Journal of Quantitative Economics (2022) 20:137–157
https://doi.org/10.1007/s40953-021-00257-9

ORIGINAL ARTICLE

US QE and the Indian Bond Market

Moumita Paul[1] · Kalluru Siva Reddy[1]

Accepted: 19 October 2021 / Published online: 30 October 2021

Abstract
This paper examines the long- and short-run spillover effects of US quantitative easing (QE) on the benchmark 10-year Indian government bond (IGB) yield by Autoregressive Distributed Lag (ARDL) bounds testing co-integration approach using monthly data from September 2008 to June 2019. The results show that a 10%-point rise in US QE led to a 4 bp rise in yields. The counterfactual analysis shows that volatility of the yields would have been less without the QE. During the episodes of QE, the Reserve Bank of India (RBI) had to alter its policy rate and engage in open-market operations (OMOs) to simultaneously maintain liquidity in the system and reduce the volatility of interest rates. Spillover on the debt yield leads to mispricing of assets and partial loss of the monetary-policy autonomy of the RBI.

Keywords Global spillover · Financial crisis · Monetary policy · Quantitative easing · Bond market

JEL Classification G01 · E52 · E58

Introduction

A robust bond market is critical for the growth of a country. When the bond market is developed the depth of financial markets increases by serving the needs of the private and public spheres. It is even more relevant now as bank balance sheets are weak, thus impeding loan growth. Part of that growth can come from the bond market. Hence, it is no surprise that the Indian regulatory and monetary authorities recognize this and have been taking continuous steps to deepen the fixed-income market in India. Consequently, the domestic bond market has grown from around INR 38trn in FY11 to INR 159trn in FY21. The following types of bonds are issued

✉ Moumita Paul
ps.moumita@gmail.com

Kalluru Siva Reddy
sivareddykalluru@gmail.com

1 Institute of Politics and Economics, Pune 411 004, India

Table 1 Activity in the bond market

INR bn	Government securities *		State development loans	Corporate bonds	Total
	Central government	State government			
2010–2011	22,689	6059	995	8895	38,638
2011–2012	25,933	7425	1599	10,516	45,473
2012–2013	32,541	8970	1636	12,901	56,048
2013–2014	37,150	10,619	2136	14,674	64,579
2014–2015	41,578	12,755	2348	17,503	74,183
2015–2016	45,325	16,314	2844	20,193	84,676
2016–2017	49,110	20,893	3736	24,049	97,789
2017–2018	53,968	24,288	4347	27,423	1,10,026
2018–2019	59,210	27,772	5237	30,672	1,22,892
2019–2020	64,866	32,660	6564	32,539	1,36,629
2020–2021	76,359	38,800	7787	36,126	1,59,072

*We have not included T-Bills with maturities of 1 year or less

**Corporate bonds include Public Sector Unit (PSU) bonds

Source: Reserve Bank of India (RBI)

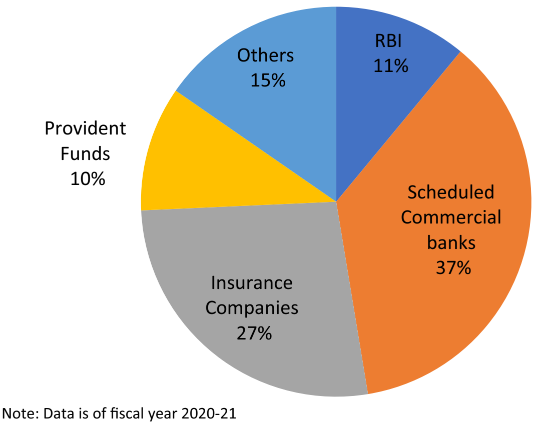


Fig. 1 Major owners of G-Secs. Source: RBI

in the Indian domestic bond markets are: (1) Government securities (G-secs), (2) State Development Loans (SDLs) and (3) corporate bonds. The activity in the bond market is given in Table 1.

As percent of GDP, government and corporate bonds have been growing. The former, which were 38% of India's GDP in FY11, have grown to 58% in FY21. More significantly, in this time, corporate bonds as percent of GDP have grown from around 12% to 18%. The major holder of government securities are Scheduled Commercial Banks (SCBs), which possessed more than one-third in FY21. The RBI and insurance companies are other significant owners, which held respectively 27% and 11% of government bonds (Fig. 1).

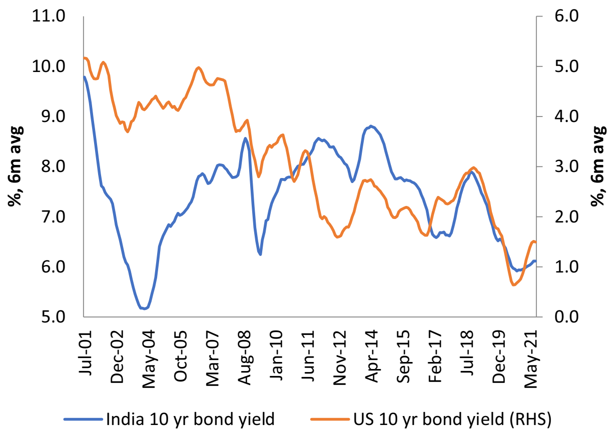


Fig. 2 Movement of US and India's long-term bond yields. Source: RBI, FRED

Compared to the G-sec market, the corporate bond market is still developing and is now one-third of the government bond market. There is strong correlation (0.83) between government and corporate bond yields. Within the various tenured government bonds, the 10-year government bond has been the most traded security, with the highest percentage of volumes being traded in the 7-year to 10-year bucket. The second-most traded security is the 5-year bond in the 5-year to 7-year bucket.[1] Between the 10-year and 5-year bond yields there is also a correlation of 0.93. We therefore identify the benchmark 10-year Indian Government Bond (IGB) yield as the most suited variable to capture the impact on the bond market in India.

After the Global Financial Crisis (GFC) in 2007, the Federal Reserve (Fed) initiated certain Unconventional Monetary Policy (UMP) measures to help the US economy to recover. Quantitative Easing (QE) was one of the tools adopted by the Fed in 2008. In QE, by purchasing assets of longer-duration, the central bank reduces the yield of these securities in US, which eventually translates into lower long term interest rates. The Fed has undertaken QE measures in 2010, 2011, 2012 and again in 2020. When the Fed purchases the long duration assets, it leads to an increase in demand for all substitute assets, like long-duration assets of Emerging Market Economies (EMEs), which has impact on the asset prices of EMEs. We note a visible co-movement between US and Indian long-term bond yields; they have moved in tandem in the last 10 years, particularly after the GFC and during the taper tantrum (Fig. 2). This allows us to question if there was any impact of US QE on the long term bond yields in India. But while considering the impact of US QE on the Indian debt market, we first need to establish the other determinants of the 10-year IGB yields.

The relationship between bond yields and GDP growth is not deterministic. Higher GDP growth generally entails higher cost of funding and inflation.

[1] As per data of The Clearing Corporation of India Ltd (CCIL) of 2019–20.

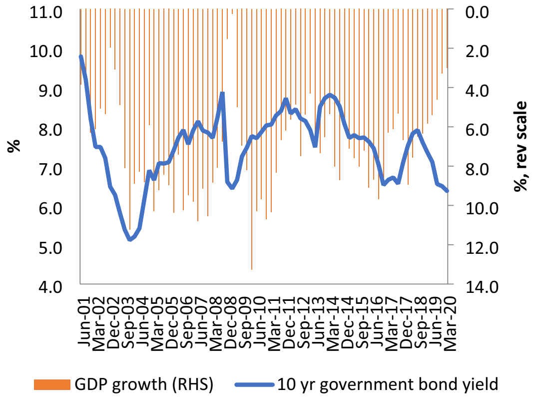


Fig. 3 Relationship between bond yield and GDP growth. Source: RBI, MOSPI

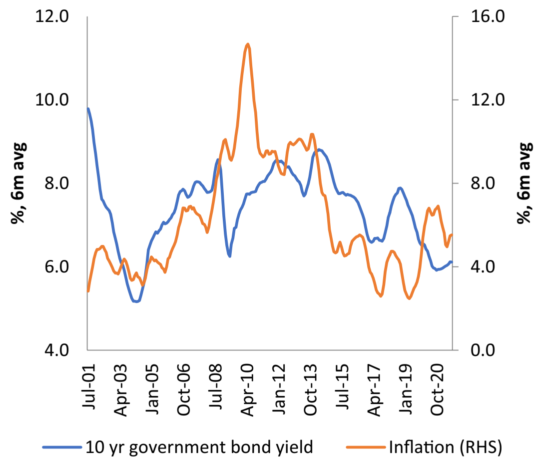
Consequently, the relationship is likely to be positive. That is, higher GDP growth should lead to higher yields on account of greater demand for funding and greater compensation required to cover higher inflation. In India we find a discernible negative relationship between GDP growth and debt yield (Fig. 3). That is, yields soften as growth accelerates–and vice-versa. The 10-year IGB yield seems to have a reasonable lead-indicator property of the GDP-growth trajectory by at least two quarters.

Higher GDP growth increases gilt demand, and reduces supply. Two main factors seem to result in the softening debt yield in India as GDP accelerates. Most government revenue in India arises from taxes. Taxation on income (both corporate and personal), in turn, constitutes the greater portion of tax revenue. Progressive taxation of income leads to tax-revenue growth surpassing GDP growth when the latter accelerates. This results in a lower fiscal deficit and, thereby, the reduced need for market borrowing when GDP growth is strong. In such situations, reduced supply of sovereign bonds softens yields.

Higher GDP growth also generally leads to a higher savings rate. In India, households are the largest savers and a large portion of household financial savings is generally channelized into bank deposits, especially in the early phase of a growth recovery. SCBs are statutorily required to invest in government securities. Higher GDP growth will lead to greater demand for such securities.

Unlike with GDP growth, the normative link between inflation and yield is straightforward. Higher inflation lowers real returns on government securities, leading to demand for higher nominal yields (Fig. 4). Like most central banks, the main monetary-policy tools of the RBI are the rates at which banks can borrow from (repo) or lend to (reverse-repo) the RBI. A change in policy rates almost immediately impacts money-market rates as the former is the effective benchmark in that market. Transmission of short-term or money-market rates on long-term or debt-market rates are, however, far from certain. Consequently, tight monetary policy translating to higher debt-market yields is not axiomatic. In fact, it can be argued that, if the debt market feels that tightening by the central bank would be effective in

Fig. 4 Relationship between bond yield and inflation. Source: RBI



bringing down long-term inflation, debt-market yields can soften rather than harden even when inflation is high.

Banks account for the largest holding of government securities. Over the years, they have been scaling down their holding of excess government securities beyond that required by the statutory-liquidity-ratio (SLR) norms. Also, since late 2010 the RBI has reduced banks' SLR requirement. Yet, banks still have considerable excess SLR holding. In 2014, the RBI introduced the Liquidity Coverage Ratio (LCR) norms as part of the Basel III Framework on Liquidity Standards. The objective was to build up resilience to face a potential acute liquidity-stressed situation lasting up to 30 days. Toward this end, banks need to maintain high-quality liquid assets (HQLA) so as to meet net cash outflow for 30 days under acute liquidity stress. Bank assets which qualify as part of HQLA are cash in hand, excess SLR holdings over the statutory norm and banks' borrowing limits under the Marginal Standing Facility (MSF).

Most government revenue in India arises from taxes. Personal and corporate tax constitutes the major portion of tax revenue. Progressive taxation of income leads to tax-revenue growth surpassing GDP growth when the latter accelerates. This results in a lower fiscal deficit and, thereby, reduced need for market borrowing when GDP growth is strong. In such situations, reduced supply of sovereign bonds softens yields.

The sharp monetary easing following the global crisis of 2008 was accompanied by banks parking huge amounts of liquidity with the RBI under the reverse repo window, ie, large net liquidity withdrawal by the RBI. Major rate easing backed by the banking-system liquidity-overhang led to a sharp softening of debt yields in this period. Thereafter, the reversal of the highly-accommodative monetary policy in 2010 coincided with a major tightening in banking-sector liquidity. From being large lenders to the RBI under the reverse-repo window, the banking system started borrowing large amounts from the RBI under the repo window. Liquidity tightening backed monetary tightening led to major hardening of gilt yields in this period (Fig. 5). To address the large banking-sector liquidity problem, the RBI started easing

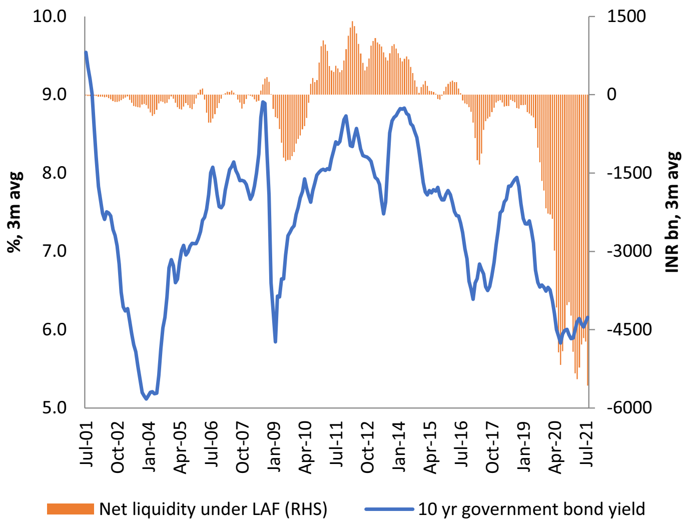


Fig. 5 Movement of between bond yields and liquidity. Source: RBI

Table 2 Changes in the policy rate and 10-year IGB yields

Time period	Δ repo rate (bps)	Δ 10-year IGB yield (bps)
Sep 2008 to Mar 2010	– 400	– 89
Apr 2010 to Nov 2012	275	42
Dec 2012 to Jun 2014	**0**	**55**
Jul 2014 to Jun 2019	**– 225**	**– 156**

Source: RBI

liquidity through outright government bond purchases under OMOs by the end of 2011, well before the start of the next rate-easing cycle. The monetary-easing cycle during 2012–2013 largely registered improvements in banking sector liquidity, and yields softened during this period. Prior to the policy-rate tightening started in 2013, the RBI sharply tightened banking liquidity in order to thwart a major depreciation in the rupee. The process led to the spike in debt yields. To change in bond yields and repo rate is compared for these periods (Table 2). The rest of the paper is arranged as follows: section "Summary and Gap" covers existing literature and the gap; section "Empirical Model" is an empirical model; section "Results and Discussion" delineates results and findings; section "Summary and Conclusion" concludes.

Summary and Gap

Following the GFC, the Fed initiated the QE measures and the program has been recurring since. In September 2008, the Fed started the QE-1 program in which the US central bank announced purchase of $1.25 trillion in Mortgage-Backed Securities (MBS) and $200 billion in federal agency debt.[2] In the second QE program (QE-2), which began in November 2010, the Fed notified its commitment to buying Treasury Securities worth $600 billion. Following this, the US conducted Operation Twist, in September 2011, where it announced it would buy short- and long-term bonds to reduce long-term rates. Then came QE-3 in September 2012, where the Fed announced an open-end bond-purchase program of MBS worth $40 billion every month. In March 2020, the Fed announced QE-4 to tackle the Covid-19 pandemic.

The stated objective of conducting QE was to reduce long-term interest rates to revive economic growth (Dudley 2010). There are three major ways in which this happens. First is the signaling channel in which the UMP measures serve as credible commitment to keep interest rates low (Eggertsson and Woodford 2003). The second is the liquidity channel: when the central bank purchases long-term securities the reserve balance of the central bank increases. This leads to increased liquidity for investors and they demand a lower liquidity premium on these assets. The third is the duration-risk channel (Vayanos and Vila 2009). Based on the assumption of a preferred habitat model, by purchasing long-term securities the central bank can reduce the duration risk and subsequently the bond yield of these securities. From existing literature we find evidence that $100 billion QE in the US leads to 3–15 bp softening of the US 10-year bond yield (Doh 2010; D'Amico and King 2010; Gagnon et al. 2011; Neely 2010; Krishnamurthy and Vissing-Jorgensen 2011; D'Amico et al. 2011; Swanson 2011).

However the impact of US QE was not contained within the US economy, it had a spillover effect on bond yields of EMEs (Sobrun and Turner 2015; Gilchrist et al. 2019; Borio and Zabai 2016; Dell'Ariccia et al. 2018). Bowman et al. (2015) uses the Vector Auto Regression (VAR) methodology to identify the impact of US UMP on 17 EMEs, using daily data of sovereign bond yields from January 2006 to December 2013. The authors find there was an impact on the EMEs (including India) and the impact was more on countries with weak macroeconomic fundamentals. In a similar study, Bhattarai et al. (2018), study the impact between January 2008 and November 2014 and come to the conclusion that a 2% increase in Fed security purchases reduces long-term yields in EMEs by 3 bps. However, they find that the impact on the "Fragile Five" EMEs– Brazil, India, Indonesia, South Africa, and Turkey–were stronger than on other EMEs.

Using a panel regression along with an event study and Global Vector Auto Regression (GVAR) as a robustness check, Moore et al. (2013) examine the impact of the US LSAP on 12 EMEs. The authors find that a 10 bp reduction in

[2] Data for different asset purchases by the US central bank have been taken from the Federal Reserve Archives.

long-term US Treasury yields reduced the EME government yield by 1.7 bps. From the event study (impact within three days from the date of announcement), the authors find that the impact on the 10-year IGB yield was significant. In a similar study, Fratzsher et al. (2013) analyse the impact of US QE on 42 EMEs using daily data between 2007 and 2011. The authors find that in QE-1 money flowed out of the EMEs, in QE-2 money flowed into EMEs. Lim et al. (2014) use panel regression to analyse the impact of QE by the Fed, the ECB, the BoJ and the BoE on quarterly gross capital inflows across 60 EMEs over 2000 and 2013. The authors identify there was transmission through the portfolio balancing channel on the yield curve.

Rajan (2014), the governor of the RBI, at that time had argued that the tapering actions of the Fed may give rise to unnecessary volatility in global financial markets and could lead to harmful spillover effects. Aizenman et al. (2014) apply a panel framework using daily financial data of EMEs and find that asset prices were most reactive to statements made by then Fed Chairman Bernanke. When classifying the 26 EMEs into robust and fragile, the authors conclude that, while in the very short term the impact was more severe in robust economies, the impact after a month was similar for robust and fragile economies.

Mishra et al. (2014) studied the impact of US QE on bond yields of 21 EMEs between 2013 and 2014 and came to the conclusion that the impact on the country depended on its macroeconomic fundamentals. Countries with deeper and more stable financial markets reacted less to the tapering events. Compared with other EMEs, the impact of tapering was less in India, as the current account balance improved in 2013 compared to 2008 (during QE-1) and the country imposed capital flow measures.

To the best of our knowledge theses papers that have looked exclusively at the spillover impact of UMP on the Indian debt market. Patra et al. (2016) study the impact of global spillovers on Indian financial variables. To capture the impact on the debt market (via the portfolio balance channel) the authors look at the US term spread and US risk spread.[3] The authors find that there was no spillover on Indian government bond yields. However FPI debt flows were impacted by the UMPs and the global spillovers do affect the transmission of monetary policy. Dilip (2019) uses VAR to study the spillover impact on daily zero coupon yields from 2009 to 2019. The author finds that there was a significant impact on the yield and that the spillover impact has increased over the years and the spillover has been through the term premium channel more compared to the risk neutral rate channel.[4] Sahoo et al. (2020) study the volatility spillover from the US UMP on the 5 EMEs (including the Indian bond market). The authors use the same variables as Patra et al. (2016); employ the AR(k)-GARCH model to estimate the impact. There was a significant impact of QE-1 and the taper tantrum on volatility of Indian bond markets and the effect was persistent.

[3] US term spread is calculated as the difference between 10-year US Treasury yield and 3-month US Treasury yield. US risk spread is the difference between US 10-year Treasury and corporate yield.

[4] The term premium is divided into the risk neutral rate and term premium.

We find the following gaps in the literature. First, very few studies have analyzed the spillover of US QE on the Indian bond market. Our model has incorporated an exhaustive list of domestic and global macro and financial variables to identify the spillover impact. The choice of control variables differentiates the work from others. To proxy the US QE variable, many studies have either used the term spread or the shadow-policy rate for their analyses. Here, the asset-purchase data of the Fed has been used. The rationale for using the asset-purchase data is that unlike the term spread which can be influenced by events other than QE, the data on asset-purchase data will not.

Most of the studies on EMEs have clustered economies together and commented on the entire basket of economies. Clustering economies which have significant fundamental differences do not allow us to incorporate the political and monetary-policy backgrounds of individual economies. Most of the work of empirical modelling has been done employing linear regression, panel data models, GVAR, dynamic factor modes (DFM) to estimate the spillover impact. However we use the Autoregressive Distributed Lag (ARDL) model, which is novel. It is more suited for the analysis as all the variables are not endogenous and the order of integration is not same.

Empirical Model

Data

The 10-year benchmark IGB yield is the dependent variable in the study. Monthly data from September 2008 to June 2019 is used in the empirical analysis. Dua and Raje (2014) note that "factors which can arise from monetary-policy shifts" are important determinants of the 10-year IGB yields. The US QE is an independent variable and the chief area of interest.[5] The QE data is normalized by taking it as a percent of total outstanding bond purchases in the US. The impact of the US QE on the 10-year IGB yield can happen via two channels. First is the portfolio- rebalancing: with the fall in supply of long-term US bonds, demand for substitute assets in India is likely to have increased. This would lead to a rise in asset prices and a fall in the bond yields in India. In the signaling channel, with low, long-term interest rates in the US, the interest rate difference between the US and India would have increased. This would have led to higher capital inflows to India and greater demand for Indian long-term securities. The impact is likely to suppress bond yields.

The relationship between GDP growth and bond yield is not deterministic. Higher GDP growth generally entails higher cost of funding and inflation. Consequently, the relationship is likely to be positive. However, since GDP is released

[5] Data for the US QE have been compiled taking the weekly average data of MBS, Federal agency debt securities and Treasury securities (Bhattarai et al. 2018). The data are published under the dataset 'Factors affecting reserve balances of depository institutions and condition statement of federal reserve banks' in the Federal Reserve Archives.

every quarter, the industrial production growth which has a monthly frequency, has been taken instead as a proxy of economic growth.

Inflation plays an important role in determining bond yields (Dilip 2019). The normative link between inflation and yield is straightforward. Higher inflation lowers real returns on government securities, leading to demand for higher nominal yields. Another way of looking at it is when inflation increases, the central bank raises policy rates to control the rise in inflation. A successful monetary-policy transmission would therefore increase the long-term rates.

For the empirical analysis, both CPI and WPI inflation were taken at the onset. There was a notable degree of correlation between these two measures. However, WPI inflation is more relevant for the analysis as, as during 2008 to 2012, only WPI inflation was there. Given its relative importance over CPI inflation, this has been included in the ARDL model. To capture the impact of global prices, both Brent crude oil and WTI were included in the initial set of regressions. Apart from prices, these indicators reflect market volatility and liquidity. A high degree of correlation was noted among the two. The Brent crude oil price, the more popular and common measure, has been included in the final model.

A few authors have found that monetary policy and monetary-policy shifts have an impact on long-term bond yields (Dua and Raje 2014; Dilip 2019). However, none of the policy variables—the repo rate or the reverse repo rate—had a significant impact on the 10-year IGB yields in the initial regression models. The reserve requirements—the Cash Reserve Ratio (CRR) and the SLR were found to be insignificant. Hence, none of these variables have been included in the ARDL model. The 6-month libor rate had also been included in the initial set of regressions which was not included in the final model as there was no literature which has found a significant impact of this variable.

Akram and Das (2019) find that the Keynesian conjecture of short-term interest rates being a key determinant of long-term interest rates holds for the Indian economy. This is based on the expectations theory of the term structure, where the long-term interest rate is defined as the weighted average of present and future short-term interest rates. With the rise in the short-term interest rate, the long-term interest rate is likely to rise. The 3-month Indian Treasury Bond (ITB) yield has been taken as proxy for the short-term rates in the ARDL model.

Goyal (2019) notes that OMOs also impact bond yields. The net open-market purchase by the RBI has been taken to proxy the OMO of the RBI. The variable has been converted into its logarithmic value to maintain consistency with the other variables in the equation. Higher net open-market purchase by the RBI would increase liquidity in the hands of investors. This would increase demand for long-term assets and compress its yields. The coefficient of net open-market purchases is expected to be negative.

Kapur et al. (2018) find that foreign investment in debt instruments has a significant impact on long-term bond yields. Foreign portfolio investment in debt markets is regulated by restrictions of capital inflows to the country. So this variable has been avoided. On the other hand, the variable of mutual-fund investment in G-secs was also compiled. However, since mutual funds are small players in the bond

Table 3 List of the variables

Variable (referred to as in the model)	Unit	Source
India 3-month Treasury bond yield (bill)	%	RBI
India 10-year government bond yield (bond)	%	RBI
India industrial production growth (iip)	Growth, %	CSO
Brent crude oil prices (crude)	dollar/bbl	FRED
India net OMO purchases (lomo)	INR	RBI
US Federal Reserve asset purchase as percent of total outstanding bonds (qe)	Ratio	Federal Reserve Archive
India wholesale price inflation (wpi)	Inflation, %	CSO

Crude and omo have been transformed to natural logarithm

market, this variable also has not been included. The final list of variables is given in Table 3.

Estimation Methodology

Many authors[6] have used the VAR model, which is more suitable when all variables are endogenous. However, in the present study, the hypothesis is that there is a one-way causality between QE and 10-year IGB yields. Using the ARDL bounds test developed by Pesaran and Smith (1998), Pesaran et al. (2001), is novel. The other advantage of using the ARDL model is that, unlike traditional co-integration models of Engle and Granger (1987), Johansen (1991), Johansen and Juselius (1990), which require all the variables to be integrated into the same order, the ARDL model requires the variables to be integrated of order I(0) or I(1) or a combination (Nkoro and Uko 2016).

The relationship between US QE and the Indian bond market is likely to take this functional form 10-year IGB yield = f (usqe).

The ARDL model specifies the functional relationship between the variables of interest as follows:

$$\begin{aligned}\Delta bond_t = & \alpha + \beta_1 \Delta(bond)_{t-1} + \beta_2 \Delta(bill)_{t-1} \\ & + \beta_3 \Delta(iip)_{t-1} + \beta_4 \Delta(lcrude)_{t-1} \\ & + \beta_5 \Delta(lomo)_{t-1} + \beta_6 \Delta(qe)_{t-1} \\ & + \beta_7 \Delta(wpi)_{t-1} + \beta_8 (bond)_{t-1} \\ & + \beta_9 (bill)_{t-1} + \beta_{10} (iip)_{t-1} \\ & + \beta_{11} (lcrude)_{t-1} + \beta_{12} (lomo)_{t-1} \\ & + \beta_{13} (qe)_{t-1} + \beta_{14} (wpi)_{t-1} + \varepsilon_t\end{aligned}$$

[6] Chen et al. (2014), Moore et al. (2013), Bowman et al. (2014) have used VAR to capture the spillover impacts on EMEs.

where Δ is the first difference operator, α and β_1 to β_7 are short-run dynamic coefficients, β_8 to β_{14} are the long-run coefficients and ε is the error term.

The null hypothesis of no long-run relationship among the selected variables (H_0:$\beta_1=\beta_2=\beta_3=\beta_4=\beta_5=\beta_6=\beta_7=0$) has been discarded against the alternative hypothesis of the existence of a long-run relationship.

In the presence of a long-term relationship among the variables, the short-run Error Correction Model (ECM) has been applied. This is specified as:

$$\Delta bond_t = \alpha + \beta_1\Delta(bond)_{t-1} + \beta_2\Delta(bill)_{t-1} + \beta_3\Delta(iip)_{t-1} + \beta_4\Delta(lcrude)_{t-1} + \beta_5\Delta(lomo)_{t-1} + \beta_6\Delta(qe)_{t-1} + \beta_7\Delta(wpi)_{t-1} + \gamma(ECT)_{t-1} + \varepsilon_t$$

where Δ is the first difference operator, α and β*'s* are the short-run dynamic coefficients, γ is the coefficient of the error correction term (ECT) and ε is the error term. γ determines the speed of adjustment to equilibrium.

The robustness of the ARDL model on the residuals has been checked by the following tests: (a) the Lagrange multiplier test of residual serial correlation; (b) the Ramsay RESET specification test of functional form; (c) the Jarque-Berra normality test, (d) the Breusch-Pagan-Godfrey heteroscedasticity test. Besides, the cumulative sum (CUSUM) test for stability of the model is also evaluated.

Four counterfactual scenarios are built where the QE variable is assumed to be zero[7] and the behaviour of the 10-year IGB yield is observed. The four scenarios are built by splitting the time period into segments when there has been a change in the US QE program. The four segments are Period 1: from September 2008 to March 2010 when the Fed increased the monthly asset purchases; Period 2: from April 2010 to November 2012 when the asset purchases fell, followed by a brief period of rise and fall again. Broadly as the number was falling, this has been taken as Period 2. Period 3: from December 2012 to June 2014 when asset purchase was on the rise again, and Period 4: from July 2014 to June 2019 when it fell. For each of these scenarios, QE is assumed to be zero for that specific time period. for the pertaining time period and the forecasting exercise is done.

Results and Discussion

From the descriptive statistics given in Table 4, we find that the 10-year IGB yield fluctuated between 5 and 9% during the time period under observation. The variables showing high fluctuation are QE, OMO and Brent crude oil prices. Three variables: industrial production growth, OMO and QE have high kurtosis, implying there may be outliers in these datasets. All the variables except industrial production and OMO have an almost normal skewed distribution.

The lag length of the model is estimated by minimizing the information criteria. The results from Akaike information criterion (AIC) and Schwarz Criterion (SC)

[7] This methodology has been adopted from Chen et al. (2012).

Table 4 Descriptive statistics

	Bill	bond	iip	lcrude	lomo	qe	wpi
Mean	0.0667	0.0767	0.0268	1.8200	– 0.6563	0.9468	0.0395
Median	0.0672	0.0778	0.0366	1.8371	– 0.7391	0.9495	0.0395
Maximum	0.1114	0.0894	0.1494	2.0395	0.0000	1.6342	0.1088
Minimum	0.0305	0.0530	– 0.5763	1.2187	– 1.9682	0.0064	– 0.0614
Std Dev	0.0173	0.0073	0.0756	0.1525	0.2436	0.3023	0.0417
Skewness	– 0.3491	– 0.4767	– 4.5925	– 0.6475	– 1.1084	0.5143	0.2899
kurtosis	2.7380	2.9547	33.8939	3.4466	9.5157	5.0210	2.3095
Jarque–Bera	3.2908	5.3896	6146.2530	11.1037	272.6081	30.4265	4.8101
Probability	0.1929	0.0675	0.0000	0.0039	0.0000	0.0000	0.0903
Sum	9.4726	10.8909	3.0181	258.4372	– 93.1947	134.3998	5.6045
Sum of sq deviation	0.0420	0.0076	0.8059	3.2794	12.8876	10.1636	0.2455
Observations	130	130	130	130	130	130	130

Source: Authors' estimates

suggest 1 as the optimal lag length of the model (Appendix Table 9). In the Augmented Dickey–Fuller test (ADF) and Phillips–Perron (PP test), the null hypothesis is that the variable (trend and intercept) has a unit root. We find that industrial production growth, QE, the 10-year IGB yield, OMO are I(0) while 3-month ITB yield, Brent crude oil prices and wholesale inflation are I(1). The results of the unit root test is given in Appendix Table 10.

Prior to estimating the ARDL model, the existence of a long-run relationship between the variables is determined. In the presence of a long-term relationship between the variables, the Error-Correction Model (ECM) is applied.[8] The F statistic of the model is 3.36, which is higher than the critical value at the 10% level of significance. (Table 5) This shows that there exists a long-term relation between QE, the 10-year IGB yield, and the control variables: 3-month ITB yield, WPI inflation, OMO, Brent crude oil prices and industrial production growth. (Table 5).

The long-term coefficient of all the variables is given in Table 6. The long-term coefficient of QE is significant and positive. A one-percentage-point increase in QE leads to a 0.4 bp rise in the 10-year IGB yield. The yields were anticipated

Table 5 Estimated statistics of the ARDL bounds test

Critical values		
Lower Bound	Upper Bound	F statistics
2.12	3.23	3.36

The bounds test is conducted at the 10% level of significance

Sources: Table CI (iii) Case III: Unrestricted intercept and no trend (Pesaran et al. 2001), Authors' estimation based on the ARDL model

8 For a detailed discussion on the ARDL model, see Alimi (2014), Abonalzel and Elnabawy (2020) and Paul and Reddy (2021).

Table 6 Estimated long-run coefficients

Dependent variable	Coefficient	T-statistic	P-value
Bill	0.0743**	2.4419	0.0160
Bond	– 0.4038***	– 4.4924	0.0000
Iip	– 0.0029	– 0.5756	0.5659
Lcrude	0.0101***	2.674	0.0085
Lomo	0.0002	0.1543	0.8776
Qe	0.0037***	2.8537	0.0051
Wpi	– 0.0065	0.6616	0.5094

*, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively

Source: Authors' estimation based on the ARDL model

Table 7 Estimated short-run statistics

Dependent variable	Coefficient	T-statistic	P-value
D(wpi(-1))	0.0742 ***	2.8107	0.0057
ECT(-1)	– 0.4031 ***	– 4.5935	0.0000

*, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively

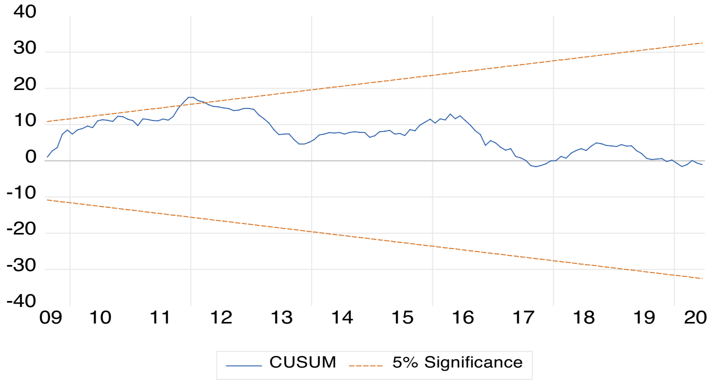
Source: Authors' estimation based on the ARDL model

Table 8 Diagnostic test results

	L M version	p-value	F-version	p-value
Serial correlation	0.004	0.9496	0.0037	0.9515
Normality	199.1275***	0	NA	
Heteroscedasticity	11.123	0.1948	1.4133	0.1967

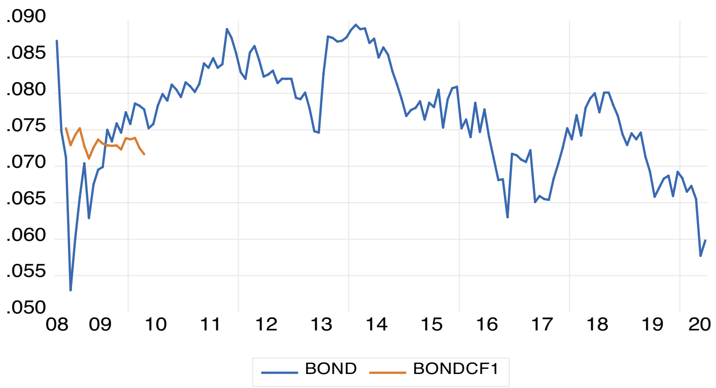
*, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively

Source: Authors' estimation based on the ARDL model



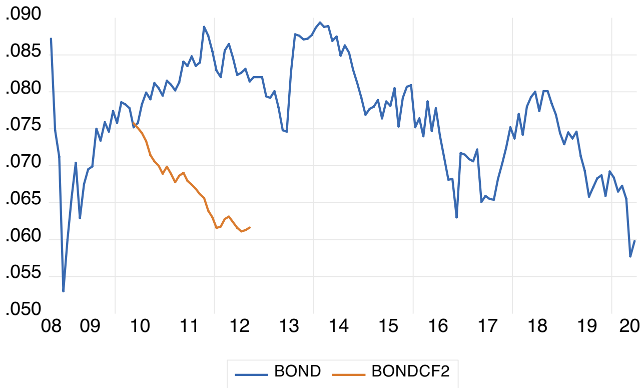
Note: The x-axis shows the years and the y-axis shows the 5% confidence interval

Fig. 6 Plot of CUSUM test. Source: Authors' estimation based on the ARDL model



Note: The x-axis shows the years and the y-axis shows the 10-year IGB yield

Fig. 7 The movement of bond yields during Sep 2008 to Mar 2010. Source: Authors' estimation based on the ARDL model

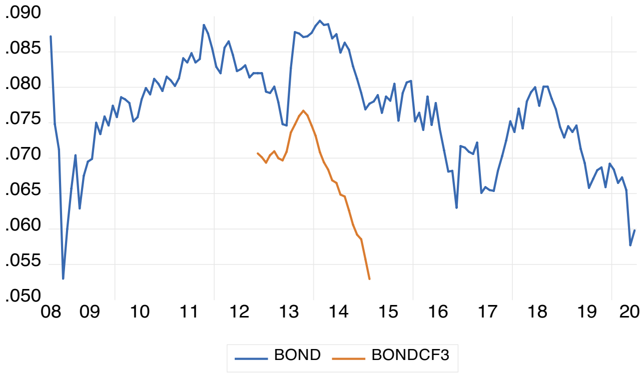


Note: The x-axis shows the years and the y-axis shows the 10-year IGB yield

Fig. 8 The movement of bond yields during Apr 2010 to Nov 2012. Source: RBI; authors' estimation based on the ARDL model

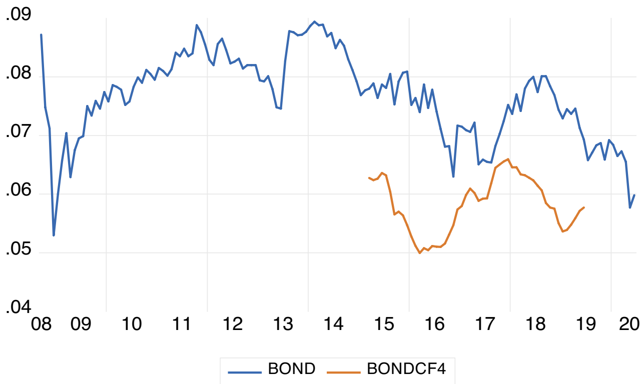
to soften due to QE (portfolio re-balancing). There are two possible reasons for this—first, the co-movement of the bond yields, which was visible in the initial years of QE, was not there in the later years. Second, policy changes by the RBI and monetary-policy transmission has impacted long-term yields.

Of the CVs, the coefficient of industrial-production growth and Brent crude oil prices are significant. The coefficient of Brent crude oil price is positive and in line with expectation. A rise in Brent crude oil prices would harden inflation and lead to a rise in the 10-year IGB yields. While the coefficient of industrial-production growth was anticipated to be positive. The rationale is that, as growth slows down, investment in a safe haven like a 10-year IGB yield would rise. However the



Note: The x-axis shows the years and the y-axis shows the 10-year IGB yield

Fig. 9 The movement of bond yields during Dec 2012 to Jun 2014. Source: RBI; authors' estimation based on the ARDL model



Note: The x-axis shows the years and the y-axis shows the 10-year IGB yield

Fig. 10 The movement of bond yields during Jul 2014 to Jun 2019. Source: RBI; authors' estimation based on the ARDL model

correlation between GDP growth and industrial-production growth is rather weak, and industrial-production growth may not reflect the actual health of the economy.

Two short-run coefficients were significant. The short-run coefficient of the past value of the 10-year IGB yield and the wholesale price inflation are significant as well. The coefficient of the ECT is negative and significant in both the models. This implies that any short-term disequilibrium is corrected each month, in line with long-term equilibrium values. The coefficient of ECT is 0.40 and any dis-equilibrium in the bond market is corrected at the speed of 40% (Table 7).

The results of the other diagnostic tests are given in Table 8. There is no auto-correlation, serial correlation, heteroscedasticity or model mis-specification in the models. However, the residual errors do not follow normal distribution. The result of the CUSUM test is given in Fig. 6. The plot of CUSUM stays within the critical 5% bounds, confirming the long-run relationships among variables and, thus, shows the stability of the coefficient.

The results of the counterfactual analysis are given in Figs. 7, 8, 9, 10. In Period 1, yields dropped sharply toward the end of 2008. The ARDL model shows that, if there were no QE, bond yields would have been flat. In Period 2, bond yields initially hardened, then softened back to the level at the beginning of Period 2. The counterfactual analysis, on the other hand (were there no QE) shows that bond yields would have softened by ~ 150 bps. Even in Period 3, the counterfactual analysis points to a consistent softening of bond yields. In Period 4, there is not much difference between the actual the constructed bond yield series in terms of volatility. The average bond yields would have been lower during that period.

Summary and Conclusion

The ultimate objective of the RBI has been to ensure complete transparency and increasing liquidity across the curve, thereby helping better discovery of prices of government and corporate bonds. Clearly articulated steps have been taken by the RBI to ensure this is achieved. Further, to make the market more vibrant, the RBI has been introducing products and encouraging more investors to actively contribute to the bond market.

The purpose of this paper is to analyze the long- and short-run effects of the US QE on 10-year IGB yields, using the ARDL bounds testing co-integration approach. There is a long-term relationship between QE, the 10-year IGB yield and the control variables. A 10-percent increase in QE leads to a 4 bp hardening of yields. Industrial-production growth and Brent crude oil prices also have a significant impact on the yields. The conclusion from the counterfactual analysis is that volatility in yields would have been lower were there no QE.

The impossible trinity in economics suggests that a country with a flexible exchange rate and capital-account convertibility cannot have an autonomous monetary policy. Due to some restrictions on cross-border capital movements (especially for outflows by residents) and the RBI intervention in the foreign exchange market, India retains some monetary-policy autonomy. That is why it could tighten monetary policy during 2010 and 2011 and again in 2013 and 2014, while most developed countries held to a prolonged pause. However despite the efforts, there was a spillover impact on the bond market. This has two broad implications—mispricing of debt-market assets and partial loss of monetary-policy autonomy of the RBI.

Appendix

See Tables 9 and 10.

Table 9 Lag-length selection

	Lag 0	Lag 1	Lag 2	Lag 3
AIC	– 9.1114	– 9.1386*	– 9.1302	– 9.1273
SIC	– 8.9593	– 8.9647*	– 8.9344	– 8.9100

* indicates the optimal lag length

Source: RBI; authors' estimation based on the ARDL model

Table 10 Estimated statistics of unit root test

	adf test		pp test	
	At level	At first difference	At level	At first difference
Bill	– 2.7205	– 8.8743***	– 2.7237	– 14.2644***
Bond	– 3.9853**		– 4.2661***	
Iip	– 3.8327**		– 5.4268***	
Lcrude	– 2.5616	– 8.4592***	– 2.1613	– 8.3086***
Lomo	– 5.5188***		– 5.4644***	
Qe	– 5.3120***		– 2.8416	– 9.2924***
Wpi	– 2.3419	– 7.6107***	– 2.2221	– 7.5632***

*, ** and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively

Source: RBI; authors' estimation based on the ARDL model

References

Abonazel, M.R., and N. Elnabawy. 2020. Using the ARDL bound testing approach to study the inflation rate in Egypt. *Economic Consultant* 31 (3): 24–41.

Aizenman, J., Binici, M., & Hutchison, M. M. (2014). The transmission of Federal Reserve tapering news to emerging financial markets. *National Bureau of Economic Research,* Working Paper No. 19980.

Akram, T., and A. Das. 2019. The long-run determinants of Indian Government Bond Yields. *Asian Development Review* 36 (1): 168–205.

Alfaro, L., S. Kalemli-Ozcan, and V. Volosovych. 2014. Sovereigns, upstream capital flows, and global imbalances. *Journal of the European Economic Association* 12 (5): 1240–1284.

Alimi, R. 2014. ARDL bounds testing approach to co-integration: A re-examination of augmented Fisher hypothesis on an open economy. *Asian Journal of Economic Modelling.* 2: 103–114.

Auerbach, A. J., & Obstfeld, M. (2004). Monetary and fiscal remedies for inflation. Paper presented at the American Economic Association meetings, San Diego.

Bauer, M. D., & Rudebusch, G. D. (2011). The signaling channel for Federal Reserve bond purchases. *Federal Reserve Bank of San Francisco,* Working Paper 2011–21.

Benford, J., S. Berry, K. Nikolov, and C. Young. 2009. Quantitative easing. *Bank of England Quarterly Bulletin* 49 (2): 90–100.

Bhattarai, S., Chatterjee, A., & Park, W. Y. (2018). Effects of US quantitative easing on emerging market economies. *Globalization and Monetary Policy Institute,* Working Paper 255. Federal Reserve Bank of Dallas.

Borio, C., & Zabai, A. (2016). Unconventional monetary policies: a re-appraisal. BIS Working Papers No. 570.

Bowman, D., J.M. Londono, and H. Sapriza. 2015. U.S. unconventional monetary policy and transmission to emerging market economies. *Journal of International Money and Finance* 55: 27–59.

Bridges, J., & Thomas, R. (2012). The impact of QE on the UK economy: Some supportive monetarist arithmetic. *Bank of England,* Working Paper 442.

C´urdia, V., & Woodford, M. 2011. The Central-Bank balance sheet as an instrument of monetary policy. *Journal of Monetary Economics* 58: 54–79.

Campbell, J. R., Evans, C. L., Fisher, J. D. M., & Justiniano, A. (2012). Macroeconomic effects of FOMC forward guidance. *Brookings Papers on Economic Activity,* pp 1–80.

Chakraborty, L. (2012). Interest Rate Determination in India: empirical evidence on fiscal deficit—interest rate linkages and financial crowding out. Working Paper 744, Levy Economics Institute, New York.

Chen, H., and C'urdia, V., & Ferrero, A. 2012. The macroeconomic effects of large-scale asset purchase programs. *Economic Journal, Royal Economic Society* 122 (564): 289–315.

Chen, Q., Fliardo, A., He, D., & Zhu, F. (2012). International spillovers of central bank balance sheet policies. *BIS Working Paper* 66.

Chen, J., Mancini-Griffoli, T., & Sahay, R. (2014). Spillovers from U.S. monetary policy on emerging markets: Different this time? *IMF Working Paper* No. 14/240.

Christensen, J. H. E., & Rudebusch, G. D. (2012). The response of interest rates to US and UK quantitative easing. *Economic Journal,* 122 (564, November), F385–F414.

D'Amico, S., W. English, D. Lopez-Salido, and E. Nelson. 2011. The Federal Reserve's large-scale asset purchase programs: Rationale and effects. *Economic Journal* 122 (564): F415–F446.

D'Amico, S., & King, T. (2010). Flow and stock effects of large-scale treasury purchases. *Federal Reserve Board Finance and Economics Discussion Series*, 2010–52.

De Long, J.B. 1998. Fiscal policy in the shadow of the great depression. In *The defining moment: The great depression and the American economy in the twentieth century*, ed. M.D. Bordo, C. Goldin, and E.N. White, 67–85. Chicago, IL: University of Chicago Press for NBER.

Dell'Ariccia, G., P. Rabanal, and D. Sandri. 2018. Unconventional monetary policies in the Euro Area, Japan, and the United Kingdom. *Journal of Economic Perspectives* 32: 147–172.

Dilip, A. (2019). Term premium spillover from the US to Indian markets. *RBI Working Paper (DEPR)*:05/2019.

Doh, T. 2010. The efficacy of large-scale asset purchases at the zero lower bound. *FRB Kansas City Economic Review* Q2: 5–34.

Dua, P., & Raje, N. (2014). Determinants of yields on government securities in India. *Margin: The Journal of Applied Economic Research,* 8(4), 375–400.

Dudley, W. C. (2010). The Outlook, Policy Choices and Our Mandate. Remarks at the Society of American Business Editors and Writers Fall Conference, City University of New York.

Eggertsson, G., and M. Woodford. 2003. The zero bound on interest rates and optimal monetary policy. *Brookings Papers on Economic Activity* 1: 139–211.

Eichengreen, B., & Gupta, P. (2014). Tapering talk: The impact of expectations of reduced Federal Reserve security purchases on emerging markets. *Munich University Library MPRA* Paper No. 53040.

Engle, R.F., and C.W.J. Granger. 1987. Co-integration and error-correction: Representation, estimation, and testing. *Econometrica* 55: 251–276.

Fratzsher, M., Duca, M. L., & Straub, R. (2012). A global monetary tsunami? On the spillovers of US quantitative easing. *Centre for Economic Policy and Research Discussion Paper* No. 9195.

Fujiwara, I. 2005. Is the central bank's publication of economic forecasts influential? *Economics Letters* 89: 255–261.

Gagnon, J., M. Raskin, J. Remache, and B. Sack. 2011. The financial market effects of the Federal Reserve's large-scale asset purchases. *International Journal of Central Banking* 7 (1): 3–43.

Ghosh, A. R., Kim, J., Qureshi, M.S., & Zalduendo, J. (2012). Surges. *International Monetary Fund (IMF) Working Paper* No. WP/12/22.

Gilchrist, S., Yue. V., & Zakrajsek, E. (2014). US monetary policy and foreign bond Yields. *National Bureau of Economic Research Working Paper* 26012.

Glick, R., & Leduc, S. (2013). The effects of unconventional and conventional US monetary policy on the dollar. *Federal Reserve Bank of San Francisco Working Paper* 2013–11.

Goyal, A. (2019). Price discovery in Indian government securities market, monetary management and the cost of government borrowing. *Economic & Political Weekly, Money, Banking & Finance, Vol 54, Issue No, 13.*

Hausman, J., and J. Wongswan. 2006. Global asset prices and FOMC announcements. *Journal of International Money and Finance* 30 (3): 547–571.

Johansen, S. 1991. Estimation and hypothesis testing of co-integration vectors in Gaussian vector autoregressive models. *Econometrica* 59: 1551–1580.

Johansen, S., and K. Juselius. 1990. Maximum likelihood estimation and inference on co-integration with application to the demand for money. *Oxford Bulletin of Economics and Statistics* 52: 169–210.

Joyce, M.A.S., A. Lasaosa, I. Stevens, and M. Tong. 2011. The financial market impact of quantitative easing in the United Kingdom. *International Journal of Central Banking* 7 (3): 113–161.
Kapur, M., John, J. & Mitra, P. (2018). Monetary Policy and Yields on Government Securities. *RBI Mint Street Memo* No. 16.
Kavediya, R. & Pattanaik, S. (2016). Operating Target Volatility: Its Implications for Monetary Policy Transmission. *RBI Occasional Paper,* Vol. 37 – Nos. 1 & 2.
Krishnamurthy, A., & Vissing-Jorgensen, A. (2011). The effects of quantitative easing on interest rates: Channels and implications for policy. *National Bureau of Economic Research Working Paper* No. 17555.
Lam, R. W. (2011). Bank of Japan's monetary easing measures: Are they powerful and comprehensive? *IMF Working Paper* WP11.264.
Lavigne, R., S. Sarker, and G. Vasishtha. 2014. Spillover effects of quantitative easing on emerging market economies. *Bank of Canada Review* 2014 (Autumn): 23–33.
Lim, J. J., Mohapatra, S., & Stocker, M. (2014, March). Tinker, taper, QE, bye? The effects of quantitative easing on financial flows to developing countries. *Policy Research Working Paper* 6820, The World Bank, Development Prospects Group, Global Macroeconomics Unit.
Lombardi, M. J., & Zhu, F. (2014). A shadow policy rate to calibrate US monetary policy at the zero lower bound. *Technical Report, Bank for International Settlements.*
Meier, A. (2009). Panacea, curse, or nonevent: Unconventional monetary policy in the United Kingdom. *IMF Working Paper* No. 09/163.
Mishra, P., Moriyama, K., N'Diaye, P., & Nguyen, L. (2014). Impact of Fed Tapering Announcements on Emerging Markets. *IMF Working Paper* No. 14/109.
Moore, J., Nam, S., Suh, M., & Tepper, A. (2013). Estimating the impacts of U.S. LSAPs on emerging market economies' local currency bond markets. Staff Report No. 595. *Federal Reserve Bank of New York.*
Mundell, R.A. 1963. Capital mobility and stabilization policy under fixed and flexible exchange rates. *Canadian Journal of Economic and Political Science* 29: 475–485.
Neely, C. J. (2010). The large-scale asset purchases had large international effects. *Federal Reserve Bank of St. Louis Working Paper* No. 2010–018D.
Nkoro, E., and A.K. Uko. 2016. Autoregressive distributed lag (ARDL) co-integration technique: Application and Interpretation. *Journal of Statistical and Econometric Methods* 5 (4): 63–91.
Okina, K., and S. Shiratsuka. 2004. Policy commitment and expectation formation: Japan's experience under zero interest rates. *The North American Journal of Economics and Finance* 15 (November): 75–100.
Özatay, F., E. Özmen, and G. Şahinbeyoğlu. 2009. Emerging market sovereign spreads, global financial conditions and U.S. macroeconomic news. *Economic Modelling* 26 (2): 526–531.
Patra, M., Pattanaik, S., John, J., & Behera, H. (2016). Monetary policy transmission in India: Do global spillovers matter? *RBI Occasional Paper,* Vol. 37, Nos. 1 & 2.
Paul, M., & Kalluru, S. R. (2020), "The Impact of US Quantitative Easing on India's Money Market", Biswas, R., & Michaelides, M. (Ed.). Financial Issues in Emerging Economies: Special Issue Including Selected Papers from II International Conference on Economics and Finance, 2019, Bengaluru, India (Research in Finance, Vol. 36), Emerald Publishing Limited, Bingley, pp 45–66.
Pesaran, M.H., and R.J. Smith. 1998. Structural analysis of co-integration VAR S. *Journal of Economic Surveys* 12: 471–505.
Pesaran, M.H., Y. Shin, and R.J. Smith. 2001. Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics* 16: 289–326.
Rai, V., & Suchanek, L. (2014). The effect of the Federal Reserve's tapering announcements on emerging markets. *Bank of Canada Working Paper* No. 2014–50.
Rajan, R. (2014). *Concerns about competitive monetary easing.* 2014 BOJ-IMES Conference on Monetary Policy in a Post-Financial Crisis Era, Tokyo, Japan
Reifschneider, D. L. (2016). Gauging the ability of the FOMC to respond to future recessions. *Finance and Economics Discussion Series* No. 2016–068, Board of Governors of the Federal Reserve System.
Reserve Bank of India. 2018. *Report of the Working Group on Operating Procedure of Monetary Policy*. Chairman: Deepak Mohanty.
Sahoo, S., Shankar, S., & Anthony, M. J. (2020). US monetary policy and spillovers to select EMEs – An episodic analysis. Biswas, R., & Michaelides, M. (Ed.). Financial Issues in Emerging Economies: Special Issue Including Selected Papers from II International Conference on Economics and Finance, 2019, Bengaluru, India (Research in Finance, Vol. 36), Emerald Publishing Limited, Bingley, pp 67–97.
Sensarma, R., and I. Bhattacharyya. 2016. Measuring monetary policy and its impact on the bond market of an emerging economy. *Macroeconomics and Finance in Emerging Market Economies* 9 (2): 109–130.

Sobrun, J., & Turner, P. (2015). "Bond Markets and Monetary Policy Dilemmas for the Emerging Markets", Bank for International Settlements, Working Papers, No. 508.
Swanson, E. (2011). *Let's twist again:* A high-frequency event-study analysis of operation twist and its implications for QE2. *BPEA (Spring),* pp 151–188.
Vayanos, D., & Vila, J.-L. (2009). A preferred-habitat model of the term structure of interest rates. *NBER Working Paper* No. 15487.
Woodford, M. (2012). Methods of policy accommodation at the interest-rate lower bound. Paper presented at the 2012 Jackson Hole conference, Federal Reserve Bank of Kansas City.
Wright, J. (2011). What does monetary policy do to long-term interest rates at the lower zero bound? *NBER Working Paper* No. 17154.
Yellen, J. L. (2016). The Federal Reserve's monetary policy toolkit: Past, present, and future. Speech at the Federal Reserve Bank of Kansas City Symposium on "Designing Resilient Monetary Policy Frameworks for the Future," Jackson Hole, Wyoming, August 26.