.933	0.166	0.847	--	--	--	--
LN_M2 does not Granger Cause 1yr	323	0.530	0.589	0.469	0.626	4.782	0.009	3.288	0.039	--	--	--	--
1yr does not Granger Cause LN_M2		1.123	0.327	0.832	0.436	0.344	0.709	0.057	0.944	--	--	--	--
LN_M4 does not Granger Cause 1yr	323	1.604	0.203	4.299	0.014	0.079	0.924	6.640	0.002	--	--	--	--
1yr does not Granger Cause LN_M4		0.106	0.899	0.293	0.746	1.329	0.266	1.730	0.179	--	--	--	--
LN_GILTHLD does not Granger Cause 1yr	323	0.280	0.756	1.859	0.158	0.932	0.395	4.147	0.017	--	--	--	--
1yr does not Granger Cause LN_GILTHLD		1.521	0.220	0.776	0.461	0.442	0.643	0.322	0.725	--	--	--	--

Table 4: Granger Causality Tests (continued)

Panel B: Granger Causality between Monetary Policy Tools and different maturity spot and forward yields													
		OIS		OIF		LIBORSPOT		LIBORFOR		IS		IF	
Null Hypothesis:	Obs	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.
LN_M1 does not Granger Cause 10yr	323	4.552	0.011	0.686	0.505	3.434	0.034	0.248	0.781	0.068	0.935	1.281	0.279
10yr does not Granger Cause LN_M1		2.420	0.091	2.606	0.075	0.141	0.868	1.247	0.289	0.035	0.966	0.126	0.881
LN_M2 does not Granger Cause 10yr	323	1.478	0.230	0.483	0.617	5.554	0.004	4.681	0.010	0.398	0.672	1.997	0.138
10yr does not Granger Cause LN_M2		0.801	0.450	0.716	0.489	0.541	0.583	0.506	0.604	1.403	0.248	2.976	0.052
LN_M4 does not Granger Cause 10yr	323	4.339	0.014	0.101	0.904	2.825	0.061	0.381	0.684	0.342	0.711	0.042	0.959
10yr does not Granger Cause LN_M4		0.397	0.673	0.521	0.594	0.054	0.947	0.424	0.655	0.865	0.422	0.486	0.616
LN_GILTHLD does not Granger Cause 10yr	323	3.448	0.033	0.711	0.492	2.343	0.098	0.625	0.536	1.009	0.366	2.354	0.097
10yr does not Granger Cause LN_GILTHLD		1.664	0.191	4.368	0.013	3.278	0.039	7.864	0.001	4.625	0.011	3.700	0.026
LN_M1 does not Granger Cause 15yr	323	3.617	0.028	0.089	0.915	1.843	0.160	0.256	0.775	0.150	0.861	4.912	0.008
15yr does not Granger Cause LN_M1		3.053	0.049	1.289	0.277	1.522	0.220	0.655	0.520	0.227	0.797	1.708	0.183
LN_M2 does not Granger Cause 15yr	323	0.844	0.431	0.721	0.487	2.280	0.104	3.277	0.039	0.713	0.491	6.543	0.002
15yr does not Granger Cause LN_M2		1.094	0.336	1.123	0.327	0.401	0.670	0.357	0.700	2.295	0.102	1.562	0.211

LN_M4 does not Granger Cause 15yr	323	3.129	0.045	0.072	0.931	5.546	0.004	0.017	0.983	0.386	0.680	1.076	0.342
15yr does not Granger Cause LN_M4		0.408	0.665	0.051	0.950	0.598	0.550	0.034	0.967	0.328	0.721	0.920	0.399
LN_GILTHLD does not Granger Cause 20yr	323	2.363	0.096	2.025	0.134	1.762	0.173	0.511	0.600	0.714	0.491	8.009	0.000
20yr does not Granger Cause LN_GILTHLD		3.147	0.044	1.353	0.260	0.588	0.556	0.372	0.689	0.641	0.527	1.231	0.293
LN_GILTHLD does not Granger Cause 20yr	323	0.361	0.697	4.034	0.019	5.483	0.005	3.197	0.042	1.270	0.282	4.426	0.013
20yr does not Granger Cause LN_GILTHLD		1.368	0.256	1.116	0.329	0.581	0.560	0.378	0.685	2.193	0.113	0.704	0.495
LN_GILTHLD does not Granger Cause 20yr	323	1.911	0.150	1.359	0.259	1.119	0.328	0.574	0.564	0.079	0.924	3.472	0.032
20yr does not Granger Cause LN_GILTHLD		0.397	0.673	0.358	0.699	0.014	0.986	0.042	0.959	0.089	0.915	0.658	0.519
LN_GILTHLD does not Granger Cause 20yr	323	1.595	0.205	1.453	0.236	0.947	0.389	0.578	0.562	0.449	0.638	4.099	0.018
20yr does not Granger Cause LN_GILTHLD		2.683	0.070	1.833	0.162	4.042	0.019	2.233	0.109	2.195	0.113	0.169	0.845
LN_GILTHLD does not Granger Cause 20yr	323	2.363	0.096	2.025	0.134	1.762	0.173	0.511	0.600	0.714	0.491	8.009	0.000
20yr does not Granger Cause LN_GILTHLD		3.147	0.044	1.353	0.260	0.588	0.556	0.372	0.689	0.641	0.527	1.231	0.293

Table 4: Granger Causality Tests (continued)

Panel C: Granger Causality among different maturity spot and forward yields													
		OIS		OIF		LIBORSPOT		LIBORFOR		IS		IF	
Null Hypothesis:	Obs	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.
1yr does not Granger Cause 0_5yr	323	6.177	0.002	0.690	0.502	5.790	0.003	6.041	0.003	--	--	--	--
0_5yr does not Granger Cause 1yr		0.998	0.370	3.971	0.020	8.726	0.000	3.670	0.027	--	--	--	--
5yr does not Granger Cause 0_5yr	323	3.247	0.040	0.138	0.871	4.644	0.010	2.492	0.084	--	--	--	--
0_5yr does not Granger Cause 5yr		1.560	0.212	0.004	0.996	2.006	0.136	1.414	0.245	--	--	--	--
10yr does not Granger Cause 0_5yr	323	1.749	0.176	2.710	0.068	3.419	0.034	0.877	0.417	--	--	--	--
0_5yr does not Granger Cause 10yr		0.976	0.378	0.305	0.737	1.137	0.322	1.473	0.231	--	--	--	--
15yr does not Granger Cause 0_5yr	323	1.352	0.260	2.021	0.134	2.302	0.102	0.229	0.796	--	--	--	--
0_5yr does not Granger Cause 15yr		0.979	0.377	0.020	0.980	0.690	0.503	0.398	0.672	--	--	--	--
2yr does not Granger Cause 0_5yr	323	4.736	0.009	0.158	0.854	5.085	0.007	2.420	0.091	--	--	--	--
0_5yr does not Granger Cause 2yr		3.137	0.045	1.658	0.192	3.252	0.040	5.137	0.006	--	--	--	--
20yr does not Granger Cause 0_5yr	323	0.995	0.371	1.687	0.187	1.755	0.175	0.210	0.811	--	--	--	--

yr0_5 does not Granger Cause 20yr		0.636	0.530	0.463	0.630	0.628	0.534	0.241	0.786	--	--	--	--
5yr does not Granger Cause 1yr	323	3.688	0.026	2.045	0.131	2.925	0.055	0.039	0.962	--	--	--	--
1yr does not Granger Cause 5yr		3.740	0.025	1.060	0.348	1.883	0.154	0.540	0.583	--	--	--	--
10yr does not Granger Cause 1yr	323	4.607	0.011	1.707	0.183	2.381	0.094	0.695	0.500	--	--	--	--
1yr does not Granger Cause 10yr		0.352	0.704	0.455	0.635	1.517	0.221	0.793	0.453	--	--	--	--
15yr does not Granger Cause 1yr	323	4.888	0.008	0.119	0.888	1.925	0.148	0.150	0.861	--	--	--	--
1yr does not Granger Cause 15yr		0.219	0.803	0.141	0.868	1.053	0.350	0.098	0.906	--	--	--	--
2yr does not Granger Cause 1yr	323	3.192	0.042	10.177	0.000	2.689	0.070	0.626	0.535	--	--	--	--
1yr does not Granger Cause 2yr		5.766	0.004	5.897	0.003	14.193	0.000	9.976	0.000	--	--	--	--
20yr does not Granger Cause 1yr	323	4.270	0.015	1.480	0.229	1.784	0.170	1.594	0.205	--	--	--	--
1yr does not Granger Cause 20yr		0.139	0.871	0.931	0.395	0.884	0.414	0.575	0.563	--	--	--	--

Table 4: Granger Causality Tests (continued)

Panel C: Granger Causality among different maturity spot and forward yields													
		OIS		OIF		LIBORSPOT		LIBORFOR		IS		IF	
Null Hypothesis:	Obs	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.
10yr does not Granger Cause 5yr	323	1.392	0.250	2.782	0.063	2.040	0.132	1.521	0.220	2.299	0.102	3.434	0.033
5yr does not Granger Cause 10yr		6.532	0.002	3.084	0.047	2.852	0.059	0.835	0.435	0.646	0.525	0.428	0.652
15yr does not Granger Cause 5yr	323	1.179	0.309	2.111	0.123	1.367	0.256	0.194	0.824	3.438	0.033	3.491	0.032
5yr does not Granger Cause 15yr		2.232	0.109	2.825	0.061	4.008	0.019	2.623	0.074	0.940	0.392	1.801	0.167
2yr does not Granger Cause 5yr	323	1.638	0.196	9.811	0.000	0.896	0.409	7.156	0.001	2.362	0.096	0.392	0.676
5yr does not Granger Cause 2yr		5.014	0.007	5.514	0.004	11.199	0.000	1.776	0.171	0.963	0.383	1.307	0.273
20yr does not Granger Cause 5yr	323	1.979	0.140	3.953	0.020	1.404	0.247	1.444	0.237	3.267	0.039	2.157	0.117
5yr does not Granger Cause 20yr		1.777	0.171	0.664	0.516	1.299	0.274	1.452	0.236	0.800	0.450	2.783	0.063
15yr does not Granger Cause 10yr	323	2.313	0.101	4.767	0.009	1.110	0.331	0.643	0.526	4.975	0.008	1.776	0.171
10yr does not Granger Cause 15yr		1.589	0.206	20.952	0.000	1.701	0.184	2.460	0.087	0.618	0.540	1.374	0.255

2yr does not Granger Cause 10yr	323	1.799	0.167	0.342	0.710	0.962	0.383	0.368	0.692	1.066	0.346	0.300	0.741
10yr does not Granger Cause 2yr		0.976	0.378	0.387	0.679	3.083	0.047	1.418	0.244	0.599	0.550	1.849	0.160
20yr does not Granger Cause 10yr	323	2.466	0.087	0.064	0.938	1.000	0.369	0.232	0.793	3.726	0.025	0.409	0.665
10yr does not Granger Cause 20yr		3.174	0.043	0.150	0.861	1.715	0.182	5.158	0.006	0.040	0.961	0.959	0.385
2yr does not Granger Cause 15yr	323	0.721	0.487	0.111	0.895	0.631	0.533	0.611	0.544	1.261	0.285	2.020	0.135
15yr does not Granger Cause 2yr		0.459	0.632	2.049	0.131	2.033	0.133	1.450	0.236	0.185	0.831	3.334	0.037
20yr does not Granger Cause 15yr	323	3.564	0.030	7.602	0.001	0.811	0.445	1.115	0.329	2.854	0.059	0.330	0.719
15yr does not Granger Cause 20yr		3.881	0.022	0.552	0.576	1.608	0.202	1.406	0.247	0.113	0.894	0.657	0.519
20yr does not Granger Cause 2yr	323	0.229	0.796	3.462	0.033	1.396	0.249	1.063	0.347	0.344	0.709	4.854	0.009
2yr does not Granger Cause 20yr		0.734	0.481	1.150	0.318	0.690	0.503	1.252	0.287	0.825	0.439	5.084	0.007

For 6 month OIS and LIBOR spots and forwards, there is also not enough evidence of Granger causality with the monetary policy tools. However, for 1 year rates of OIS and LIBOR spot and forwards, there exists a unidirectional causality relationship between monetary policy tools and target variables. Within the different maturities of the spots and forwards, Granger causality results are significant in both the shorter maturity yields and longer maturity yields subgroups. To conclude, it is notable that the summary results of the Granger causality tests do not provide sufficient evidence in favor of the Expectation Hypothesis.

5. Conclusion

This paper analyzes the impact of conventional and unconventional monetary policy tools on a set of interest rates with different maturities. Although we do not present OLS regression results in this version of draft, we find the response to conventional monetary tools is significant in a) the overall period, b) the pre-QE period, and c) the QE period. The official bank rate becomes ineffective as a monetary policy tool as it reaches the threshold lower bound and becomes fixed. During the QE period, government balance of gilt purchases is an effective non-conventional policy tool.. OLS regression also results show that the explanatory power of monetary policy tools decreases monotonically with an increase in maturity. We consider two possible explanations: a) spots and forward rates are interrelated consistent with the pure Expectation Hypothesis or b) spots and forward rates have autocorrelation.

The Autocorrelation Function and Partial Autocorrelation Functions of the target variables conform to the second explanation that the variables have significant autocorrelation. In general, most of the spots and forward rates are AR (1) processes. The ADF test of unit root shows that variables are mostly I(1) process with a few exceptions. Pair-wise Granger causality tests reveal no evidence of a strong presence of Granger causality between different spots and forwards rates. However, monetary policy tools Granger cause target variables but are not caused otherwise. Results from pair-wise Granger causality do not provide enough evidence to confirm the Expectation Hypothesis.

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