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## Article

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Journal of Risk and Financial Management

## Provided in Cooperation with:

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*Suggested Citation:* Bao Cong Nguyen To; Tam Van Thien Nguyen; Nham Thi Hong Nguyen; Hoai Thu Ho (2022) : Responses of the international bond markets to COVID-19 containment measures, Journal of Risk and Financial Management, ISSN 1911-8074, MDPI, Basel, Vol. 15, Iss. 3, pp. 1-11, <https://doi.org/10.3390/jrfm15030127>

This Version is available at:

<https://hdl.handle.net/10419/258850>

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## Article

# Responses of the International Bond Markets to COVID-19 Containment Measures

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**Abstract:** Using an international sample during the COVID-19 outbreak, our study gives evidence that COVID-19 containment measures impact volatility in the international bond markets in different ways. We found that the positive effect of increasing new COVID-19 vaccinations markedly mitigates bond market volatility, while non-pharmaceutical government interventions resembling bad news increase volatility in bond markets. Besides this, changes in total COVID-19 cases and total deaths have co-movement and a significant relationship with this volatility. Our results imply that the investors' responses to the trigger of increased uncertainty seem to differ in a way that depends on bad or good news as a reflection of the possibility of pandemic control and the health of the economy. The mass vaccinations not only signal a lower probability of stringent government responses to the pandemic but also stabilize investors' behavior and mitigate compliance fears to open a period of safe living with coronavirus. Our findings are still robust when using alternative measures of independent variables and different forecasting models of conditional volatility.



**Citation:** To, Bao Cong Nguyen, Tam Van Thien Nguyen, Nham Thi Hong Nguyen, and Hoai Thu Ho. 2022.

Responses of the International Bond Markets to COVID-19 Containment Measures. *Journal of Risk and Financial Management* 15: 127. <https://doi.org/10.3390/jrfm15030127>

Academic Editors: Ruipeng Liu and Thanasis Stengos

Received: 13 January 2022

Accepted: 3 March 2022

Published: 8 March 2022

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**Keywords:** COVID-19 containment measures; government interventions; international bond market; vaccinations

**JEL Classification:** G01; G10; G12; G15; G18; H12; H51; I18

## 1. Introduction

In the process of development, the global financial market has experienced several crises and been severely impacted. However, the appearance of the COVID-19 pandemic has resulted in significant changes and had many harmful effects on the macroeconomic and finance systems of different countries around the world (Laing 2020). A consequence of this pandemic has been altered prices of various asset classes in the financial market, such as the international stock market (Ashraf 2020b; Goodell 2020), alternative assets such as cryptocurrency (Bakas and Triantafyllou 2020), commodity markets (Liu et al. 2020; Mensi et al. 2020), and debt markets (Arellano et al. 2020; Sène et al. 2021). Governments have adopted many containment measures, applied social distancing, and limited domestic and international travel. Besides this, a few nations have introduced monetary policies, such as lower interest rates (Argentina, England), quantitative easing expansion (United States), lower reserve requirement ratio (Brazil, China), or financial policies related to the application of income assistance and debt relief programs (United States).

Nevertheless, the effectiveness of government strategies remains controversial, especially regarding non-pharmaceutical interventions. Many researchers have identified such interventions as having high economic costs, such as by creating a decline in industrial production (Deb et al. 2021) and, at the same time, an increase in the proportion of unemployed (Arnon et al. 2020). Moreover, Fan et al. (2018) argued that different countries have different medical system preparations, rigor in government regulations, social factors such as pandemic comprehension, and response capacity. Thus, the impact of COVID-19 on

the volatility of the financial market can be disparate. [Zaremba et al. \(2020\)](#) demonstrated that reactions to non-pharmaceutical interventions and the rigor of national regulations resulted in a considerable fluctuation of the stock market.

On the other hand, from a behavioral perspective, the COVID-19 pandemic leads to a fear of ambiguity, hence affecting all the other aspects, especially the international economic and financial system ([Phan and Narayan 2020](#)). News regarding the rise of COVID-19 cases, number of deaths, number of distancing days, and number of people being tested during the pandemic period has a major impact on the market volatility ([Haroon and Rizvi 2020](#)). The awareness of citizens about recent economic developments, health conditions, and future expectations directly affects the profitability and volatility of the financial market ([Alfaro et al. 2020](#); [Ashraf 2020a, 2020b](#)). Financial markets are unpredictable, and in this pandemic, uncertainty is even more difficult to predict than in times of crisis ([Wagner 2020](#)). Any crisis, from either an economic perspective or a medical one, does increase uncertainty across all markets, leading to a cautious response by investors and thereby limiting investment in risky assets, negatively affecting the financial markets in general. Results retrieved from various recent studies prove that the COVID-19 pandemic has increased the volatility of the financial market ([Cong Nguyen To et al. 2021](#); [Demir et al. 2021](#); [Ozili and Arun 2020](#); [Uddin et al. 2021](#); [Yu et al. 2021](#)). Other studies related to COVID-19 illustrate the increase in uncertainty in all markets and economies during the pandemic period ([Liu et al. 2020](#); [Salisu and Adediran 2020](#); [Sharma 2020](#)).

The previous studies analyzed the devastation COVID-19 has wrought on cryptocurrency ([Chen et al. 2020](#)), the stock market ([Salisu and Akanni 2020](#)), and commodity prices ([Salisu et al. 2020](#)). Research on government bonds, an asset which makes up an important part of global trading, is very rare. In particular, only a few studies paid attention to the impact of the pandemic on bond yields, prices, or liquidity ([Arellano et al. 2020](#); [Ashraf 2020b](#); [Zaremba et al. 2020](#)), while research rarely mentions the volatility of the international bond markets. [Ashraf \(2020a\)](#) reported that restrictive government strategies, particularly the announcement of traffic limitations, harmfully affect the bond market, while policies that impose quarantine and inspection have a positive impact. In contrast, [Narayan et al. \(2021\)](#) proved that traffic restrictions and economic assistance have an optimistic influence on the international bond market. [Zaremba et al. \(2021a\)](#), with an interest in the liquidity of the international bond market, examined the impact of government distancing policies such as workplace and school closures, finding that they reduced liquidity in the market in emerging economies, while campaigns to raise awareness about the virus had the opposite effect.

In this study, we analyze the impact of COVID-19 containment measures on bond market volatility in hard-hit countries during the pandemic. Our findings contribute to the literature on the impact of the COVID-19 outbreak on international bond markets ([Arellano et al. 2020](#); [Zaremba et al. 2021a, 2021b](#)). Our study shows that non-pharmaceutical interventions have adverse impacts on the international bond market ([Arnon et al. 2020](#); [Deb et al. 2021](#)), increasing the volatility in bond markets. On the other hand, our findings prove that an increase in COVID-19 cases and deaths adversely impacts the volatility of the international bond market. This shows that the feeling of anxiety regarding rising numbers of COVID-19 cases creates panic in all aspects ([Aslam et al. 2020](#)). More importantly, mass vaccinations seem to be a positive signal, increasing the confidence of investors in the international bond markets.

The study is organized as follows: We detail the sample, proxy variable measurements, and econometric models in Section 2. We report the results in Section 3 and discuss concluding remarks in Section 4.

## 2. Sample, Model, and Methodology

### 2.1. Sample

Covered in our dataset are the national daily 10-year government bond returns, the explanatory variables related to the COVID-19 containment measures as provided by

the Oxford COVID-19 Government Response Tracker (OxCGRT), and new COVID-19 vaccinations over the period of 7 February 2020 to 15 August 2021. We also used the numbers of confirmed cases and deaths and the country-level control and macroeconomic variables in our empirical models. Observations that were not available and non-trading were excluded in this study. Table 1 provides a detailed list of the variables and their definitions, calculations, and sources. To ensure that the unit root problem did not occur in the dataset, we used the first or second difference of the data in suitable conditions. For the unbalanced panel data set, the Fisher-type Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests (Choi 2001) were utilized to confirm that our variables were stationary. The results of these tests are not reported but are available on request from the authors. At the end of the process, we had built unbalanced panel data for 34 countries (see Appendix A), composed of 8446 country–day observations.

**Table 1.** Variable definitions.

Variable	Definition	Sources
Dependent variable		
BVOL	Volatility in the daily 10-year government bond, measured by the conditional variance extracted from the asymmetric GJR-GARCH(1,1) for country $i$ at time $t$ .	Calculation based on data from <a href="https://www.investing.com/rates-bonds/">https://www.investing.com/rates-bonds/</a> (accessed on 17 August 2021)
Explanatory variables related to COVID-19		
RTI	The daily relative change in the Oxford COVID-19 Government Response Tracker (OxCGRT) for country $i$ at time $t$ .	Calculation based on data from <a href="https://github.com/OxCGRT/covid-policy-tracker">https://github.com/OxCGRT/covid-policy-tracker</a> (accessed on 17 August 2021)
VACCINE	The daily relative change in the new COVID-19 vaccinations per million individuals for country $i$ at time $t$ .	Calculation based on data from <a href="https://ourworldindata.org/coronavirus">https://ourworldindata.org/coronavirus</a> (accessed on 17 August 2021)
CASES	The daily relative change in COVID-19 total cases per million individuals for country $i$ at time $t$ .	Calculation based on data from <a href="https://ourworldindata.org/coronavirus">https://ourworldindata.org/coronavirus</a> (accessed on 17 August 2021)
DEATHS	The daily relative change in COVID-19 total deaths per million individuals for country $i$ at time $t$ .	Calculation based on data from <a href="https://ourworldindata.org/coronavirus">https://ourworldindata.org/coronavirus</a> (accessed on 17 August 2021)
Variables related to macroeconomic variables		
ER	The daily percentage change in the exchange rate (ER) for country $i$ at time $t$ .	Calculation based on data from <a href="https://www.investing.com/currencies/single-currency-crosses">https://www.investing.com/currencies/single-currency-crosses</a> (accessed on 17 August 2021)
VIX	The daily relative change in the CBOE volatility index implying the market expectation of near-term volatility conveyed by stock index option prices at time $t$ .	Calculation based on data from <a href="https://fred.stlouisfed.org/series/VIXCLS">https://fred.stlouisfed.org/series/VIXCLS</a> (accessed on 17 August 2021)
OP	The daily relative change in the oil price based on crude oil WTI in U.S. dollars per barrel at time $t$ .	Calculation based on data from <a href="https://www.investing.com/commodities/crude-oil">https://www.investing.com/commodities/crude-oil</a> (accessed on 17 August 2021)

## 2.2. Model and Methodology

### 2.2.1. The GJR-GARCH (1,1) Model

Playing a vital role in the finance sector, volatility—a measure of return variability—has been employed as a tool to assess the total risk of financial assets. Not only is it used in a variety of value-at-risk models to measure market risk, but it was also applied by Black and Scholes (1972) to derive the price of traded options and other theoretical asset pricing models such as Sharpe’s (1964) model. The GARCH model, first initiated by Bollerslev (1986) and Taylor (1987), was developed on the basis of the ARCH model by Engle (1982) to produce better-forecasted models of conditional volatility. In stark contrast with the

traditional GARCH models—wherein financial data are claimed to follow an asymmetric distribution—the AR, MA, and ARMA models do not capture volatility clustering and leptokurtosis, which makes them not conditionally heteroskedastic (Fabozzi et al. 2014).

Black's (1976) research pointed out that the correlation between financial asset returns and changes in return volatility is negative, implying that the negative shocks (bad news) at time  $t - 1$  have a stronger impact on the volatility at time  $t$  than do positive shocks (good news). In fact, such a lack of a symmetrical distribution used to be defined as the leverage effect, since the increase in risk comes from the increased leverage prompted by a negative shock (Bollerslev et al. 1992; Tao and Brooks 2019). However, the above phenomenon is not addressed in the GARCH models since supposing the magnitude and not the positive or negative sign of excess returns influences the conditional volatility. Equally importantly, as there is no stability of volatility, non-negativity constraints may be violated, meaning that more challenges in estimating the GARCH model would result. Also, as suggested by Engle and Bollerslev (1986) related to the persistence of shocks and their impact on conditional variance, if shocks persist indefinitely, the long-lived capital goods will likely bear significant impacts (Poterba and Summers 1986).

The Glosten–Jagannathan–Runkle–GARCH (GJR-GARCH) and exponential GARCH (EGARCH) models were developed by Glosten et al. (1993) and Nelson (1991). Glosten et al. (1993) adjusted the EGARCH model based on the modifications incorporated with the GARCH-M model, which put an emphasis on asymmetries in volatility responding to negative and positive shocks. Financially, the risk–return tradeoff is an investment principle that is familiar to everyone. It indicates that the higher the risk, the higher the potential reward. Besides this, the best model orders  $p$  and  $q$  (where  $p$  is the order of the GARCH terms and  $q$  is the order of the ARCH terms) can be chosen by using the Bayesian Information Criterion (BIC), also known as the Schwarz Information Criterion (SIC), or the Akaike Information Criterion (AIC).

We used the asymmetric GJR-GARCH ( $p, q$ ) model to analyze the conditional variance of the bond market returns during COVID-19, which is defined as bond market volatility. We used  $p = 1$  and  $q = 1$  because this is usually the most appropriate alternative for financial time series (Glosten et al. 1993; Zakoian 1994). The GJR-GARCH (1,1) model is specified as follows:

$$r_t^{BM} = \mu + \varepsilon_t$$

$$h_t^{BM} = \omega + (\alpha + \gamma d_{t-1})\varepsilon_{t-1}^2 + \beta_1 h_{t-1}^{SM}$$

where  $r_t^{BM}$  is the country's daily 10-year government bond return calculated as  $\ln(P_t/P_{t-1})$ ,  $\varepsilon_t$  is zero-mean white noise and does not need to be serially independent,  $h_t^{BM}$  is the conditional forecasted variance at time  $t$ ,  $\gamma$  denotes the asymmetric parameter, and  $d_{t-1}$  is a dummy variable defined as follows:

$$d_{t-1} := \begin{cases} 0 & \text{if } \varepsilon_{t-1} \geq 0 \text{ (good news)} \\ 1 & \text{if } \varepsilon_{t-1} < 0 \text{ (bad news)} \end{cases}$$

Compared with GARCH, the GJR-GARCH model has an additional term,  $\gamma d_{t-1} \varepsilon_{t-1}^2$ . With this additional term, the GJR-GARCH is more capable of showing the stronger impact of negative news.

## 2.2.2. Research Model

Panel data analysis was conducted to examine the impacts of the variables related to COVID-19 containment measures on the bond market volatility during the COVID-19 outbreak, according to the following equation:



$$BVOL_{i,t} = \beta_0 + \beta_1 RTI_{i,t} + \beta_2 VACCINE_{i,t} + \beta_3 CASES_{i,t} + \beta_4 DEATHS_{i,t} + \varphi V_{i,t} + \delta_t + \varepsilon_{i,t} \quad (1)$$

where  $i$  and  $t$  refer to the country and time, respectively.  $\beta_0$  is a constant term. The dependent variable  $BVOL_{i,t}$  denotes volatility in the 10-year government bond return measured by the conditional variance extracted from the asymmetric GJR-GARCH (1,1) for country  $i$  at time  $t$ . The key independent variables include the daily relative change in the Oxford COVID-19 Government Response Tracker Index ( $RTI_{i,t}$ ), the mass vaccinations ( $VACCINE_{i,t}$ ) measured as the daily relative change in the new COVID-19 vaccinations per million individuals, and the daily relative change in COVID-19 total cases and deaths per million individuals ( $CASES_{i,t}$  and  $DEATHS_{i,t}$ ) for country  $i$  at time  $t$  (Zaremba et al. 2021b).  $V_{i,t}$  is a set of control variables that include country-level control variables suggested by previous studies (Zaremba et al. 2021a, 2021b). The daily percentage change in the exchange rate ( $ER_{i,t}$ ) for country  $i$  at time  $t$ , the volatility index related to the systematic component of global financial markets ( $VIX_t$ ), and the oil price ( $OP_t$ ) have been well addressed in these variables.  $\delta_t$  is a dummy variable to account for time-invariant country unobserved daily fixed effects of the error term, and  $\varepsilon_{i,t}$  is an error term. Table 1 provides a detailed calculation of the variables stated above.

To test the aims of this study, we use panel data regressions based on the pooled ordinary least squares (OLS) method, fixed-effects estimation (FE), and random-effects estimation (RE). To measure the validity of the models, post-estimation tests such as the F-test, Breusch–Pagan Lagrange Multiplier (LM) (Breusch and Pagan 1980), and Hausman (1978) were used to decide the appropriate estimation method. To test the robustness of our results, alternative measures of the explanatory variables related to COVID-19 containment measures were examined, including the daily relative change in the government response stringency index (GSI) and the new COVID-19 vaccinations divided by the total population (VACCINE2). We also used the COVID-19 pandemic fear index<sup>1</sup> (PFI) (Salisu et al. 2020) in Equation (1).

A summary of the main variable data is given in Table 2. The mean value of bond market volatility (BVOL) was 5.8441 for the 34 countries over the sample period. The BVOL variable exhibited wide-ranging fluctuation during COVID-19, with minimum and maximum values reaching orders of 0.3631 and 38.395. This variable has a high standard deviation of 6.7651, implying significant wavering. Regarding the government's responses to COVID-19 measured by the RTI variable, the range of recorded values was from  $-0.5598$  to  $0.6193$ . A potential impact of the COVID-19 vaccine (VACCINE) is reported at  $0.0105$  in mean value, with a range from  $-3.1632$  to  $3.3309$ . Furthermore, it was calculated that the mean daily relative changes in total confirmed cases (CASES) and deaths (DEATHS) per million individuals were  $0.0181$  and  $0.0205$ , respectively. We used Pearson and Spearman correlation tests for all the variables. It is also worth noting that based on the Variance Inflation Factor (VIF) scores, multicollinearity is not a concern in our study. The results of the correlation table are not presented here but are available on request from the authors.

**Table 2.** Descriptive statistics.

Variable	Obs.	Mean	Min.	Med.	Max.	Std. Dev.	Skew.	Kurt.
BVOL	8446	5.8441	0.3631	3.2942	38.395	6.7651	2.2956	8.7358
RTI	8446	0.0011	$-0.5598$	0.0000	0.6193	0.0259	1.3501	118.58
VACCINE	8446	0.0105	$-3.1632$	0.0000	3.3309	0.1327	1.3906	119.14
CASES	8446	0.0181	$-0.0583$	0.0054	1.2978	0.0538	9.7416	140.74
DEATHS	8446	0.0205	0.0000	0.0037	3.0714	0.0953	16.095	390.54
ER	8446	$-0.0001$	$-0.0728$	0.0000	0.0711	0.0059	0.2094	14.066
VIX	8446	$-0.0079$	$-0.6745$	$-0.0127$	0.8248	0.0980	1.6730	21.180
OP	8446	0.0072	$-0.1363$	0.0045	0.9866	0.0643	12.429	189.83

### 3. Results

Table 3 demonstrates the results of Equation (1). Overall, our findings indicate that government responses led to an increase in the volatility of the international bond markets to some extent. However, the impact of containment measures is not consistent between the emerging markets (EMs) in column (ii) and the developed markets (DMs) in column (iii). To be specific, there is a strong relationship between the rise in the volatility of the bond markets in EMs and the stringency of government strategies, at the highest statistical significance level of 1%. Moreover, when replacing the RSI with the government stringency index (GSI) to properly investigate our results, we obtained interesting insights: the GSI gives a consistent effect on EMs and DMs at the 1% and 5% significant levels. Therefore, tightening government interventions can cause investors to infer bad news about the struggle with COVID-19, which increases investor fears and, thus, the volatility of bond markets. Our findings are the opposite of those of Zaremba et al. (2021a), who concluded that government policies (closure policies, fiscal measures, health system interventions) can reduce uncertainty in the bond market.

Another important point in our outcome represents the rate of vaccination. As evident from Table 3, the vaccination rate highly contributes to reducing the volatility in the bond markets, especially in the DMs. Since the daily vaccination rate in EMs remains relatively low compared to that in DMs, the impact of the VACCINE variable is not significant, but it still helps to mitigate the volatility in the international bond markets. In this case, we also replaced VACCINE with VACCINE2 to test whether our findings are robust. Based on this type of measure, it is undeniable that a rise in new COVID-19 vaccinations markedly diminished bond market volatility. Besides this, in testing the impact of news related to changes in total COVID-19 cases and deaths, we found that these elements have co-movement and a significant relationship with volatility in international bond markets. The information related to deaths and confirmed cases is reflected in the behavior of investors as an increase in uncertainty about how effective the government policies are.

Nevertheless, using the COVID-19 pandemic fear index (PFI) to replace total cases and deaths per million individuals gives inconsistent results. It has been pointed out that this difference may come from the nature of the measure of the variable. The PFI is a composite index constructed by pulling daily reported cases and deaths together with equal weights assigned (0.5). In our view, these equal weights can lead to an unreliable relationship between pandemic fears and stock market volatility in Equation (1). Finally, all control variables in our model are statistically significant, which is consistent with some previous studies. The results of control variables are not reported herein but are available on request from the authors.

To ensure the validity of the results, we conducted a robustness test using alternative measures of forecasted models of conditional volatility in different ways. Table 4 shows that our findings are robust when conducting the estimations based on ARMA (1,1)-GJR-GARCH (1,1), EGARCH (1,1), and TARCH/ZARCH (1,1). Otherwise, it is necessary to consider the difference between the RTI and VACCINE on the EMs and DMs. Our outcomes show a contrary trend in these two markets, where the governments' measures prove their effectiveness in the EMs but not in DMs, and vice versa in the case of vaccination rates. Indeed, the gap in the availability and distribution of vaccines for EMs and DMs can be taken as proof of this difference. To be specific, the low progress of vaccination plans in EMs contributes to a wave of uncertainty in citizens who must follow the actions of the government to mitigate the adverse impact of COVID-19. Therefore, the tighter the containment measures, the greater the instability in the EMs' bond markets. On the other side, according to the specific national context in DMs, investors' actions are mainly driven by the vaccine information, rather than the government responses.

**Table 3.** Impact of COVID-19 containment measures on bond market volatility during the COVID-19 pandemic.

Dependent Variable = BVOL	All	EMs	DMs	All	EMs	DMs
	(i) FE	(ii) RE	(iii) RE	(i) FE	(ii) RE	(iii) RE
RTI	3.0342 * (1.76)	2.2084 *** (3.22)	3.5558 (1.20)	-	-	-
GSI	-	-	-	2.9779 *** (2.91)	1.9286 *** (4.46)	3.5467 ** (2.06)
VACCINE	-0.6112 *** (-7.34)	-0.0473 (-0.51)	-3.3440 *** (-3.22)	-	-	-
VACCINE2	-	-	-	-0.3784 *** (-2.89)	-0.4283 *** (-7.29)	-0.3625 * (-1.70)
CASES	10.899 *** (11.14)	6.1841 *** (15.41)	11.419 *** (6.80)	-	-	-
DEATHS	4.5781 *** (8.41)	1.4259 *** (7.67)	8.2774 *** (7.79)	-	-	-
PFI	-	-	-	-0.2396 * (-1.73)	-0.0932 (-1.49)	-0.3205 (-1.43)
Constant	5.5439 *** (118.00)	1.5991 *** (4.97)	9.4426 *** (7.70)	5.8939 *** (114.63)	1.7967 *** (5.97)	9.8585 *** (7.75)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Day dummies	Yes	Yes	Yes	Yes	Yes	Yes
N. observ.	8446	3831	4615	8446	3831	4615
N. countries	34	15	19	34	15	19
R <sup>2</sup>	0.0496	0.1272	0.0592	0.0041	0.0244	0.0041
F	62.60 ***	-	-	5.76 ***	-	-
$\lambda^2$	-	555.70 ***	288.55 ***	-	94.79 ***	19.15 ***
Hausman test	19.99 ***	0.04	8.57	14.35 **	0.88	6.12
LM test	$33 \times 10^4$ ***	$14 \times 10^4$ ***	$10 \times 10^4$ ***	$31 \times 10^4$ ***	$13 \times 10^4$ ***	94,457.17 ***

Note: This table presents the results of Equation (1) using panel data regressions with the final estimation method chosen from among pooled ordinary least squares (OLS), fixed-effects estimation (FE), and random-effects estimation (RE) via post-estimation tests such as the F-test, Breusch–Pagan Lagrange Multiplier (LM) test, and Hausman test. Column (i) refers to our empirical analysis for countries in the sample during the COVID-19 pandemic. Our remaining analysis is based on the sample of emerging markets (EMs) or developed markets (DMs), reported in columns (ii) and (iii), respectively. We also used alternative measures of the explanatory variables related to COVID-19 containment measures, including the daily relative change in the government response stringency index (GSI), the new COVID-19 vaccinations divided by the total population (VACCINE2), and the COVID-19 pandemic fear index (PFI) in Equation (1). Besides this, VACCINE2 was multiplied by 100 to improve the readability of our tables. T statistic values are reported in parentheses. \*\*\*, \*\*, and \* denote statistical significance of the coefficients at the 1%, 5%, and 10% levels, respectively. All specifications also include day dummies. N. observ, N. countries, and R<sup>2</sup> denote the number of observations, number of countries, and adjusted coefficient of determination, respectively. The results of control variables are not reported here but are available on request from the authors.



**Table 4.** Robustness tests—an alternative measure of forecasted models of conditional volatility.

No.	Robustness Check				
All countries		RTI	VACCINE	CASES	DEATHS
(1)	BVOL based on the ARMA (1,1)-GJR-GARCH (1,1) model	3.6213 ** (2.06)	−0.6008 * (−1.78)	11.109 *** (11.16)	4.4902 *** (8.11)
(2)	BVOL based on the EGARCH (1,1) model	2.5718 (1.13)	−1.2235 *** (−2.79)	11.009 *** (8.53)	3.8959 *** (5.42)
(3)	BVOL based on the TARCH/ZARCH (1,1) model	3.3092 ** (2.09)	−0.4529 (−1.49)	9.1008 *** (10.17)	4.1520 *** (8.33)
Emerging Markets (EMs)		RTI	VACCINE	CASES	DEATHS
(1)	BVOL based on the ARMA (1,1)-GJR-GARCH (1,1) model	2.1573 *** (3.27)	−0.0472 (−0.53)	6.0279 *** (15.60)	1.4218 *** (7.94)
(2)	BVOL based on the EGARCH (1,1) model	2.0383 *** (3.67)	−0.0546 (−0.73)	5.4773 *** (16.82)	1.1098 *** (7.36)
(3)	BVOL based on the TARCH/ZARCH (1,1) model	2.2031 *** (3.79)	−0.0449 (−0.58)	5.6095 *** (16.46)	1.3867 *** (8.79)
Developed Markets (DMs)		RTI	VACCINE	CASES	DEATHS
(1)	BVOL based on the ARMA (1,1)-GJR-GARCH (1,1) model	4.5494 (1.51)	−3.3091 *** (−3.13)	11.843 *** (6.93)	8.1043 *** (7.49)
(2)	BVOL based on the EGARCH (1,1) model	3.1293 (0.80)	−6.7245 *** (−4.86)	12.061 *** (5.39)	7.1795 *** (5.07)
(3)	BVOL based on the TARCH/ZARCH (1,1) model	4.0047 (1.48)	−2.4543 ** (−2.58)	9.2362 *** (5.99)	7.3935 *** (7.58)

Note: This table presents the results of Equation (1) when using the forecasted models of conditional volatility in different ways: ARMA (1,1)-GJR-GARCH (1,1), EGARCH (1,1), and TARCH/ZARCH (1,1). The final estimation method was chosen from among pooled ordinary least squares (OLS), fixed-effects estimation (FE), and random-effects estimation (RE) via post-estimation tests such as the F-test, Breusch–Pagan Lagrange Multiplier (LM) test, and Hausman test. T statistic values are reported in parentheses. \*\*\*, \*\*, and \* denote statistical significance of the coefficients at the 1%, 5%, and 10% levels, respectively. The results of control variables and model tests are not reported here but are available on request from the authors.

#### 4. Concluding Remarks

Herein, we explored how government containment measures impacted international bond markets through panel data regression. We point out that governments' non-pharmaceutical interventions can produce high volatility in the bond markets because such volatility reflects the high-risk perception of investors and citizens related to the governments' actions due to the long-lasting negative effect of COVID-19 in both emerging and developed countries. In addition, we also found that mass vaccination programs can considerably alleviate volatility in the international bond markets. This result implies that an expansion in the immunization rate mirrors good news, which improves investor sentiment, hence contributing to stabilizing the bond markets. The robustness of our results was proven under different models of conditional volatility and another proxy for the key independent variables. Finally, we indicate that change (increase/decrease) in the number of infections and deaths results in more-than-proportional volatility in the bond market. The main limitation of our research is the lack of consideration of other economic issues such as inflation, interest rate, change in GDP, etc. Although the addition of macroeconomic variables is important, we leave it for future study. In the scope of our study, we focused on the relationship between containment measures taken by the government and volatility in international bond markets. Besides this, we examined the impacts of vaccine coverage when countries had to consider new approaches and implement a strategy based on living with the coronavirus. Indeed, the movements of these factors during the research period had an obvious impact on the bond market and investor expectations.

**Author Contributions:** Conceptualization, B.C.N.T. and T.V.T.N.; methodology, B.C.N.T., T.V.T.N. and N.T.H.N.; software, B.C.N.T.; validation, B.C.N.T., T.V.T.N., N.T.H.N. and H.T.H.; formal analysis, B.C.N.T., T.V.T.N. and H.T.H.; investigation, B.C.N.T. and T.V.T.N.; resources, B.C.N.T., T.V.T.N., N.T.H.N. and H.T.H.; data curation, B.C.N.T. and T.V.T.N.; writing—original draft preparation, B.C.N.T., T.V.T.N., N.T.H.N. and H.T.H.; writing—review and editing, B.C.N.T. and T.V.T.N.; visualization, B.C.N.T., T.V.T.N. and N.T.H.N.; supervision, B.C.N.T. and T.V.T.N.; project administration, B.C.N.T. and T.V.T.N. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research is fully funded by University of Economics Ho Chi Minh City (UEH), Vietnam.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest.

#### Appendix A. List of Emerging and Developed Markets as Classified by the Morgan Stanley Capital International (MSCI) Classification

Panel A: Emerging Markets (EMs)		Panel B: Developed Markets (DMs)	
No.	Country	No.	Country
1.	Brazil (BRA)	1.	Australia (AUS)
2.	China (CHN)	2.	Austria (AUT)
3.	Egypt (EGY)	3.	Belgium (BEL)
4.	Greece (GRC)	4.	Canada (CAN)
5.	India (IND)	5.	France (FRA)
6.	Indonesia (IDN)	6.	Germany (DEU)
7.	Malaysia (MYS)	7.	Hong Kong (HKG)
8.	Mexico (MEX)	8.	Ireland (IRL)
9.	Philippines (PHL)	9.	Israel (ISR)
10.	Poland (POL)	10.	Italy (ITA)
11.	Qatar (QAT)	11.	Japan (JPN)
12.	South Africa (ZAF)	12.	Netherlands (NLD)
13.	South Korea (KOR)	13.	New Zealand (NZL)
14.	Thailand (THA)	14.	Norway (NOR)
15.	Turkey (TUR)	15.	Portugal (PRT)
		16.	Spain (ESP)
		17.	Switzerland (CHE)
		18.	United Kingdom (GBR)
		19.	United States (USA)

#### Note

$$^1 \quad PFI_{i,t} = 0.5 \times \left[ \frac{Cases_{i,t}}{Cases_{i,t} + Cases_{i,t-14}} + \frac{Deaths_{i,t}}{Deaths_{i,t} + Deaths_{i,t-14}} \right] \times 100.$$

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