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Volatility Spillover Effects of U.S. Quantitative Easing Policies: Evidence from BRIC Bond Markets

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Abstract: We gauge the U.S. quantitative easing (QE) volatility spillover effects on BRIC (Brazil, Russia, India and China) bond markets. The results show a pronounced volatility spillover effect of U.S. QE policy shocks on BRIC bond markets. In particular, BRIC bond markets experienced a more volatile position during the early U.S. QE phases. The adverse U.S. QE spillover effects trigger volatility in BRIC bond markets and partially counteract the market-stabilizing domestic monetary policy effects. This finding indicates an improvement in international policy collaboration, especially between emerging and leading economies.

Key words: quantitative easing; monetary policy shock; BRIC bond markets; volatility spillover; DCC-MGARCH model

JEL codes: E52; F42; G15

1. Introduction

The last decade has witnessed many policy innovations, especially monetary policy innovations. Among these policy innovations, quantitative easing (QE) is among the most popular unconventional monetary policies implemented by central banks (such as Federal Reserves) to stimulate a depressed economy (Klyuev et al., 2009). This policy significantly increased U.S. economic growth, lowered the unemployment rate (Kim & Nguyen, 2009; Chen et al., 2016; Stockhammar & Österholm, 2017), and affected the financial asset returns of international markets (Bauer & Neely 2014; Gagnon et al., 2017). In addition to studying U.S. QE policies from the return perspective, recent studies have assessed the potential volatility spillover effects of U.S. QE policies (Li & Giles, 2015; Yang & Zhou, 2016).

However, these previous studies focused on the U.S. QE volatility spillover effects on international stock markets without analyzing the effects on government bond markets. Government bonds represent an important part of the financial market used by governments to gather funds, and the performance of the government bond market is of significant importance. Changes in the volatility level of government bond markets could not only alter investors' portfolios and investment choices but also consequently change government income and spending. Therefore, studying the U.S. QE volatility spillover effects on bond markets could provide risk management

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guidance to international investors and benefit international monetary cooperation.

This paper empirically examines the volatility spillover effects of U.S. QE policies, particularly on BRIC bond markets. One reason for choosing the ten-year government bond market is that the government bond, especially the long-term government bond, is closely related to U.S. QE operations (Bernanke & Reinhart, 2004). Moreover, emerging financial markets are less developed than advanced markets; thus, such markets are more vulnerable to latent turbulence due to external policy shocks (Chudik & Fratzscher, 2011). In this study, we evaluate the U.S. QE policy shocks to long-term assets (USQEPSLA), which are calculated based on ten-year treasury futures data, to gauge the U.S. QE volatility spillover effects on BRIC bond markets. The empirical results suggest that the USQEPSLA significantly increase the bond yield volatilities in BRIC bond markets during early U.S. QE periods and that these volatilities gradually fade.

This paper offers several contributions. First, we develop a novel approach to measuring external U.S. QE policy shocks independently. One advantage of this method is that the measure is immune to the model specification. The results suggest that the unilateral monetary easing policy injects volatilities in BRIC bond markets during the early U.S. QE phases. This finding provides new evidence supporting market integration and international policy interaction, especially between the U.S. and emerging bond markets.

The remainder of the paper is organized as follows. Section 2 reviews the literature related to the U.S. QE spillover effects on global financial markets from both the return and volatility perspectives. Section 3 presents the data and econometric models used in this study. In section 4, we discuss the empirical results of this study. Section 5 provides the robustness tests, followed by practical implications and conclusions in section 6.

2. Literature Review

Since their first implementation after the 2008 global financial crisis, unconventional monetary policies, such as U.S. QE policies, have attracted much interest and debate (Aysun & Hepp, 2011; Krishnamurthy & Vissing-Jorgensen, 2011). The U.S. QE policies are designed to address economic recession problems in the U.S. economy. However, following the initial U.S. QE1 announcement, scholars have mainly focused on the impacts of U.S. QE policies on domestic markets and the economy (Gagnon et al., 2011; D’Amico & King, 2013). For example, Krishnamurthy and Vissing-Jorgensen (2011) found that the U.S. QE policy announcements significantly lowered bond yields of various maturities, but the intensity of the effect depended on the maturity of the bond.

2.1 U.S. QE Spillover Effects on Asset Returns

Following the implementation of U.S. QE policies, the focus of the literature shifts from the domestic effects of U.S. QE policies to international spillover effects. For example, Neely (2015) assessed the U.S. QE spillover effects on long-term bond yields from five developed markets using the event study method. This author found a significant decrease in all bond yields closely following the U.S. QE announcements. Similarly, Gambacorta et al. (2014) examined U.S. QE spillover effects and found a temporary increase in consumer prices in eight developed markets.

In addition to studies related to developed markets, many studies investigated the U.S. QE spillover effects on emerging markets. Park et al. (2016) examined capital flows in developing Asian markets during the U.S. QE phases. The authors found larger capital flows to developing Asian markets during the U.S. QE periods, and compared to before the 2008 global finance crisis, bonds played a larger role in capital flows. Miyakoshi et al.

(2017) examined the U.S. QE spillover effects on eight Asian emerging markets with a time-varying parameter vector autoregression (VAR) model and found that the U.S. QE policy contributed to a significant increase in stock prices in their sample of emerging markets. Xu and La (2017) assessed the U.S. QE spillover effects on Asian credit markets and observed a substantial increase in the U.S. dollar credit in Asian emerging markets. These results further confirmed the U.S. QE spillover effects on credit markets.

2.2 U.S. QE Volatility Spillover Effects on Financial Assets

In addition to the literature concerning the U.S. QE spillover effects on asset returns, increasing studies have investigated the U.S. QE spillover effects on volatility. For example, Li and Giles (2015) examined the stock market correlations among the U.S., Japan and six developing Asian markets during the U.S. and Japan QE phases. Their results suggest that in both the long run and short run, emerging markets are influenced by domestic policy shocks more than developed markets. However, the U.S. QE volatility spillover effects are more pronounced than those of the Japanese market on the sample emerging markets. Another study conducted by Ghosh and Saggar (2016) examined the U.S. QE volatility spillover effects on BRICS markets and some additional emerging markets during the taper talk period. The authors found a significant volatility clustering phenomenon in the emerging bond markets and observed a contemporaneous volatility covariance between the U.S. and other emerging markets in both equities and government securities. Yang and Zhou (2016) used implied volatility indices to test the volatility spillover effects on U.S. bond and global stock markets. Their empirical results indicated that the volatility spillover effects of U.S. markets intensified three times during the U.S. QE periods. These authors also noted that the U.S. QE policy was the primary driver intensifying the volatility spillover effects and could account for approximately half of the variations in the spillover effects.

However, some gaps exist in the existing literature. First, most studies focus on the U.S. QE volatility spillover effects on global stock markets, and few studies address the effects on bond markets. Furthermore, the event study approach used in some studies is highly dependent on the length of the event window and is unable to capture the persistent effects of U.S. QE policies. Moreover, although time series models, such as the generalized autoregressive conditional heteroscedastic (GARCH) model or the VAR model, can measure the interactions among different markets, such models are unable to properly identify the U.S. QE policy shocks. The shocks generated by the GARCH and VAR models cannot explicitly explain exogenous U.S. QE policy shocks but rather represent the shocks of these markets in general. Therefore, in this study, using the DCC-MGARCH framework, we explain exogenous U.S. QE policy shocks calculated based on ten-year U.S. Treasury futures data. We expect to capture both the market interactions and model-free exogenous U.S. QE policy shocks during different U.S. QE phases.

3. Methodology

3.1 Data

The sampling period ranges from January 2007 to January 2016, and the data are of daily frequency. To calculate the stationary time series data, we use the bond yield change calculated in the following formula: $\ln(P_t/P_{t-1})*100$. P_t is the bond yield price in each market at time t. The sampling period covers all three U.S. QE periods (U.S. QE1, QE2 and QE3 periods), enabling the assessment of U.S. QE policy shocks during all U.S. QE periods. All three U.S. QE periods are determined based on the Federal Reserve QE announcements. To control for potential interactions across international bond markets, we use the daily bond yield from the three leading bond markets (the U.S., the U.K. and Japan) and the BRIC ten-year government bond markets. Furthermore, we include the monetary base (MB) from the BRIC markets to control for their domestic monetary policy impacts[1].

The summary statistics of the sample bond yield data are presented in Table 1. The mean coefficient indicates that, by a large margin, the BRIC bond yields are higher than those in their developed counterparts, especially the Russian and Indian markets. This higher reward triggers investors' interests and induces capital inflow from developed bond markets to emerging economies. The standard deviation coefficient suggests that the BRIC bond markets (except for China) are more volatile than the developed bond markets, which is unsurprising because higher returns are associated with higher risk.

The log-differentiated daily bond yield data are displayed in Figure 1. The three shaded areas represent each individual U.S. QE period[2]. A pronounced spike in the daily bond yields during or around each U.S. QE period can be observed in the BRIC markets. This finding indicates that the bond yields in the BRIC markets became more volatile in response to U.S. QE policies.

Table 1 Descriptive Statistics of Government Bond Yields from the Sample Markets (2007 to 2016)

Market	Nobs	Mean	Median	Max	Min	Std. Dev.
US	2340	2.92	2.74	5.29	1.39	0.91
UK	2340	3.13	2.98	5.55	1.33	1.12
JP	2340	1.04	1.03	1.97	0.20	0.43
CH	2340	3.72	3.60	4.71	2.78	0.43
BR	2340	4.61	4.59	11.13	2.24	1.18
IN	2340	7.97	7.98	9.48	5.08	1.62
RU	2340	8.55	7.87	16.24	6.26	2.03

Source: Author's calculation based on data from Bloomberg and DataStream

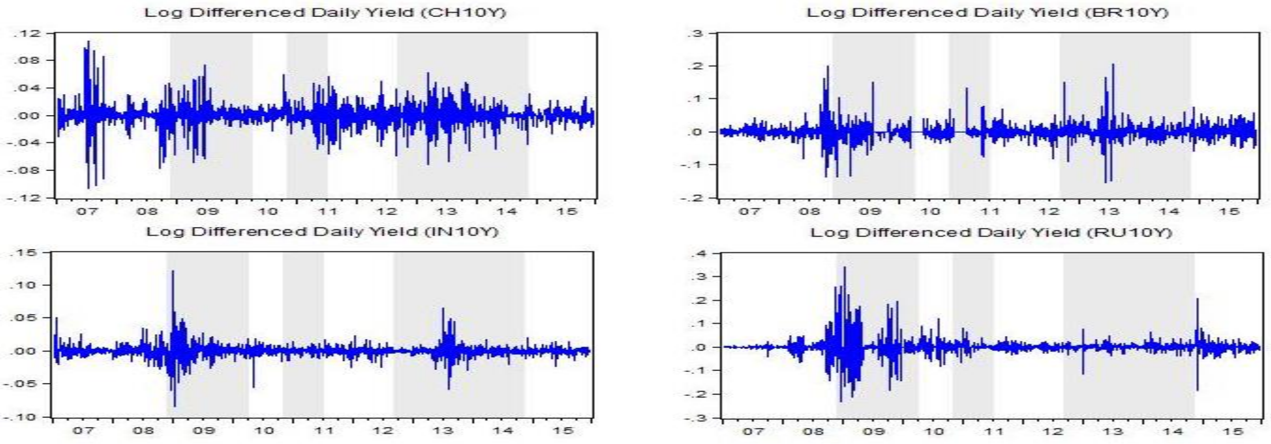

Figure 1 Log-Differentiated Daily Bond Yields of BRIC Markets

3.2 Measuring U.S. QE Policy Shocks

One issue addressed in the previous literature related to U.S. QE policies is the proper measurement of the unexpected components of monetary policies, such as the U.S. QE policy. According to the efficient market

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[1] The monetary base data are of monthly frequency and calculated using the formula $\ln(P_t/P_{t-1})*100$. P_t represents the monetary base data at time t.

[2] In this study, we do not include the Maturity Extension Program, but the taper talking period is included in the U.S. QE3 period.

hypothesis, the expected monetary policy changes should already be reflected in the current market prices. Only unexpected monetary policy changes, i.e., monetary policy shocks, can affect market prices. Hence, it is essential to distinguish the anticipated and unanticipated components of monetary policies. One common approach advocated by the previous literature (Kuttner, 2001) is to use the change in futures prices to calculate exogenous policy shocks. In contrast to the spot market in which prices precisely reflect an asset's current market value, the futures market prices reflect the market expectations of future economic developments. Therefore, the futures market provides a price discovery function and can measure the unexpected components of current monetary policies. Compared to conventional monetary policies, which adjust the short-term interest rates, unconventional monetary policies, such as the QE policy, mainly target long-term interest rates. Therefore, we develop the USQEPSLA with U.S. monetary policy shocks to long-term assets (MPSLA) based on the long-term (ten-year) treasury futures data[3]. We adopt the Kishor and Marfatia (2013) method developed based on Kuttner's (2001) study.

The daily U.S. MPSLA is defined in equation (1).

$$\Delta r_t^{MPSLA} = \frac{n_s}{n_s - u}\left(g_{s,u}^0 - g_{s,u-1}^0\right) \tag{1}$$

where Δr_t^{MPSLA} is the daily U.S. MPSLA, n_s is the number of days in month s, $g_{s,\upsilon}^0$ is the current-month ten-year treasury futures price on day υ of month s, and $g_{s,\upsilon-1}^0$ is the current-month long-term treasury futures price on day $\upsilon - 1$. The model applies to all days within one month, except for the first and last days. When the U.S. MPSLA occurs on the first day of the month, the expectation of its impact would have been reflected in the rate of the previous month; thus, the prior month's ten-year treasury futures rate on the last day, i.e., $g_{s-1,\upsilon-1}^1$, is applied instead of $g_{s,\upsilon-1}^0$. Similarly, when the U.S. MPSLA occurs on the last day of the month, the difference in the 1-month long-term U.S. Treasury futures rate is used. The U.S. MPSLA transpiring on the last day of each month cannot affect the current-month spot rate. Furthermore, to avoid amplifying the month-end noise, no adjustments in terms of scaling are applied when the U.S. monetary policy change announcement occurs within the last 3 days of the month.

We multiply the variable Δr_t^{MPSLA} calculated in equation (1) by dummy variables (defined in Table 2) to obtain the USQEPSLA variables (shown in the second equation).

$$USQEPSLA_{i,t} = d_i * \Delta r_t^{MPSLA} \tag{2}$$

The USQEPSLA$_{i,t}$ variables represent the daily monetary policy shocks generated within the U.S. QE1, QE2 and QE3 periods. The dummy variables d_i represent the time frame of each individual U.S. QE period decided by the federal QE announcements. In both cases, i = 1, 2, and 3. Variable Δr_t^{MPSLA} measures the daily U.S. monetary policy shocks during the entire sampling period.

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[3] In addition to applying long-term treasury data to calculate the U.S. MPSLA, we include federal funds futures data to calculate the U.S. QE policy shock to short-term asset (USQEPSSA). We include this shock as a robustness test only.

Table 2 Different U.S. QE Rounds

Dummy Variable	1	0
d_1	November 25, 2008 to March 25, 2010	Otherwise
d_2	November 3, 2010 to June 25, 2011	Otherwise
d_3	September 13, 2012 to October 29, 2014	Otherwise

3.3 Empirical Model

To estimate the volatility spillover effects of the U.S. QE policy shocks on the BRIC bond markets, we use the DCC-MGARCH model (Engle 2002). The DCC-MGARCH model has been widely applied to examine the volatility spillover effects in international financial markets (for example, Baklaci et al., 2016; Kang et al., 2016). The DCC-MGARCH model is given as follows. The mean equation is shown in equation (3):

$$\mathrm{D}Y_t = C + e_t \tag{3}$$

where ΔY_t is the change in the yield data at time t in each bond market, ε_t is the error term, and C is a constant.

Then, we add the control variables and the USQEPSLA variables defined in section 3.2 to the variance equation of the DCC-MGAGRCH model as follows:

$$h_t = C_1 + a_1 e^2_{t-1} + b_1 h^2_{t-1} + a_1 MB^{ds}_{i,t} + b_1 USQEPSLA_{1,t} + b_2 USQEPSLA_{2,t} + b_3 USQEPSLA_{3,t} \tag{4}$$

where h_t is the conditional variance at time t, ε^2_{t-1} is the square of residuals in time t-1, which is the previous period of t, and h^2_{t-1} is the square of the conditional variance in time t-1, which also refers to the previous period of t. $USQEPSLA_{i,t}$ represents the daily U.S. QE policy shocks within each QE period. MB^{ds}_t represents the monthly MB change that controls for the domestic monetary policy effects in each BRIC market.

This is the model for each univariate GARCH model. Then, we estimate the dynamic conditional correlation based on the univariate results and the residual ε_t generated from both equations (3) and (4) as follows:

$$e_t = D_t v_t \square N(0, H_t) \tag{5}$$

where ε_t is an m × 1 column vector of the residuals of ΔY_t in equation (3), m is the number of markets included, v_t is an m × 1 column vector of the standardized residuals, and H_t is an m × m matrix of the time-varying variances. Specifically,

$$H_t = D_t R_t D_t \tag{6}$$

where D_t is an m x m diagonal matrix of the time-varying standard deviation of the residual mean in equation (1) and $D_t = diag\left\{\sqrt{h_t}\right\}$, where each h_t is calculated from the univariate GARCH (1, 1) model in equation (4).

The framework also consists of a specific DCC structure R_t, which is an m x m matrix of the time-varying correlations and can be expressed as follows:

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1} \tag{7}$$

The dynamic conditional correlation structure is given by equation (8) as follows:

$$Q_t = (1-\theta_1-\theta_2)\bar{Q} + \theta_1 v_{t-1} v'_{t-1} + \theta_2 Q_{t-1} \tag{8}$$

where Q_t is the conditional variance–covariance matrix of the residuals, and its unconditional variance–covariance matrix $\bar{Q}$ is obtained from the GARCH (1, 1) process in equation (4). Q_t^* is a diagonal matrix with the square root of the diagonal elements of Q_t, and $Q_t^* = diag\left\{\sqrt{Q_t}\right\}$. $v_t = \varepsilon_t / \sqrt{h_t}$, and the scalars θ_1 and θ_2 are nonnegative and satisfy $\theta_1 + \theta_2 < 1$.

The parameters in both equations (4) and (8) can represent the time-varying volatility spillover effects of the U.S. QE policy shocks on different bond markets. In contrast to the estimation by the univariate GARCH model alone, which ignores the interaction within each market, the DCC-MGARCH model jointly considers the interdependence among the markets and exogenous U.S. QE shocks and can better identify the spillover effects triggered by U.S. QE policies.

4. Empirical Results

The estimation results are presented in Table 3. Regarding the ARCH and GARCH effects, the coefficients are significant in all BRIC markets. The sum of all coefficients is less than one, indicating the short- and long-term persistence of the variance. The pronounced coefficients also provide evidence of volatility clustering.

The estimated coefficient of the domestic monetary change is negative and statistically significant in each BRIC market. This finding indicates that in these economies, the domestic monetary easing policy effectively lowers the market risk level of bond yields. The increasing monetary supply injects liquidity into the market. Consequently, this monetary easing policy mitigates the obstacles to transferring assets and stabilizes market volatility.

Table 3 USQEPSLA Effects on Global Bond Yield Volatility

Market	ARCH	GARCH	MB	USQEPSLA1	USQEPSLA2	USQEPSLA3	θ_1	θ_2
CH	0.155***	0.527***	-0.018***	0.036***	0.045***	-0.061	0.021**	0.633**
BR	0.112***	0.555***	-0.013**	0.079***	0.134***	-0.037**	0.005**	0.990***
IN	0.147***	0.570***	-0.018***	0.030***	0.042**	-0.033*	0.026**	0.624**
RU	0.148***	0.572***	-0.026***	0.235**	0.431***	-0.319	0.024**	0.261*

***, ** and * indicate that the values are significant at the 1%, 5% and 10% levels, respectively.

In contrast to the domestic monetary easing policy, which has a negative impact on the bond yield volatility level, the estimated coefficient of the U.S. QE volatility spillover effects is positive and statistically significant in all BRIC bond yields during the early QE stages (U.S. QE1 and QE2). This finding indicates that the instability of the BRIC bond yield volatility is due to the constant disorder induced by the U.S. QE policies during their early phases. However, during the QE3 period, the estimated coefficient is nonsignificant or only marginally significant. This finding suggests that the volatility turbulence in the BRIC bond markets decreases likely because of the market adjustments or stricter regulations in these economies.

The DCC parameters are positive and significant in all markets. The sum of all estimated coefficients is less than one, indicating that the dynamic correlation between the BRIC markets and leading bond markets is stationary and mean reverting.

Figure 2[4] depicts the dynamic conditional correlations between the U.S. bond market and BRIC bond markets from 2007 to 2016. The three shaded areas represent the individual U.S. QE phases. Generally, the dynamic correlation is persistent with no significant upward or downward trends (except for Brazil). However, significant correlation changes are observed during or around each U.S. QE period.

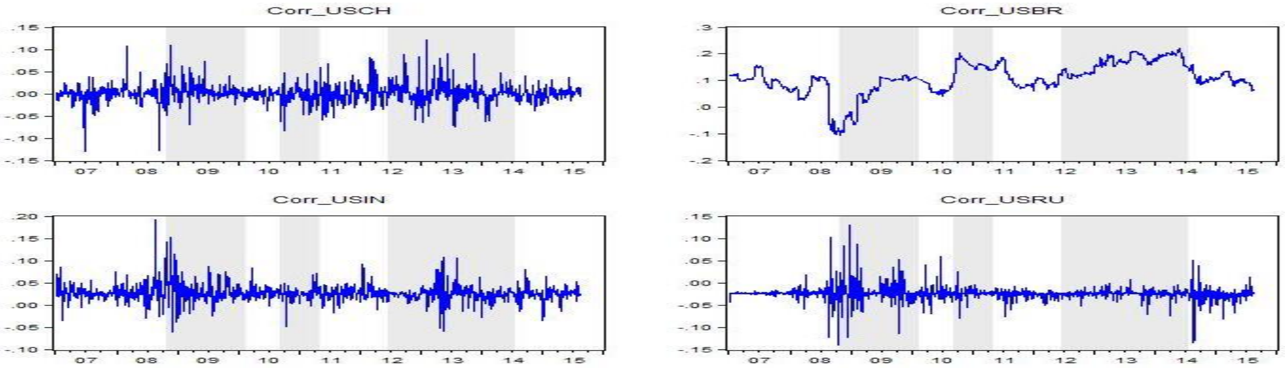

Figure 2 Dynamic Conditional Correlation between the U.S. and BRIC Bond Markets

5. Robustness Test

To better examine the volatility spillover effects of U.S. QE policies, in addition to the USQEPSLA variables defined in equation (2), we calculate the U.S. QE policy shocks to short-term assets (USQEPSSA) with federal funds futures data. The USQEPSSA variables are calculated using the same method as that defined in equations (1) and (2). First, we calculate the U.S. monetary policy shocks to short-term assets (MPSSA) with federal funds futures data in equation (9).

$$\Delta r_t^{MPSSA} = \frac{n_s}{n_s - \upsilon}(f^0_{s,\upsilon} - f^0_{s,\upsilon-1}) \tag{9}$$

Then, we develop the USQEPSSA variables by multiplying the U.S. MPSSA variables by time dummies representing each individual U.S. QE period (shown in Table 2) in equation (10).

$$USQEPSSA_{i,t} = d_i * \Delta r_t^{MPSSA} \tag{10}$$

To avoid the potential multicollinearity problem between the USQEPSSA and USQEPSLA variables, we examine the Pearson correlations between these variables. The correlation coefficient (shown in Panel A, Table 4) is significant but only moderately (0.102). Moreover, we examine the Granger causality relationship between these two variables, and the results are reported in Panel B of Table 4. The nonsignificant results indicate that we cannot reject the null hypothesis that there is no Granger causality relationship between these two variables. These results jointly suggest that there is no multicollinearity problem when incorporating these two variables in the same equation.

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[4] For brevity, only the dynamic conditional correlations between the U.S. bond market and BRIC markets are reported.

Table 4 Pearson Correlations and Granger Causality Test between USQEPSLA and USQEPSSA

Panel A: Pearson Correlations between USQEPSLA and USQEPSSA	
	USQEPSLA
USQEPSSA	0.103***
Panel B: Granger Causality Test between USQEPSLA and USQEPSSA	
Null Hypothesis:	F-Statistic
USQEPSSA does not Granger Cause USQEPSLA	1.6501(0.1991)
USQEPSLA does not Granger Cause USQEPSSA	1.4702(0.2248)

***indicates that the value is significant at the 1% level. The number shown in brackets represents the probability.

The variance equation with both the USQEPSSA and USQEPSLA variables is given as follows:

$$h_{1t} = C_2 + a_2 e_{t-1}^2 + b_2 h_{1t-1}^2 + a_1^{'} MB_{i,t}^{ds} + b_1^{'} USQEPSLA_{1,t} + b_2^{'} USQEPSLA_{2,t} + b_3^{'} USQEPSLA_{3,t} + b_4 USQEPSSA_{1,t} + b_5 USQEPSSA_{2,t} + b_6 USQEPSSA_{3,t} \tag{11}$$

The results are reported in Table 5. Following the inclusion of the USQEPSSA variables, the USQEPSLA results show minimal difference from those reported in Table 3, indicating that our results are robust.

Table 5 USQEPSLA and USQEPSSA Effects on Global Bond Yield Volatility

Market	ARCH	GARCH	MB	USQEPSLA1	USQEPSLA2	USQEPSLA3	USQEPSSA1	USQEPSSA2	USQEPSSA3	θ_1	θ_2
CH	0.102***	0.582***	-0.007***	0.028**	0.034***	-0.021	-0.448	-0.726*	-3.649	0.039***	0.729***
BR	0.106***	0.582***	-0.013**	0.114***	0.115***	-0.081*	3.742	-6.523	-18.591*	0.008**	0.985***
IN	0.177***	0.519***	-0.016***	0.009**	0.017**	-0.023**	3.650	-2.346	9.825*	0.039***	0.620***
RU	0.148***	0.572***	-0.026**	0.235***	0.273***	-0.321*	0.497	-72.849*	-92.983*	0.027**	0.457*

***, ** and * indicate that the values are significant at the 1%, 5% and 10% levels, respectively.

6. Conclusion

The main purpose of this article is to assess the U.S. QE volatility spillover effects on the long-term government bond yield in BRIC markets. We develop a novel means to measure the individual U.S. QE policy shocks to long-term assets with ten-year treasury futures data. We adopt this measure to examine the bond yield volatilities in BRIC bond markets from 2007 to 2017, covering all three QE phases. We also incorporate another shock calculated with federal funds futures data as a robustness test.

Our results indicate that similar to their effect in stock markets, the U.S. QE shocks induce volatility bursts in BRIC bond markets. Although the adverse impact of this unilateral policy gradually weakens due to market adjustments, it still mitigates the benefits of the domestic monetary policy in stabilizing the market. Therefore, in emerging economies, such as BRIC markets, monetary authorities should develop policies in collaboration with leading economies, such as the U.S., and improve their market regulation and supervision.

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