THE CONNECTEDNESS AMONG GREEN BONDS AND OTHER ASSET CLASSES: EVIDENCE FROM EMERGING MARKETS

Yeşil Tahvillerin Diğer Yatırım Araçları ile İlişkisinin İncelenmesi: Gelişmekte Olan Piyasalar Örneği

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Abstract

As climate change intensifies, current climate finance remains insufficient to achieve Paris Agreement goals, particularly in developing countries. Closing this gap requires greater international private capital involvement. However, uncertainties about climate finance instruments in developing markets challenge private investment. This study examines green bonds issued in emerging markets, analyzing their dependencies with debt, equity, and commodity markets using the cross-quantilogram method. Results reveal short-term positive dependencies between green bonds and equity and debt markets, indicating high cross-market contagion initially. Yet, these dependencies diverge after a week. While green bonds maintain a positive medium-term relationship with other debt instruments, their medium-term dependence on equity and commodities turns negative. This negative relationship strengthens under normal market conditions but weakens during extreme market events. These findings highlight green bonds' potential as diversification tools for equity and commodity investors in emerging markets. However, short-term contagion remains a challenge for regulators, demanding further analysis of financial stability implications.

Öz

İklim değişikliği etkileri şiddetlenirken mevcut finansman akışı, özellikle gelişmekte olan ülkelerde Paris Anlaşması hedeflerini karşılamaya yetersiz kalmaktadır. Bu açığın kapatılması için uluslararası özel sermayenin katılımı şarttır. Ancak gelişmekte olan ülkelerdeki iklim finansmanı araçlarına dair belirsizlikler, özel sermayenin katılımını zorlaştırmaktadır. Bu çalışma, gelişmekte olan piyasalarda ihraç edilen yeşil tahvillerin, diğer borçlanma araçları, pay ve emtia piyasalarıyla bağımlılığını Çapraz-Kantilogram yöntemiyle incelemektedir. Sonuçlara göre, kısa vadede yeşil tahvillerin pay ve borçlanma araçlarıyla pozitif bağımlılığı bulunmakta ve piyasa bulaşıcılığı yüksektir. Ancak bağımlılık zamanla ayrışmaktadır; yeşil tahvillerin orta vadede diğer borçlanma araçlarıyla pozitif bağımlılığı sürerken, pay ve emtia piyasalarıyla ilişkisi negatif yönde gelişmektedir. Ayrıca, olağan piyasa koşullarında bu negatif bağımlılık güçlenirken, aşırı koşullarda zayıflamaktadır. Bulgular, gelişmekte olan piyasalar yeşil tahvilin portföy çeşitlendirmesi için potansiyelini ortaya koymaktadır. Kısa vadede gözlenen bulaşıcılık finansal istikrar açısından önem taşımakta ve regülatörlerin bu konuda dikkatli olması, risk aktarım mekanizmalarının ve risk-getiri performanslarının daha ayrıntılı incelenmesi gerekmektedir.

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1. Introduction

The impact caused by climate change has become a reality that will affect not only the future but also the present. In the second decade of the 21st century, the global surface temperature has risen by approximately 1.1 degrees Celsius compared to the pre-industrial era. This temperature rise has led to the retreat of glaciers in the North and South Poles and an increase in the temperature of the oceans and marine waters. Further, there is an increasing trend in the occurrence of natural disasters, including extreme rainfall, hurricanes, heat waves, and droughts (IPCC, 2021). These effects have already begun to have widespread negative consequences, affecting both ecosystems and individuals. Economic losses attributed to climate change have been identified in sectors particularly affected by climatic conditions, including agriculture, forestry, fisheries, energy, and tourism. The negative impacts of climate change can reduce the availability of financial resources owing to losses and damages, thus hindering a country's economic growth. This is particularly the case for developing and least developed countries, which can face further limitations in accessing investment capital (IPCC, 2023). While developed countries have the largest cumulative share of greenhouse gas emissions, emissions in these countries have tended to decline owing to technological investments, productivity increases, and many other reasons. However, greenhouse gas emissions are expected to continue to grow in countries at the beginning of industrialization. As the least developed and developing countries face various difficulties in attracting development capital, the need for new resources has been added to their efforts to combat climate change so that they can access low-emission production technologies and increase their resilience to the harmful effects of climate change. According to the United Nations Framework Convention on Climate Change (UNFCCC, 1992), it is critical to provide additional resources to combat climate change without reducing development investments.

Hence, developed countries, which have the largest share in the release of greenhouse gases accumulated in the atmosphere, started to support the efforts of developing countries to combat climate change with public resources in the 1990s. The resources provided for this purpose are referred to as climate finance. Through the Green Climate Fund (GCF), established in 2010, developed countries that are parties to the UNFCCC committed to mobilizing public-source climate finance. Thereafter, at the Conference of the Parties to the UNFCCC in Paris in 2015, it was agreed to concretize the goals of combating climate change and reduce global emissions in a way that the climate temperature increase by the end of the 21st century does not exceed 2 degrees Celsius; the climate temperature increase is limited to 1.5 degrees Celsius compared to the pre-industrial average; and the necessity of mobilizing the necessary financial resources to achieve these goals is emphasized. However, in practice, the climate finance provided remains far from the amount of investment needed to realize these targets, particularly in developing countries (Buchner et al., 2021). For instance, when the GCF was established in 2010, developed countries committed to gradually increasing their annual climate finance flows to developing countries to reach USD 100 billion by 2020. However, that year, the GCF could only provide USD 55 billion in climate finance (Amighini et al., 2022)

The gap between the targeted climate finance and climate finance provided in practice shows that the targets set out in the Paris Agreement cannot be achieved with public resources alone, although they play a critical role in reducing risk and encouraging private sector engagement. Existing literature (Amerasinghe et al., 2017; Amighini et al., 2022) emphasizes the significance of public investment in climate-related endeavors to incentivize private sector

involvement by fostering market development, facilitating innovation, and managing risks. Nevertheless, attaining the targets established in the Paris Agreement hinges on the active participation of private investment. The engagement of private capital, however—and unlike the public sector, which considers the Public Good—is contingent upon tangible performance indicators, such as risk and return, as well as the predictability of these metrics. Bansal et al. (2016) argue that the impacts of climate change on individuals and the overall economy also affect the risks and returns of firms. Giglio et al. (2021) conclude that physical and transitional risks are the leading economic risks related to climate change and advocate that the unignorable dimensions of these risks have made it imperative to investigate and assess these risks for all financial assets.

The finance literature has mainly addressed these risks in two ways. First, it incorporates these risks into firm and asset valuation models by examining their implications on fundamental financial metrics, such as cash flows, debt coverage, and profitability (Giglio et al., 2018; Huynh and Xia, 2020). The second approach, however, focuses on the correlation and interdependence between assets within the framework of portfolio theory and investment portfolio diversification. This approach revolves around portfolio reallocation necessitated by climate change, which will demand adjustments to conventional assets and the exploration of alternative, environmentally sustainable financial instruments aligned with the objectives of the Paris Agreement. This shift in the global economy has led researchers and investors to evaluate new investment alternatives and reallocate their portfolios. Krueger et al. (2019) report that institutional portfolio investors believe that climate risks, particularly those related to regulation, have consequences for portfolio investments. Most investors surveyed by the researchers indicated that these consequences are not only in the future but are already being felt. Many portfolio managers have reported that they are gradually reducing their fossil fuel investments while increasing the share of sustainable investments in their portfolios. Benedetti et al. (2019) argue that portfolio risk can be reduced by diversifying portfolios in line with policies to reduce carbon emissions.

Buchner et al. (2021) demonstrate that more than half of the investments aligned with carbon mitigation policies are directed toward energy projects, with the majority being provided by debt instruments, particularly green bonds (GBs). According to Glomsrød and Wei (2018), GBs can help address income inequality by increasing the supply of clean energy and the share of labor in the economy and promoting economic growth, as measured by gross domestic product. The rapid development and growth of the green, social, and sustainability (GSS) bond market reflects the manifestation of these developments in climate change policy. First issued in the mid-2000s, these instruments grew from a niche and limited market to a multi-trillion (USD) market in a relatively short time, driven by investor demand. According to the Climate Bond Initiative (CBI) report, the cumulative issuance amount as of June 2023 was approximately USD 4.2 trillion (Harrison et al., 2023). However, concerning emerging markets (EMs), although the issuance of GSS and socially responsible investment instruments in developing countries has shown an accelerated increase, their share in cumulative issuances has not exceeded 20% (IFC and Amundi, 2023). Ferrer et al. (2021) argue that GBs with investment-grade credit ratings do not constitute a separate asset class, exhibiting the volatility of treasury and corporate bonds with higher credit ratings. However, Reboredo (2018) and Nguyen et al. (2021) show that GBs can be useful in hedging equity and commodity assets.

However, almost all research on GBs is based on global GB indices, which cover GBs issued in developed and developing countries. The small share of GBs issued in developed countries means that these indices do not resemble GBs issued in these countries. The literature on GBs fails to answer questions about GBs in developing countries using GB indices, most of which include GBs issued in developed countries. Addressing this gap, our study contributes to the literature in four ways. First, we investigate the bidirectional dependence between global and EMs and GBs; thus, we bind EM GBs to the abundant literature on global GBs. Second, we analyze the dependence of GBs issued in EMs on the debt and equity markets. Third, we test the unidirectional dependence of EM GBs on gold, commodity, and energy markets. Finally, we reapply these tests by controlling for market conditions, enabling us to examine the impact of extreme market conditions on the investigated relationships.

2. Literature Review

The concept of climate finance is defined as "the financial resources mobilized and provided to finance actions that mitigate the effects of climate change and adapt to them, including public climate finance commitments by developed countries under UNFCCC." In this context, the concept points to a vast financial universe ranging from consumer loans, such as those for electric cars and green mortgages, to corporate projects worth billions of dollars. The most prevalent climate finance instrument in capital markets is the "green bond." A bond is defined as "a debt instrument whereby an investor lends funds to an organization for a specific period (longer than one year) at a variable or fixed interest rate". A green bond, in turn, is defined as "any type of bond instrument framed by the Green Bond Principles (GBP)" (International Capital Markets Association, 2021), and the proceeds, or an equivalent amount, are to be used to finance or refinance new and/or existing eligible green projects (Buchner et al., 2021).

A review of the extant literature on green bonds reveals that research in this field is primarily concentrated on two main axes. One axis addresses the "intrinsic value" of green bonds and the risks they carry in this context (Buchner et al., 2021; Cuculiza et al., 2021; Giglio et al., 2021; Sautner et al., 2023). The other axis focuses on the interrelationship and movement of green bonds with other asset classes from the perspective of portfolio diversification (Baur and Lucey, 2010; Reboredo, 2018; Ferrer et al., 2021; Liu et al., 2021; Nguyen et al., 2021; Pham, 2021; Chatziantoniou et al., 2022).

The repercussions of climate change are poised to exert a deleterious influence on the future activities of specific sectors and the overall economy (Martinez-Diaz and Keenan, 2020). These impacts have already resulted in economic damage in many regions, and the severity of this damage is not evenly distributed across regions (IPCC, 2023). Accordingly, the extant literature reveals that climate change affects green bonds through two main channels: physical risks (e.g., heat waves, floods, and droughts disrupting production, thereby increasing default probabilities and risk premiums) and transition risks (e.g., regulation, carbon pricing, and technology shocks creating uncertainty in cash flows and discount rates) (Giglio et al., 2021: 24). Physical climate risk is defined as "risks related to the direct disruption of productive assets as a result of climate change." The presence of physical risk is indicated by adverse effects such as heat waves, drought, and extreme rainfall, which have the potential to impact the operations of companies and the health of individuals. Transitional risk is defined as the set of uncertainties

related to cash flows that arise from the transition to a low-carbon economy. It refers to the risks associated with the changes required in consumption and production as part of the process of combating and adapting to climate change. For instance, increased regulation and oversight of coal-fired power plants can result in reduced profitability or even phased closures (Sautner et al., 2023).

In light of these definitions, it is imperative to underscore the fact that the ramifications of these risks at the company and sector levels are non-uniform and exert an influence on green bond pricing through disparate channels. While transition risk persists as a significant threat, inducing cost pressures and cash flow imbalances for certain companies and sectors, it concomitantly engenders competitive advantages and heightened investment attractiveness for entities that demonstrate high carbon efficiency or a propensity for expeditious green technology adoption. Conversely, physical risks encompass a broader spectrum and are more general in nature. However, the severity of these risks exhibits significant variations depending on spatial and sectoral exposure. In fact, Cuculiza et al. (2021) demonstrate that in regions encountering heat waves, the discrepancy between companies' forecasts and actual earnings escalates considerably in the periods following heat wave events. Consequently, while physical risks generate a general impact, their consequences are more pronounced in companies that are directly exposed to these risks. This asymmetric pattern necessitates the systematic investigation and pricing of climate-related economic and financial risks for all asset classes. It also renders the accurate determination of the cost and attractiveness of climate finance, which plays a pivotal role in mitigating these risks, more critical than ever.

A substantial body of research has examined the role of Green Bonds (GBs) in portfolio diversification rather than their intrinsic value. In this context, the relationship between GBs and total and sectoral equities, commodities, and different bond types, primarily traditional bonds, has been analyzed (Reboredo, 2018; Liu et al., 2021; Nguyen et al., 2021; Pham, 2021; Chatziantoniou et al., 2022). This relationship is predicated on the assumption that the "value" of an asset within a portfolio is contingent not only on its intrinsic characteristics but also on its co-movement with other asset classes in the portfolio (Ferrer et al., 2021). According to the principles of Modern Portfolio Theory (MPT), the contribution of an asset to a given portfolio is contingent not only on its intrinsic risk-return profile, but also on its correlation with other assets (Markowitz, 1952).

As Glomsrød and Wei (2018) have noted, green bonds have the potential to offer macroeconomic benefits such as supporting economic growth and reducing income inequality, in addition to environmental goals like increasing clean energy supply. A substantial body of literature has emerged in the aftermath of the initial issuance, examining this novel financial instrument. While certain studies have concentrated on formulating performance indicators and valuation techniques tailored to these bonds, researchers such as Ferrer et al. (2021) have contended that green bonds do not constitute a distinct asset class, but rather mirror the activities of traditional corporate and treasury bonds. However, a substantial body of research has examined the value of these instruments in the context of portfolio diversification and their relationship with other asset classes, rather than their intrinsic value.
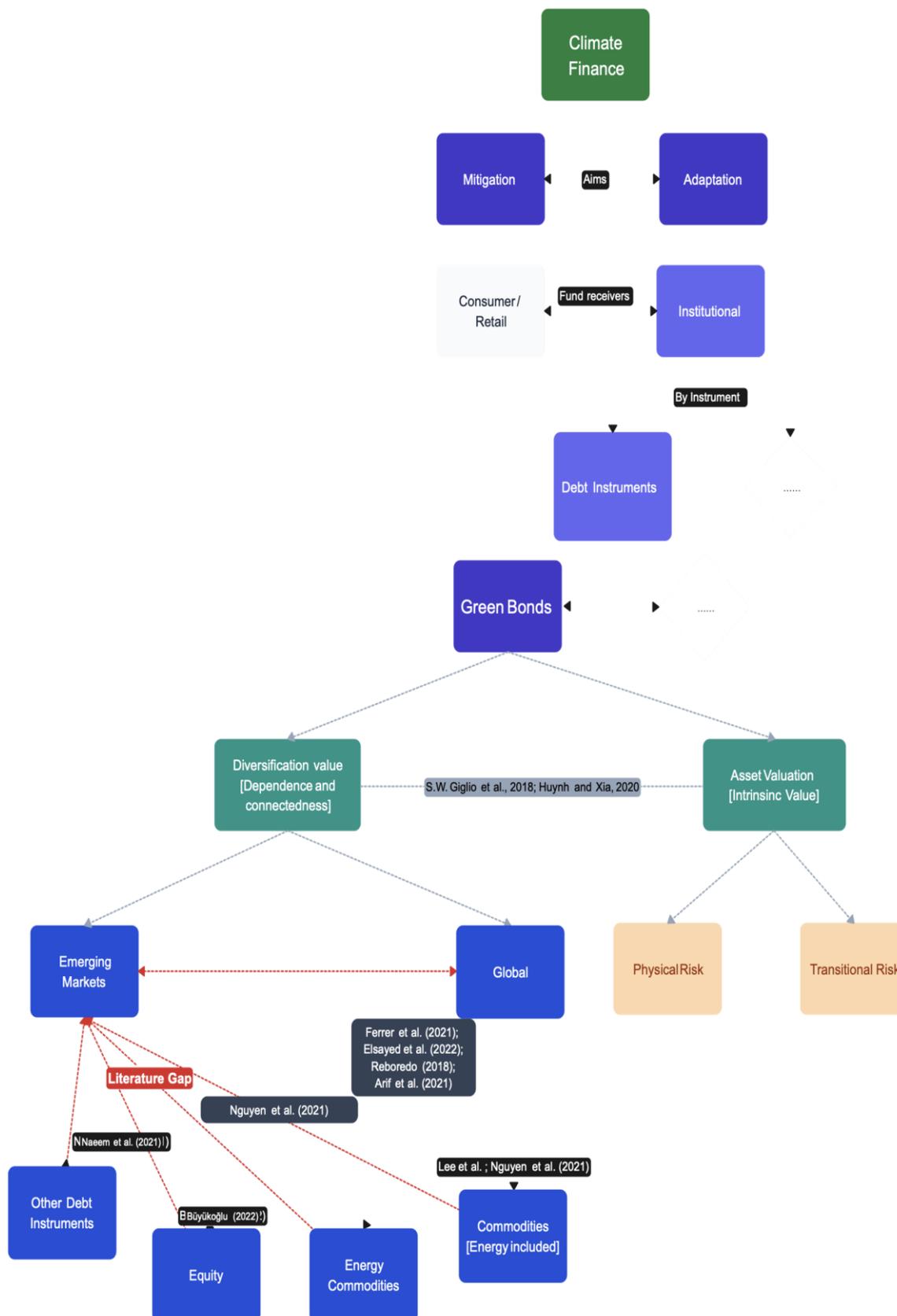
Figure 1. Summary of Empirical Climate Finance Literature

These studies employ global indices, notably the S&P GB and the Barclays Bloomberg GB, to assess the performance of green bonds. However, this approach is not without significant limitations. According to a report by Amundi and IFC (2021), only a small portion of the total green bonds issued in 2021 were in developing countries. This prompts further inquiry into the extent to which global indices can adequately represent the performance of green bonds in these countries. The failure of global indices to adequately reflect the circumstances in developing countries engenders considerable uncertainty for investors and policymakers in these regions. This uncertainty has the effect of increasing the perceived risk of green bonds, which makes it difficult for these countries to meet their climate finance needs.

Consequently, the present study endeavors to address this lacuna in the extant literature, as demonstrated in Figure 1. By selecting an indicator that can more accurately reflect the performance of green bonds in developing countries, the risk-return profile of these assets and their relationship with other investment instruments will be examined in detail. The objective of this study is to provide a more nuanced understanding of the prospects and obstacles associated with green bonds in developing economies.

3. Materials and Methods

3.1. Data and Constraints

This study analyzes the dependence of EM GBs on other asset classes. The study uses nine variables, including EM aggregate debt, global GBs, global-aggregate debt, EM and Developed Markets (DMs) equity instruments, gold, commodities, and energy commodities. Additionally, to control for financial conditions, we use the commonly accepted CBOE Volatility Index (VIX) in addition to the Financial Stress Index (FSI) as proxies for market conditions. The FSI, a relatively new index, has been gaining popularity in recent years. It is being utilized in several studies, such as Elsayed et al. (2022), Lundgren et al. (2018), and comprises 33 financial indicators, including credit conditions, funding, and equity valuation criteria. It is used in both developed and developing countries (Office of Financial Research, n.d.).

Table 1 summarizes our datasets, which consist of 11 variables covering daily prices from January 2, 2015, to March 21, 2022. We converted the price datasets extracted from the Bloomberg data terminal into natural logarithms by taking the price difference between day t and day t – 1 and applying the following formula:

$$ln(P_t) - ln(P_{t-1}) = ln(P_t / P_{t-1}) \tag{1}$$

Following Reboredo (2018) and Naeem et al. (2021), we use the Bloomberg MSCI Green Bond and Bloomberg Global Aggregate Total Return indices to represent global GBs and global-aggregate debt, respectively. We use the MSCI World and S&P GSCI Energy Total Return indices, which are popular in the relevant literature, as proxies for DM equity and energy commodity markets. To provide an overview of the commodity market, we use the S&P GSCI Total Return index, which is widely used in the literature (Nguyen et al., 2021; Karim et al., 2022).

Table 1. Datasets Used in This Study

Bloomberg ticker	Index	Proxy for*	Variable*	Price	Obtained obs.	Paired obs.**
JPEIGBCW	J.P. Morgan Green Bond Emerging Markets 10% Capped Index	EM Green Bond	EM GB	Mid	1805	1804
EMUSTRUU	Bloomberg EM USD Aggregate Total Return Index Value Unhedged	EM (Aggregate) Debt	EM DEBT	Close	1882	1804
I31572	Bloomberg MSCI Global Green Bond Index	Global Green Bond	GLB GB	Close	1882	1804
MXWO	MSCI World Index	DM Equity	DM EQU	Close	1882	1804
EMT	Bloomberg Emerging Markets Large & Mid Cap Total Return Index	EM equity	EM EQU	Close	1882	1804
XAU	Gold Spot USD	Gold	GLD	Close	1882	1804
SPGSCITR	S&P GSCI Total Return CME Index	Commodity	COMMD	Close	1882	1804
SPGSENTR	S&P GSCI Energy Total Return Index	Energy Commodity	ENRGY	Close	1882	1804
LEGATRUU	Bloomberg Global-Aggregate Total Return Index Value Unhedged USD	Global (Aggregate) Debt	AGG. DEBT	Close	1882	1804
VIX	CBOE Volatility Index	Volatility	VIX	Close	1882	1804
RFSITOTL	Financial Stress Index Total Global	Financial conditions	FSI	Close	1882	1804

Note: * Used interchangeably throughout the study. ** Paired and price differences naturally logarithmized.

Before moving on to EM GBs, it is necessary to identify a benchmark index for EM equity and EM debt markets. The Bloomberg EM Large and Mid-Cap index is used for the former, while the Bloomberg EM USD Aggregate Total Return Index Value Unhedged is used for EM aggregate debt in the analysis. While this index has the advantage of limiting the impact of exchange rate fluctuations by covering only USD-denominated bonds, it is limited because it does not include debt denominated in other currencies. Additionally, the analysis of these two is constrained by the fact that the selected indices have not previously been used in the literature reviewed.

Finally, a proxy for our dependent variable, EM GBs, must be found. In May 2023, at the time of data collection, two indices existed as flagships representing EM GBs. The first index is the Bloomberg EM GB index, which was not selected owing to its monthly pricing since it was first launched in 2017 up to the last quarter of 2021. From then to May 2023, 408 daily observations were recorded. However, this was not sufficient to produce a significant result using the method used in this study.

The second option was J.P. Morgan GB EMs' 10% Capped Index. The index data, which were launched in 2014, consist of bond prices issued in EMs and recognized as GBs by the CBI. The index covers EM sovereign and corporate GBs issued in US dollar, euro, and British pound currencies, as well as government bonds issued in the national currencies of 20 EMs, based on specific criteria (Global Index Research, 2022). With daily frequency price data spanning over seven years, this index, while not a perfect indicator, currently appears to be the most

appropriate choice as a proxy for EM GB. However, as outlined in Table 2, it is important to identify and address any limitations that may affect the study results. Nonetheless, as the EM GB market continues to mature, and its indices proliferate and improve, this limitation may gradually disappear.

Table 2. Research Limitations Related to the Dependent Variable

i.	Price movement stagnated between 2015 and 2016, likely owing to limited market size and trading volume.
ii.	The updates to the index were suspended owing to the Russian invasion of Ukraine. The daily price data available from the data provider are limited to the period starting from late 2014 until March 21, 2022.
iii.	Assets in the EM GB index are priced based on daily mid-prices rather than closing prices, unlike other variables in this study, as they use the generally accepted close-to-close price difference approach.
iv.	Although the index price is denominated in US dollars, as with other variables, the assets in the index are denominated in various currencies, and the hedging status of the exchange rates varies. Therefore, the impact of exchange rate movements on the Index price is unknown.
v.	The J.P. Morgan EM GB Index is missing 77 daily observations for the period between January 2, 2015 and March 21, 2022. These observations were not provided by the index or data provider and were spread over several months. To minimize the impact of this omission on the results of this study, we removed all missing observations from the time series of other variables.*

Note: *The dates of observation breaks are shown in the Appendix (see Appendix 1).

As stated in Table 2, the primary time series for the dependent variable, the J.P. Morgan EM GB Index, contained 77 missing daily observations over the seven-year study period. However, this limitation is expected to have a minimal impact on the study's findings for several key reasons. Firstly, these gaps constitute a minimal proportion (less than 5%) of the total 1804 observations and are not accumulated within a single timeframe, but rather, they are distributed sporadically throughout the entire sample period. In order to maintain analytical integrity, the corresponding dates were removed from all other time series, ensuring a perfectly paired dataset. In conclusion, the utilization of log-differenced prices in the calculation of returns inherently accounts for price movements across a missing day. This is due to the subsequent observation capturing the cumulative change. Consequently, due to their sparse distribution and the methodological handling, these missing values do not systematically bias the results.

3.2. Descriptive Statistics

Table 3 presents the descriptive statistics. Gold and developed equity markets have the highest average returns of 0.03%. The EM GB also has a positive average return of around 0.01%, which is comparable to the average return on traditional US dollar-denominated debt instruments of EMs, represented by EM debt Instruments. By contrast, EM GB exhibited lower volatility, with a standard deviation of 0.20%.

The commodity and energy markets have relatively low average returns but high volatility (standard deviation). Nevertheless, the highest standard deviation was observed for the indicators of market conditions. Financial stress ranks first, with a standard deviation of 33%, while the volatility index (VIX) ranks second, with a standard deviation of approximately 8%, indicating that the period covered by this study was highly volatile and exhibited extreme

market behavior. These findings are consistent with the fact that this study covers the COVID-19 and global monetary tightening periods.

Table 3. Descriptive Statistics

Variable	Mean (%)	Min. (%)	Max. (%)	SD (%)	Skewness[1]	Kurtosis[2]	Jarque–Bera*	ADF* (12)**	PP* (8)**
EM GB	0.012	-2.80	1.65	0.196	-2.99	46.43	144458.21	-9.82	-1416.59
EM DEBT	0.012	-3.71	2.02	0.275	-3.33	44.70	134030.73	-10.41	-1392.63
GLB GB	0.002	-3.03	2.20	0.374	-0.56	8.35	2248.38	-12.47	-1676.59
DM EQU	0.032	-10.44	8.41	0.977	-1.36	24.25	34482.07	-11.81	-1957.86
EM EQU	0.024	-6.47	4.96	0.987	-0.69	8.33	2279.41	-11.72	-1650.91
GLD	0.027	-5.86	4.97	0.879	-0.26	6.73	1064.69	-11.50	-1702.06
COMMD	0.010	-12.52	7.62	1.479	-0.89	11.84	6109.28	-11.15	-1933.00
ENRGY	0.004	-30.17	15.99	2.503	-1.46	23.33	31714.36	-11.59	-1922.34
AGG. DEBT	0.005	-2.20	1.53	0.299	-0.52	7.87	1864.80	-12.94	-1638.45
VIX	0.016	-29.98	76.82	8.440	1.30	10.04	4241.70	-13.59	-1734.61
FSI	-0.126	-573.01	506.05	33.274	0.02	104.53	774769.99	-12.48	-1526.20

Note: * Test at the 1% significance level. ** Indicates the lag value in the test.

Testing for stationarity conditions is necessary when extreme market conditions are present, as this is a precondition of the Cross-Quantilogram (CQ) method. For this purpose, the widely accepted Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests were used to test stationarity. According to Uddin et al. (2019), although both tests are used to test whether variables have unit roots, the Phillips–Perron is a nonparametric test with autocorrelation and heteroscedasticity correction. The null hypothesis of the tests is that the variables are non-stationary, whereas the alternative hypothesis is that the variables are stationary. The test applied at the 1% significance level resulted in rejection of the null hypothesis and acceptance of the alternative hypothesis for all variables. Hence, the stationarity of the variables was determined.

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[1] Calculated using the R package by Komsta, L. and Novomestky, F. (2022). moments:Moments, cumulants, skewness, kurtosis and related tests. *R package version*, *14*(1). https://doi.org/10.32614/CRAN.package.moments .

[2] Kurtosis, Jarque-Bera, ADF, and Phillips Perron tests calculated using the R package "tseries" Trapletti, A., Hornik, K. and LeBaron, B. (2023). tseries: Time Series Analysis and Computational Finance. *R package version 0.10-35*. https://doi.org/10.32614/CRAN.package.tseries
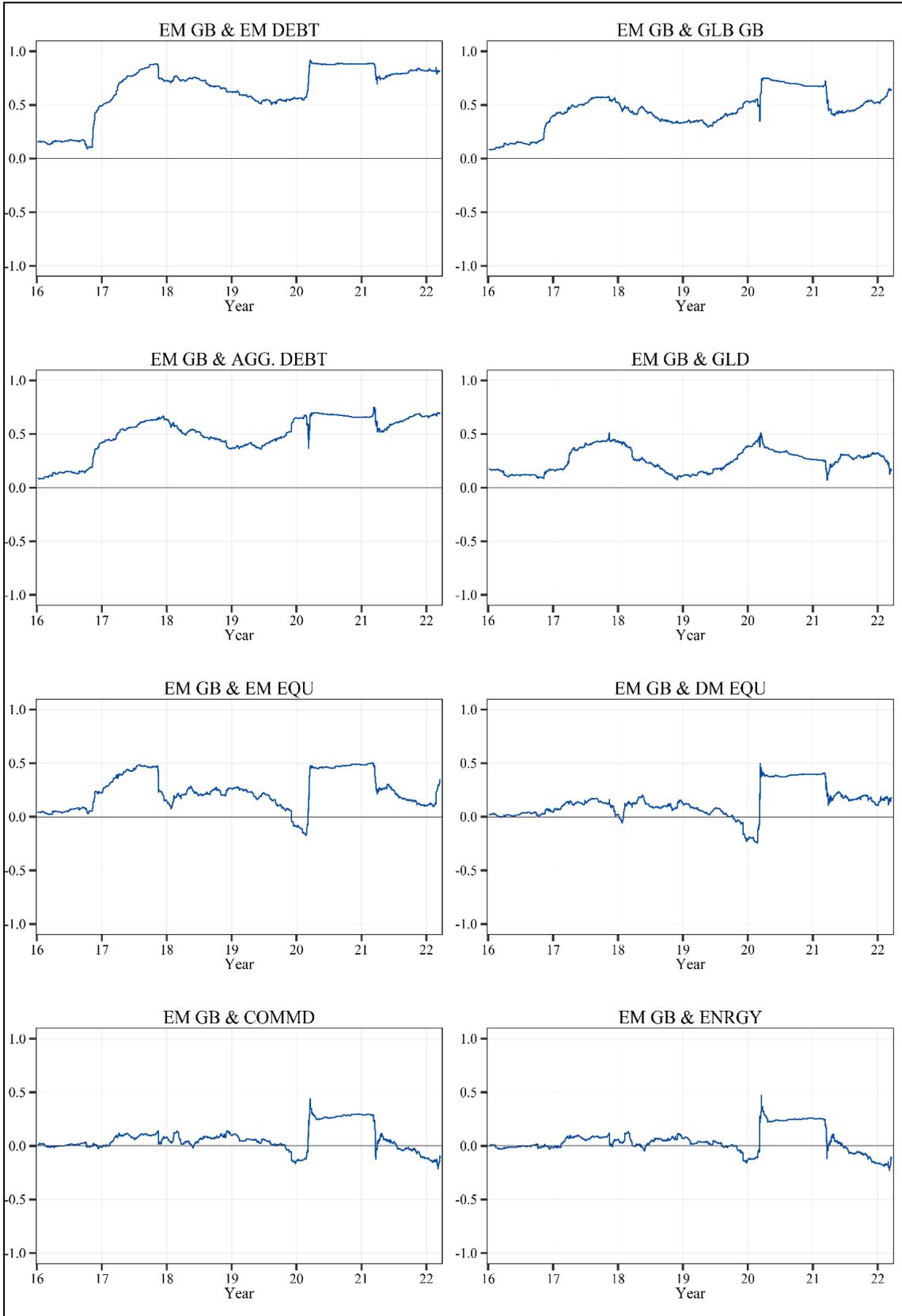
Figure 2. 252–day (one year) Rolling Correlation
Note: The correlation test indicates that EM Green Bonds have a growing correlation with other debt instruments.

The Jarque–Bera normality test, used to determine whether observations are normally distributed, revealed that the data distribution is not normal. This is consistent with the fact that price returns are typically not normally distributed (Fama, 1965). However, the observed non-normality indicated significant heterogeneity among the variables, as evidenced by the Jarque–Bera test, skewness, and kurtosis.

Regarding skewness, EM GB and debt securities had the highest negative skewness with negative values of 2.99 and 3.33, respectively. Negative skewness, also known as left skewness, implies that the left tail of the distribution is longer and extends in the negative direction, and the probability of negative values is higher than the probability of positive values. Conversely, right skewness implies that the right tail of the distribution is longer, also known as positive skewness. In a right-skewed distribution, the probability of a positive value occurring is higher than that of a negative value.

With negative skewness, DM equity and energy instruments exhibited the highest negative values after EM GB and EM debt instruments. However, the highest positive skewness of 1.3 was observed in the volatility index. Another measure of the normality of distribution was kurtosis. Kurtosis is used to measure the degree of steepness/kurtosis of the distribution. As the kurtosis coefficient moves away from zero in the positive direction, the distribution tapers. When it moves away from zero in the negative value direction, the distribution is kurtotic. A kurtosis coefficient of zero indicates that the distribution is normal in terms of kurtosis.

The abnormality of EM GB and general EM debt securities also stood out in terms of kurtosis. This is because these variables had the highest kurtosis (46.4 and 44.7, respectively) after the FSI and exhibit a pointed distribution. Energy and GP equity repeated the anomalous pattern in skewness and followed EM GB and EM debt securities with high kurtosis. However, the kurtosis coefficient for all the variables was higher than six. This means that the weight/thickness of the distribution tails was high and indicates more extreme price volatility than in the normal distribution.

Following Uddin et al. (2019), the rolling correlation between variables (one year–252 observations) and performance trends is visualized to present the data, as shown in Figures 2 and 3, respectively. Rolling correlations were calculated using the R software package developed by Ulrich (2021).

3.3. Trend and Performance

As shown in Figure 3 and Figure 4, the cumulative return (geometric) of the variables was calculated by indexing their prices to 100. The EM GB posted higher returns and lower volatility than the global GB both under normal and extreme market conditions in March 2020, when the COVID-19 pandemic emerged globally.

However, in the one-year period until early 2021, the performance of EM GB lagged behind that of the global GB. Equity markets in emerging and DMs, in contrast, offered higher returns to investors while requiring them to assume higher risks. In 2015, an investor investing $100 (US) in EMs equity markets would have $140 by the beginning of 2020.

The panic triggered by the COVID-19 pandemic eroded their gains and the investment value fell below the principal amount. By contrast, an investor who invested $100 in EM GBs in

the same period had only \$125 by the beginning of 2020. When panic prevailed in the market in the following three months, the depreciation of this investor's investment remained relatively low, not exceeding 10%. The cumulative return was calculated using the R software package developed by Wuertz et al. (2023).
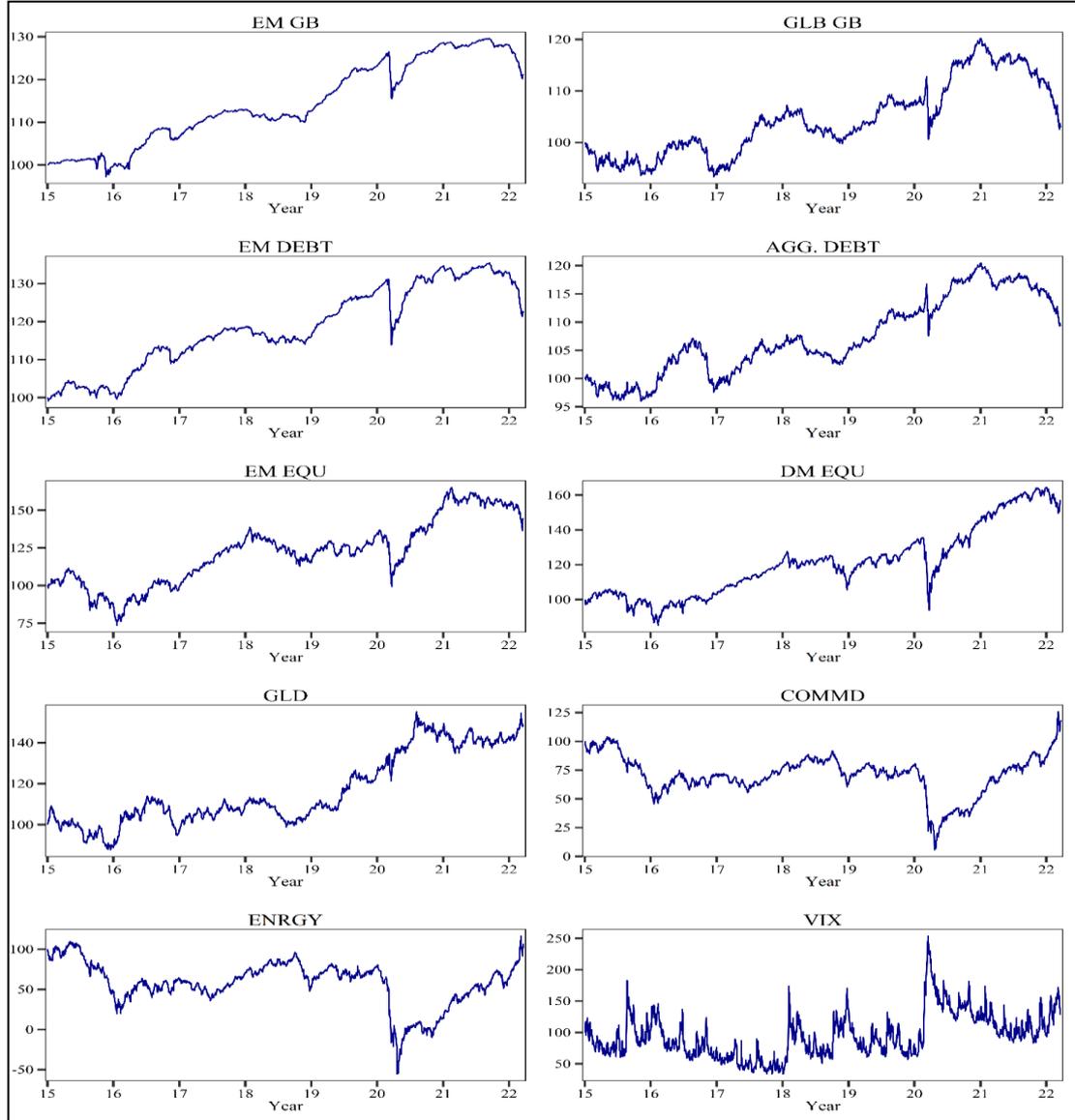

Figure 3. Trend and Cumulative Returns

Note: The prices of all variables are set to 100 on January 2, 2015, and the cumulative return (geometric cumulative return) is shown based on the natural logarithm of the daily price differences for the period covered in the study. The geometric cumulative return is calculated as follows Bacon (2004):

$$(1 + r_1) \times (1 + r_2) \times (1 + r_3) \times \cdots \times (1 + r_{n-1}) \times (1 + r_n) = (1 + r)$$

By contrast, when compared to traditional debt instruments of EM, the EM GB yielded lower returns under normal market conditions. However, in extreme market conditions, for instance, during March 2020, EM GB exhibited higher resilience with less volatility, as

illustrated in Figures 5. The relative performance displayed in the chart was calculated using the method described by Peterson and Carl (2020) in the R software package.
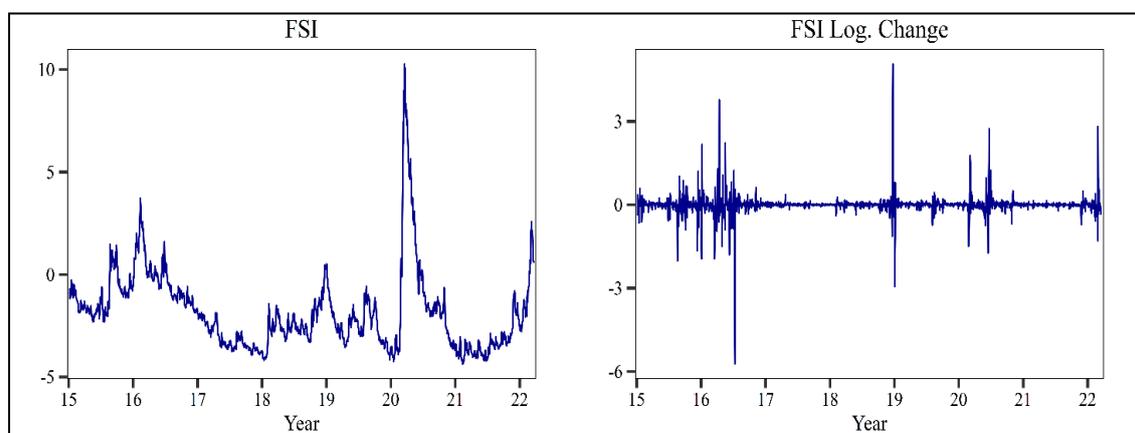

Figure 4. Financial Stress Index Performance

Note: Instead of presenting the performance and trend test in **Figure 3**, we show the daily price closures of the index on the left and the natural logarithmic price change used in the model on the right. This is because the Financial Stress Index is not well-suited for cumulative return calculation.

Further, compared to traditional EM debt instruments, the EM GB has delivered lower returns under normal market conditions. However, in extreme market conditions, such as the period between 2015 and 2016 and in 2020, the EM GB exhibited higher resilience with less volatility. This outlook is even better illustrated in Figure 5. The relative performance displayed in the chart is calculated using the methodology and R software package developed by Peterson and Carl (2020).
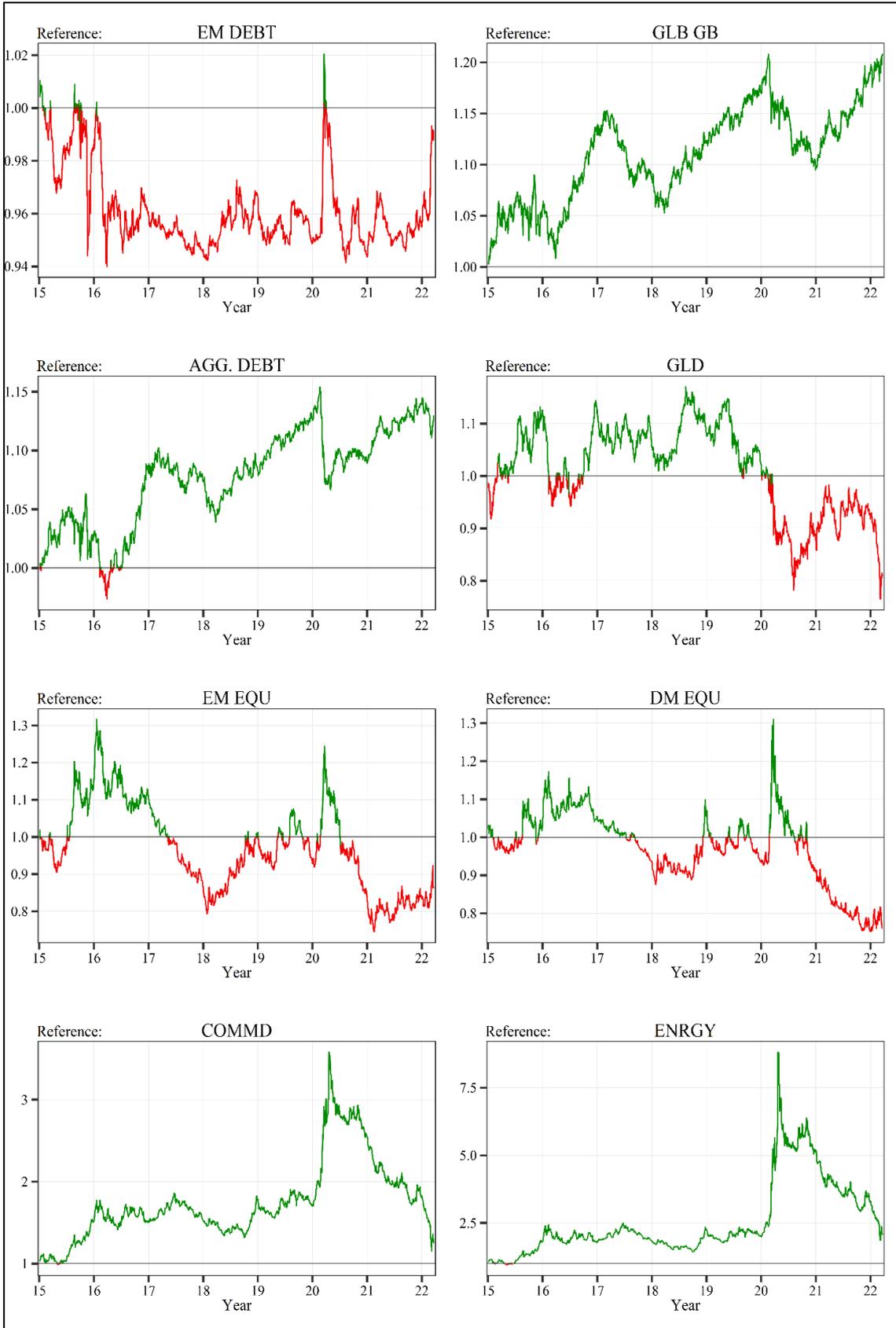
Figure 5. Relative Performance of Cumulative Returns

3.4. Methodology

This study applied the CQ method developed by Han et al. (2016). This method tests the correlation and dependence relationships between the two variables. Common tests typically measure variables from mean to mean. They divide the observations into a group or several groups and test by correlating the mean points of the groups (Uddin et al., 2019). Therefore, extreme values cannot be included, and the analyzed relationships cannot be fully revealed. By contrast, a feature of the CQ method is that the relationships tested are not only applied from mean to mean but also at various quantiles of the distribution; that is, at different probability values. Thus, different points (probability value quantiles) of the distribution, including the extreme values on the far right and far left in the distribution of the two linked variables, can be tested by associating them with the analysis at different lags. Another advantage of the method is that it tests the relationship by adjusting for macro conditions, such as volatility and financial stress (FS), through a Partial CQ [PCQ] (Han et al., 2016).

For the variables, we assume that yt and xt (t $\in$ Z) represent a stationary time series. Namely,

$\mathbf{y}_t = (y_{1t}, y_{2t}) \in \mathbb{R}^2$ and $\mathbf{x}_t = (x_{1t}, x_{2t}) \in \mathbb{R}^{d_1} \times \mathbb{R}^{d_2}$. Additionally, $x_{it} = \left[x_{it}^{(1)}, \dots, x_{it}^{(d_{it})}\right]^{\top} \in \mathbb{R}^{d_i}$, $d_i \in \mathbb{N}$ for each $i = 1,2$. In this case, the conditional distribution function for y_{it} is calculated as $F_{y_i|x_i}(\cdot \mid x_{iit})$, assuming the density function of x_{it} is $f_{y_i|x_i}(\cdot \mid x_{it})$, and the conditional quantile function $q_{i,t}(\tau_i) = \inf\{v : F_{y_i|x_i}(v \mid x_{it}) \geq \tau_i\}$. Here, $\tau_i \in (0,1)$, for each $i = 1,2$. The two intervals between (0,1) of the symbol $\mathcal{T}$ are assumed to represent a cartesian product. This cartesian product can be represented as $\mathcal{T} \equiv \mathcal{T}_1 \times \mathcal{T}_2$. Here $\mathcal{T}_i$ comprises two values in the interval $0 < \underline{\tau}_i < \bar{\tau}_i < 1$ and can be represented as $\mathcal{T}_i = [\underline{\tau}_i, \bar{\tau}_i]$.

The CQ estimates the dependence relationship between two events/variables, represented as $\{y_{1t} \leq q_{1,t}(\tau_1)\}$ and $\{y_{2,t-k} \leq q_{2,t-k}(\tau_2)\}$, by selecting a quantile q for each variable, at a quantile combination $\tau = (\tau_1, \tau_2)^{\top} \in \mathcal{T}$ and a lag k. CQ starts with a process defined as the quantile-hit. Han et al. (2016) define the CQ as "the cross-correlation between two quantile-hit processes," and is calculated as follows:

$$\rho_\tau(k) = \frac{E\left[\psi_{\tau_1}\left(y_{1,t} - q_{1,t}(\tau_1)\right)\psi_{\tau_2}\left(y_{2,t-k} - q_{2,t-k}(\tau_2)\right)\right]}{\sqrt{E\left[\psi_{\tau_1}^2\left(y_{1,t} - q_{1,t}(\tau_1)\right)\right]}\sqrt{E\left[\psi_{\tau_2}^2\left(y_{2,t-k} - q_{2,t-k}(\tau_2)\right)\right]}} \tag{2}$$

Han et al. (2016) propose dividing the time series into smaller samples by a process called resampling or bootstrap in the application of the method and calculation of the confidence interval. The CQ for the sample is as follows:

$$\hat{\rho}_t(k) = \frac{\sum_{t=k+1}^{T}\psi_{\tau_1}\left(y_{1t} - \hat{q}_{1,t}(\tau_1)\right)\psi_{\tau_2}\left(y_{2,t-k} - \hat{q}_{2,t-k}(\tau_2)\right)}{\sqrt{\sum_{t=k+1}^{T}\psi_{\tau_1}^2\left(y_{1t} - \hat{q}_{1,t}(\tau_1)\right)}\sqrt{\sum_{t=k+1}^{T}\psi_{\tau_2}^2\left(y_{2,t-k} - \hat{q}_{2,t-k}(\tau_2)\right)}} \tag{3}$$

In the resampling process, the method of Politis and Romano (1994) was used, following Han et al. (2016). The correction parameter used in this process was calculated using methods developed by Politis and White (2004) and Patton et al. (2009). The significance of the CQ test depends on whether the null hypothesis is rejected. The null hypothesis of this study is that the

relationship between the variables $\{y_{1t} \leq q_{1,t}(\tau_1)\}$ and $\{y_{2,t-k} \leq q_{2,t-k}(\tau_2)\}$ is not different from zero in the quantile combination $\tau = (\tau_1, \tau_2)^\mathsf{T} \in \mathcal{T}$ and lag k:

$$H_0: \rho_\tau(1) = \cdots = \rho_\tau(p) = 0 \tag{4}$$

The alternative hypothesis is that at lag $k \in \{1, \dots, p\}$, there is a predictable relationship between the variables, and it is different from zero:

$$H_1: \rho_\tau(k) \neq 0 \tag{5}$$

The second stage of the research tested the adequacy of the results obtained with the CQ test to reject the null hypothesis. For this purpose, the Box–Ljung Q test (sup-version - sup-Q test)—also known as the Portmanteau test—was used, as suggested by Han et al. (2016). Box–Ljung is calculated as follows:

$$\grave{Q}_T^{(p)} \equiv T(T+2)\sum_{k=1}^p \grave{\rho}_\tau^2(k)/(T-k) \tag{6}$$

Hence, as visualized in Chart 11, the CQ value is set to zero in quantiles and lags, in which the null hypothesis cannot be rejected. We then apply the PCQ model derived from the CQ test to adjust for volatility (VIX) and financial conditions (FS), which represent uncertainty indicators. The PCQ is an extended CQ test for the variables $\{y_{1t} \leq q_{1,t}(\tau_1)\}$ and $\{y_{2,t-k} \leq q_{2,t-k}(\tau_2)\}$ to control for an environmental factor in the period between $\tilde{t}$ and $t-k$. For the control, $\mathbf{z}_t \equiv \left[\psi_{\tau_3}\left(y_{y_t} - q_{3,t}(\tau_3)\right), \dots, \psi_{\tau_4}(y_{lt} - q_{l,t}(\tau_l))\right]^\mathsf{T}$ represents a numerical vector of the control variable $(l-2) \times 1$ with condition $l \geq 3$. Here, $q_{i,t}(\tau_i) = x_i^+ \beta_i(\tau_i)$, for τ_i and the vector $d_i \times 1$ is $x_{it}(i = 3, \dots, l)$.

To calculate the partial CQ, the quantile-hit process is first applied, and the correlation matrix and deviated correlation matrix are obtained with the following PCQ model:

$$R_{\tilde{\tau}} = E[h_t(\tilde{\tau})h_t(\tilde{\tau})^\mathsf{T}] \tag{7}$$

$$R_{\tilde{\tau}}^{-1} = E[h_t(\tilde{\tau})h_t(\tilde{\tau})^\mathsf{T}]^{-1} = P_{\tilde{\tau}} \tag{8}$$

where $h_t(\tilde{\tau})$ represents the Quantile-Hit process and is defined as follows:

$$h_t(\tilde{\tau}) = \left[\psi\left(y_{1t} - q_{1,t}(\tau_1)\right), \dots, \psi_{\tau l}\left(y_{lt} - q_{l,t}(\tau_l)\right)\right]^\mathsf{T} \tag{9}$$

Finally, the CQ dependence coefficient conditioned on the control variable z is obtained as follows:

$$\rho_{\tilde{\tau}|\mathbf{z}} = -p_{\tilde{\tau},12}/\sqrt{p_{\tilde{\tau},11}p_{\tilde{\tau},22}} \tag{10}$$

Since GBs are net receivers, they are treated as the dependent variable in the research, and the impact of other variables is the focus. In addition, the relationship between global and EM GBs is investigated bidirectionally. To implement the above stages, the "quantilogram" R software package developed by Oka (2022) is used.

In the research, 19 quantile values [q = (0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95)] are selected for each variable and tested in 361 quantile combinations. Following Uddin et al. (2019) and Pham (2021), the relationships between the variables included in the analysis are examined at four lags: daily, weekly,

monthly, and quarterly. In the analysis, the correlation and dependence relationship between the two variables tested in various quantiles are visualized in a heat map with the cross-quantile correlation (CQC) value according to the color value scale. Non-significant values are set to zero.

4. Results and Discussion

The findings of the test are revealed and discussed in two stages: CQC and PCQ, in which the test is repeated, controlling for market conditions.

4.1. Cross-Quantile Correlation: CQC

The results of the bidirectional dependence analysis between global GBs and GBs issued in EM are demonstrated in Figure 6. There is a significant but unequal relationship between these two assets in the short term, such as one day or one week. This is because the impact of the global GB on the EM GB is wider and lasts longer. Regarding the breadth of the effect, both positive and negative price movements in the global GB are directly proportional to the EM GB.

However, it is noteworthy that at high quantiles of 0.9, extreme appreciation of the global GB is not reflected in the EM GB. By contrast, extreme depreciation, represented by the low quantiles of the global GB, spills over to the EM GB and continues to negatively affect these bonds even a week later. Accordingly, the interdependent relationship between the global GB and the EM GB strengthens, and the pass-through increases during periods of extreme depreciation. The effect of depreciation in EM GBs is observed in global GBs the following day. However, unlike the effect of the global GB on the EM GB, this effect is very short and not seen after a week. Thus, EM GBs are positively dependent on short-term global GBs.

However, it is possible to say that the strongest impact on EM GBs does not stem from global GBs. As presented in Figure 7, the short-term impact of the dollar (US) denominated conventional debt instruments of EM DEBT on EM GBs is evident and stronger in all quantiles. This effect is particularly strong during periods of negative returns. Since the EM GB is a debt instrument in EMs, this dependency relationship can be understood.

The global-aggregate debt market (AGG DEBT) exhibits an effect similar to that of global GBs. Although the global debt market proportionally affects EM GBs in most quantiles, the excessive appreciation in higher quantiles is not reflected in EM GBs. However, a striking detail in the effect of the global-aggregate debt market is seen in the one-month lagged effect. Namely, when the EM GB is in the middle cantilevers, that is, in periods when it is stable and does not show a large movement, the movements in the global debt markets are reflected in the EM GB in a low but negatively proportional manner one month later. In particular, one month after a moderate depreciation in general debt instruments, limited and mild reflections in the opposite direction are observed for the EM GB.

Regarding the relationship between EM GBs and equity markets, EM GBs have a dynamic dependency relationship with the equities of both emerging and DMs, which vary across maturities and quantiles. When analyzed in terms of EM equity, there is a positive spillover from EM equity to EM GBs, except for the periods when EM equity generates excessively positive returns and EM GBs generate static or negative returns.
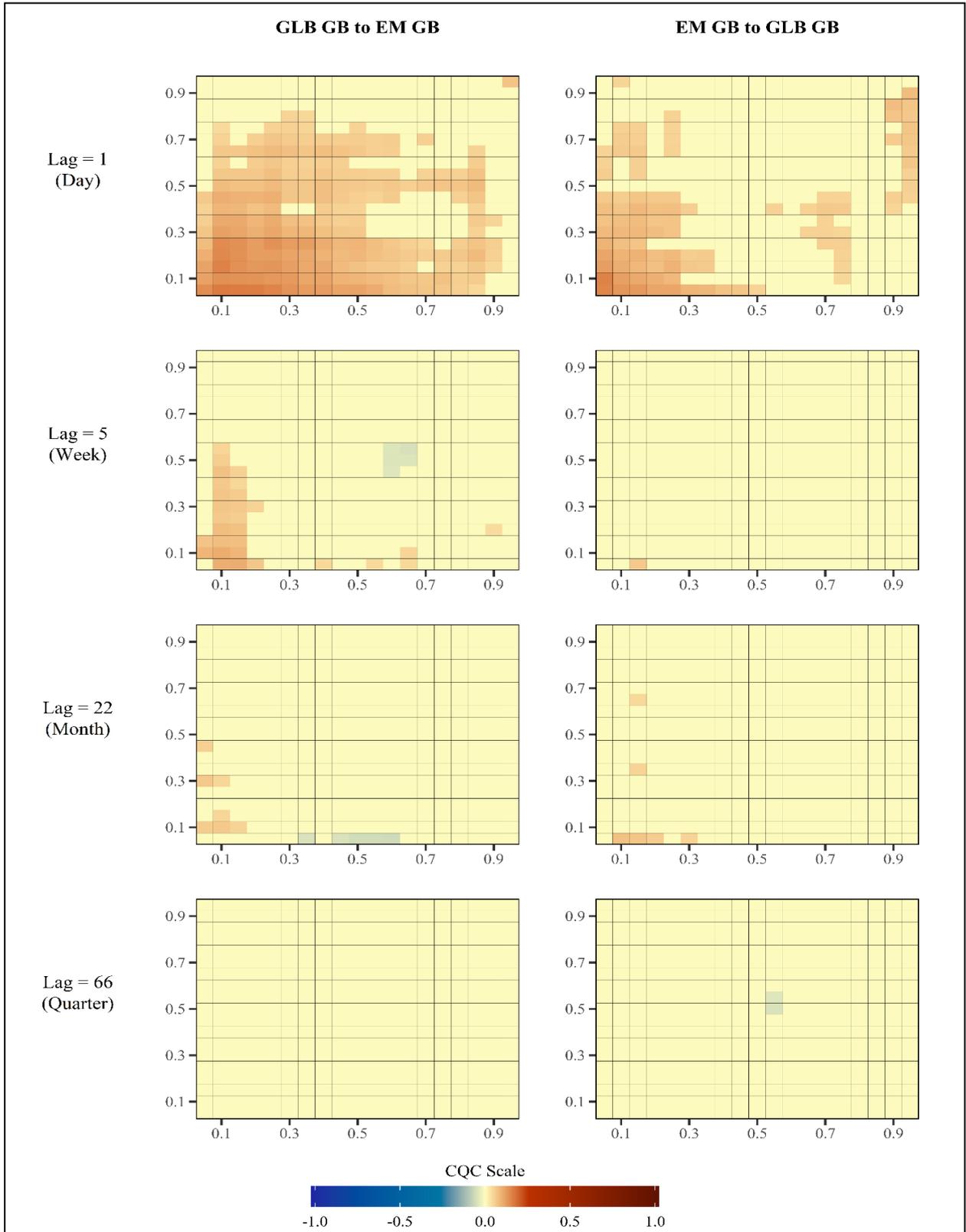
Figure 6. CQ Interdependence between Global GB and EM GB

Note: The independent variable is represented on the vertical axis, while the dependent variable is represented on the horizontal axis. The graph displays the relationship between the independent and dependent variables. The numerical values on the axes indicate the quantile values of the distribution. The CQC values are color-coded based on the value scale. Statistically insignificant results have been set to zero.
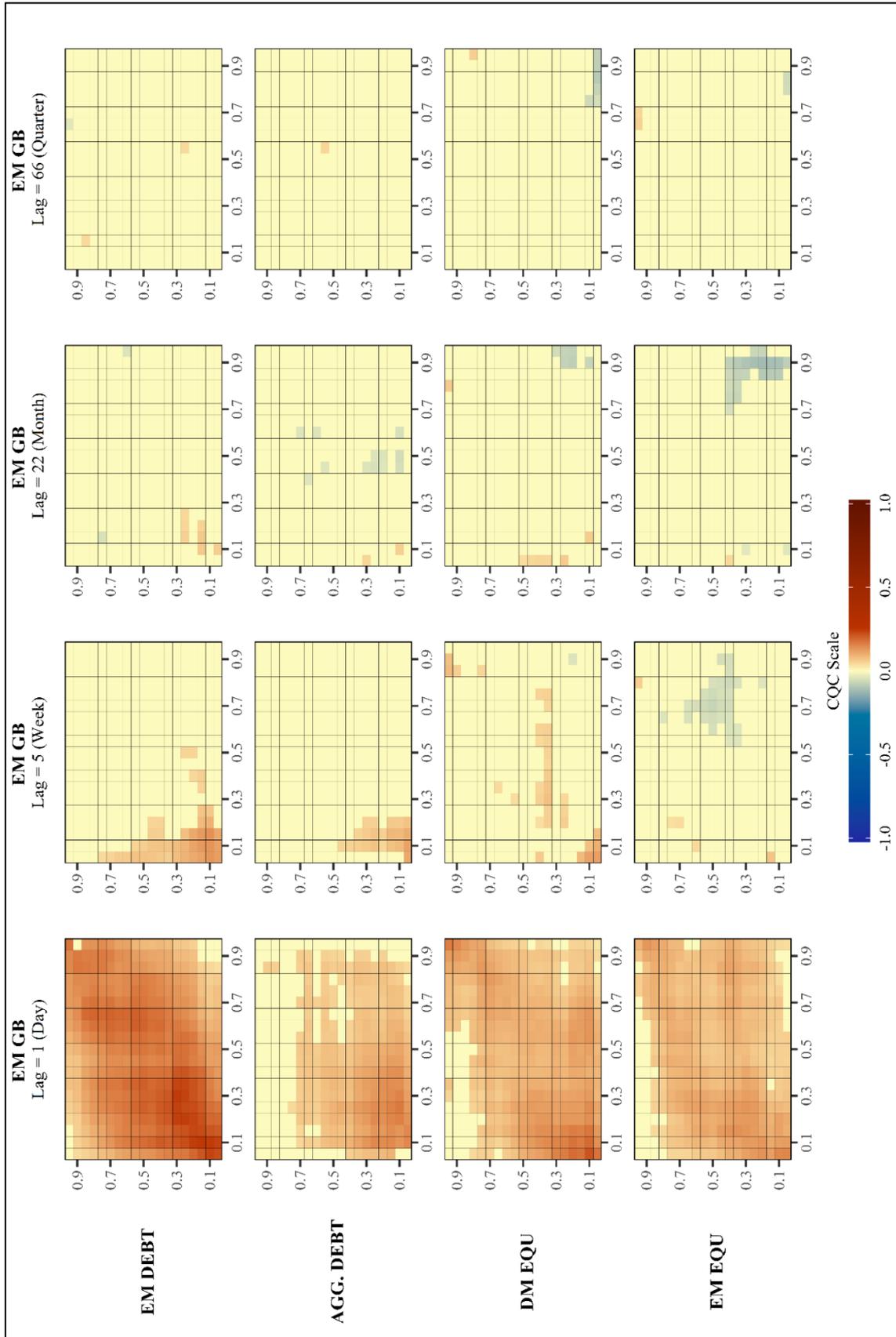
Figure 7. The Dependency of EM GB on Debt and Equity Markets

However, at a one-week time window, this spillover turns into an opposite and more limited effect. What is meant by more limited is that this effect is seen in fewer quantiles. This is because there is no negative dependence in periods when EM equity is stable, and EM GBs are positive. This negative relationship persists for one month later. However, this one-month lagged effect is limited to periods when EM GBs are extremely positive, and EM equity yields negative returns.

Nevertheless, the effect of the DM equity market in the very short term, such as one day, seems stronger than that of EM equity. This effect is even stronger during periods of high volatility; that is, during periods of extreme positive or negative values. However, compared to DM equity, the effect of DM equity on weekly and monthly maturities is complex and weaker. At one-day maturity, EM GB has a positive dependence on both DM and EM equity markets. The effect of the DM share is stronger at this maturity and disappears at longer maturities. By contrast, the effect of EM share turns negative and weakens but persists for a longer period.

Figure 8 demonstrates the analysis results of the dependence of the EM GB on gold, energy commodities, and commodity markets in general. At a one-day time window, EM equity is generally positively dependent on gold, except in periods of extremely positive returns. Conversely, the dependence of EM GB on commodity markets is limited to periods of extremely negative returns. At a one-month time window, there is a weak negative dependence relationship that varies across the quantiles.
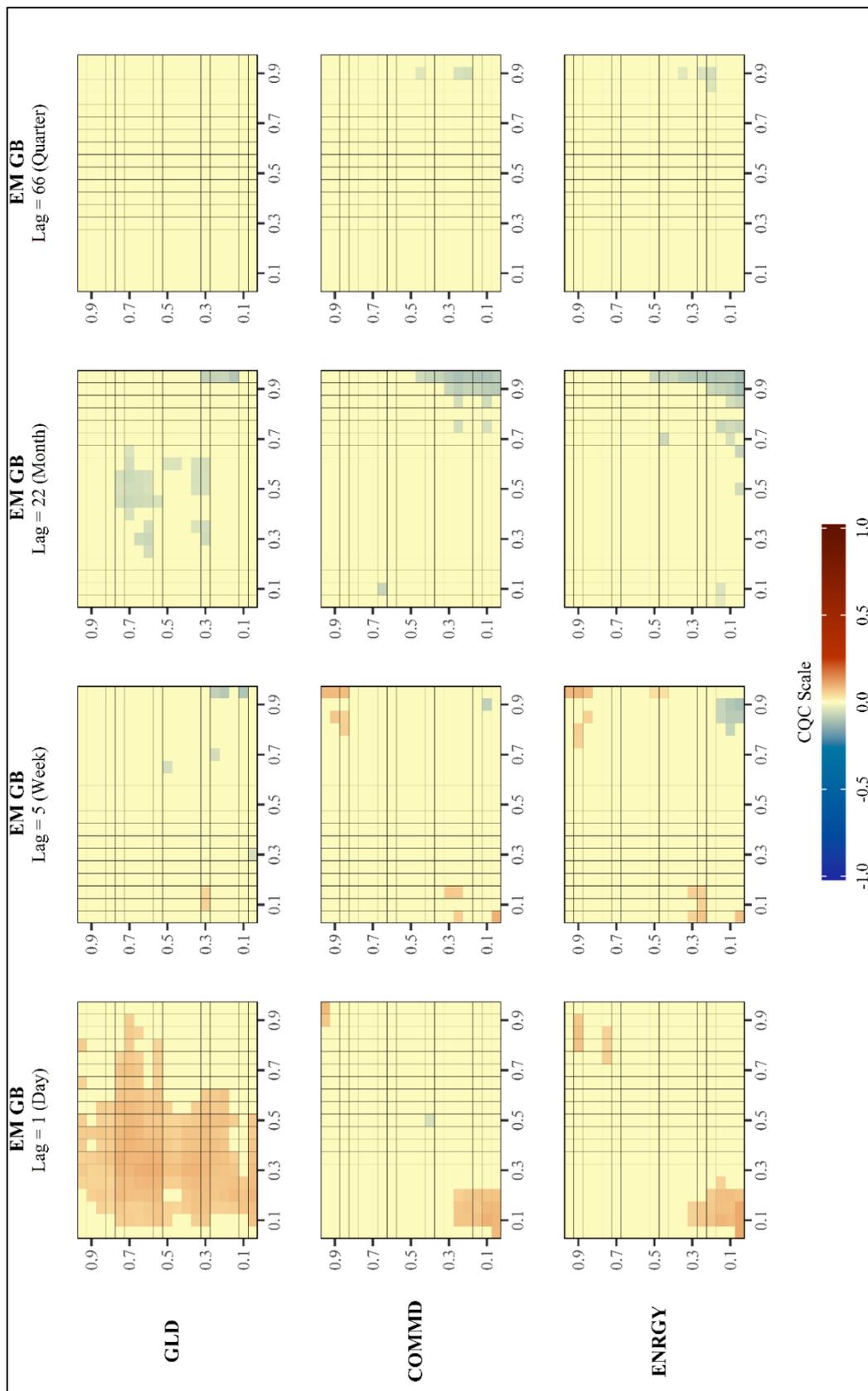
Figure 8. Dependency of EM GB on Gold, Commodity, and Energy Markets

4.2. Control for Market Conditions: PCQ

In situations in which uncertainty and/or the perception of uncertainty are prominent, the dependence relationship between variables may change as investors' views and preferences change. For example, Pham (2021), who analyzed the relationship between GBs and green stocks, stated that although there is a weak dependence relationship between the variables under normal market conditions, this dependence strengthens under extreme market conditions and rises and falls together. Therefore, it is useful to include uncertainty (environmental) as a control variable in the analysis and repeat the test. In the control test, the PCQ described in the methodology section was applied. The variables selected as uncertainty indicators were considered to have a quantile value of 0.90. Although daily, weekly, monthly, and quarterly lags were investigated in this study, a PCQ test was applied only for daily and monthly lags because of its salience. Controlling for volatility (VIX index) and FS, a proxy for financial conditions—the CQC between global GBs and EM GBs—did not change significantly, except for dependence spanning several quantiles. This result indicates that the positive dependence relationship between EM GB and global GB is insensitive to market conditions (Figure 9). From an investor perspective, this result implies that there is no hedging value in buy–sell transactions because of the direct correlation between very short-term EM GB and global GB. The same result implies that an investor who holds a global GB in their medium/long-term portfolio can hold some EM GB without disturbing portfolio diversification.

A similar pattern is observed for the dependence of EM GBs on other debt instruments. When extreme market conditions are controlled, the dependence of EM GBs on EM DEBT and debt instruments in general, as represented by AGG DEBT, did not change significantly (Figure 10). However, the situation differs in terms of the dependence of the EM GB on equity instruments.

As market uncertainty is controlled, the negative impact of the EM GB on the dependency relationship with equity instruments in the medium term, such as one month, is strengthened by spreading to more quantiles. This negative dependency relationship of EM GB is especially valid for EM equity. When the impact of the latter is compared to that of DM equity on EM GB, the impact of EM equity is more pronounced.

However, there was no significant change in the CQC of either equity instrument at a one-day lag. These findings indicate a medium-term negative correlation between EM GB and equity instruments, which weakens during periods of uncertainty. Here, the very short-term direct correlation between EM GB and equity instruments, such as one day, may be attributed to cross-market volatility. The longer-term negative correlation can be attributed to economic fundamentals.

These findings suggest that investors holding DM equity assets in their portfolios may diversify by investing in the EM GBs. Investors investing in EM equity markets, in contrast, reduce their portfolio risk by investing in green bond instruments in EMs while making additional investments in these countries.
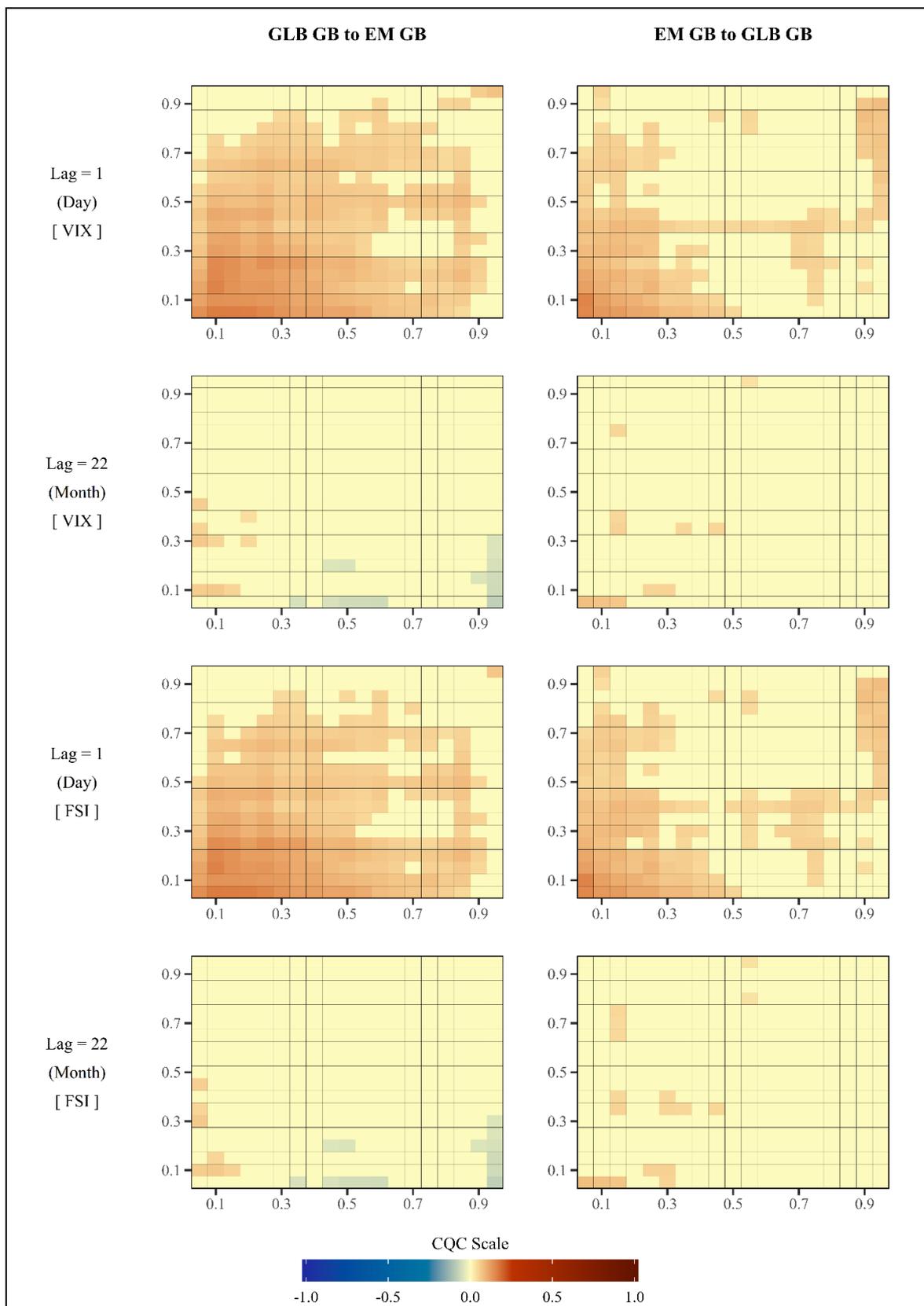
Figure 9. Interdependence Between Global GB and EM GB After Controlling for Market Conditions—PCQ
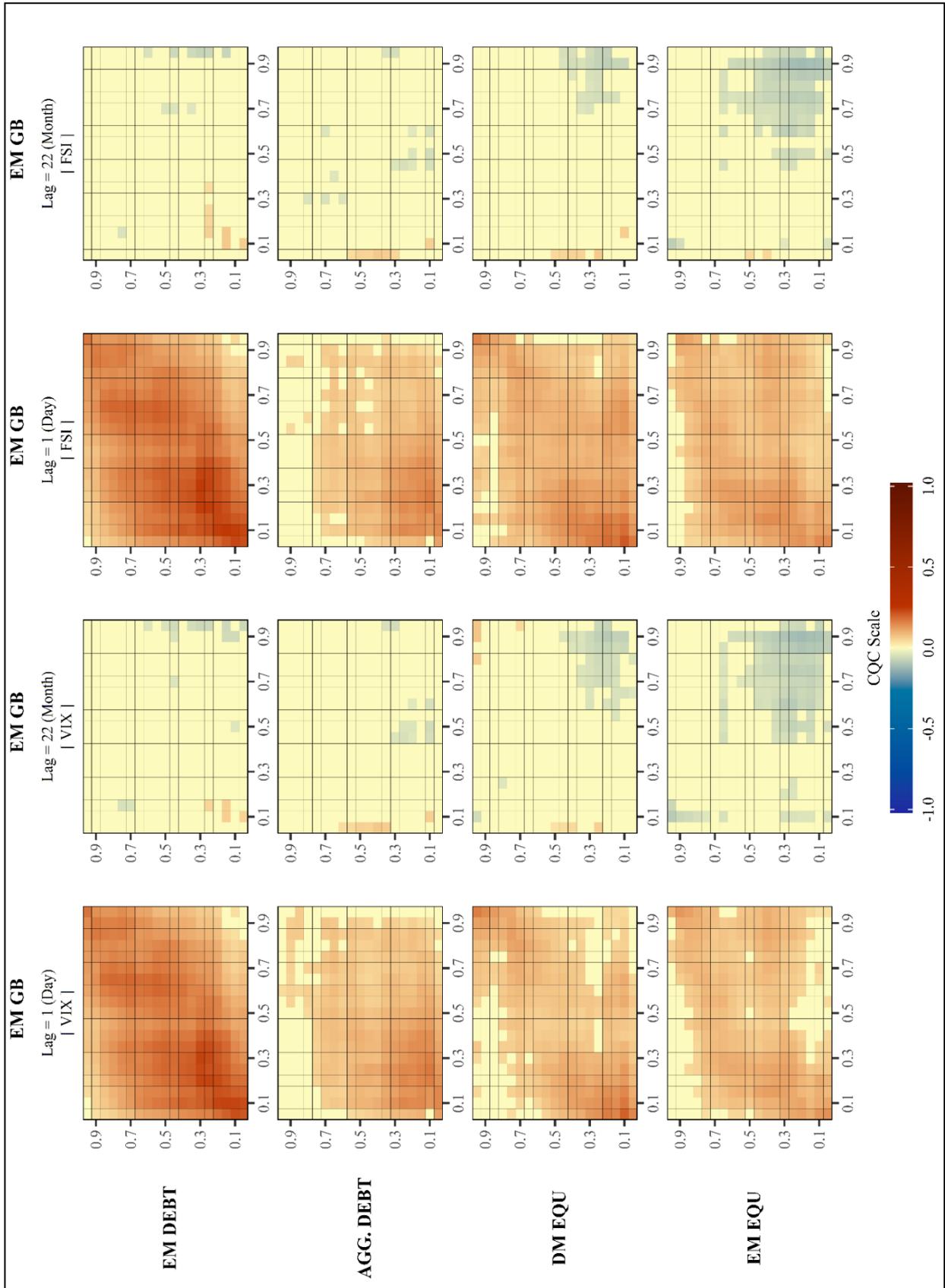
Figure 10. Dependency of EM GB on Debt and Equity Markets After Controlling for Market Conditions

Finally, the relationship between EM GBs, gold, and commodities can be analyzed. When market conditions are controlled for in Figure 11, the positive effect of gold in the very short term slightly increases. There is no significant change at one-month maturity. When gold is in the mid-quantiles, that is, when it exhibits its usual volatility, this volatility is reflected in the EM GB in the opposite direction one month later. In general, except for the very short term, the gold–EM GB relationship does not show a remarkable change according to market conditions.

However, the commodity to EM GB relationship is open and dynamically dependent on volatility and financial conditions. This is especially true for longer maturities, such as one month. While the dependence of EM GB on commodity instruments is weak and limited to a few quantiles with a one-month lag in the CQ test, a significant negative correlation emerges when financial conditions are controlled for in the PCQ test.

The negative dependence of EM GB on both the general commodity market and energy commodities is similar. This is because the moderate and slightly positive volatility of these commodities is generally reflected negatively in the EM GB. Similarly, when the EM GB is extremely positive, the depreciation in these assets is reflected in the opposite direction and supports the positive mobility of the EM GB. However, unlike the general commodity market, whose excessive negative volatility is not reflected in the EM GB, energy commodities impact the dependent variable at their lowest quantiles of 0.05–0.15, meaning that excessive depreciation of energy commodities is reflected in the EM GB in the opposite direction and increases its return. These findings on the dependence of EM GB on commodity instruments shed light on important diversification potential and may have positive implications for investors and EM GB issuers.

4.3. Policy Implications and Regulatory Outcomes

The findings of this study offer critical regulatory implications for the development and oversight of the Green Bond (GB) market in Emerging Markets (EMs). The most significant observation is the presence of a high and often instantaneous contagion risk between EM GBs and nearly all other asset classes examined, including conventional debt and equity markets. This outcome fundamentally challenges the notion of EM GBs as isolated assets and signals a vulnerability from the perspective of financial stability. These findings result in several concrete policy implications and recommendations for regulators tasked with maintaining financial stability and overseeing the development of sustainable finance in emerging economies.

1. Systemic Risk Monitoring Enhancement: Given the intensity of risk spillovers—particularly the asymmetric negative shocks propagating from global markets to EM GBs during periods of extreme depreciation—EM regulatory authorities must establish enhanced systemic risk monitoring mechanisms. These systems must be designed to meticulously monitor and oversee these channels of instantaneous contagion, with the objective of averting any potential market disruption.

2. Proactive Financial Regulations: The strong interdependence found suggests that regulators should not treat green financial instruments as inherently risk-decoupled. Instead, it is imperative that they consider the implementation of proactive financial regulations, such as adequate capital buffers or liquidity requirements. These regulations are designed to shield EM capital markets from external shocks that rapidly transmit via the green bond segment.

3. An In-Depth Analysis of Risk Transmission: In light of the anticipated sustained expansion of the EM GB market, it is imperative for regulatory authorities to conduct a meticulous examination of the underlying risk transmission mechanisms. This research should aim to specifically identify the threats posed by these mechanisms to financial stability, thereby enabling the development of targeted, preemptive, and sector-specific regulations to minimize systemic exposure.

4. Integrating Green Instruments into Stability Frameworks: The study's findings indicate that the financial behavior of EM GBs is significantly influenced by the broader conventional EM financial system. Consequently, regulatory authorities must acknowledge that the "green" label does not inherently mitigate financial contagion risk. Consequently, the integration of green financial instruments within the prevailing financial stability framework is imperative, as opposed to their treatment as discrete entities, which are perceived as lower risk.

4.4. Practical Implications and Investment Strategies

The findings of this study offer concrete strategic implications for portfolio managers and international investors targeting Emerging Markets. The analysis indicates that Emerging Market Green Bonds (EM GBs) possess a multifaceted and evolving value with respect to the objectives of portfolio diversification and hedging. The intricate dependencies observed across different asset classes have significant consequences for investment strategy, portfolio construction, and risk management. These consequences can be enumerated as follows:

1. The present study explores the limited substitution and diversification value in debt. An examination of the observed high and direct correlation between EM GBs, global GBs, and conventional USD-denominated EM debt instruments indicates that EM GBs do not exhibit independent movement in their risk-return profile. Consequently, investors should regard EM GBs as a substitute product within the debt segment, offering limited incremental diversification benefit to an existing bond portfolio. The elevated contagion risk further accentuates the constrained capacity of EM GBs to mitigate overall portfolio risk, particularly during periods of market stress.

2. Medium-Term Diversification Potential: Despite the short-term contagion effects, the dynamic dependency relationship between EM GBs and equity markets suggests a crucial role in the medium-term portfolio horizon. EM GBs offer the potential for diversification and risk reduction against equity exposure. Portfolio managers would be wise to consider a strategic allocation to EM GBs in order to balance the volatility inherent in EM equity markets. This would require a recognition of their value as a counterweight over a longer timeframe.

3. Hedging Effectiveness against Commodities: The study identifies a differentiated relationship between EM GBs and commodity markets. While a robust positive correlation with gold is evident, a negative proportional relationship with broader commodity markets becomes apparent under standard market conditions. This particular negative correlation offers a strategic insight: EM GBs have the potential to function as an effective hedging instrument against risks stemming from commodity price fluctuations, thereby contributing a distinctive value to a multi-asset portfolio.
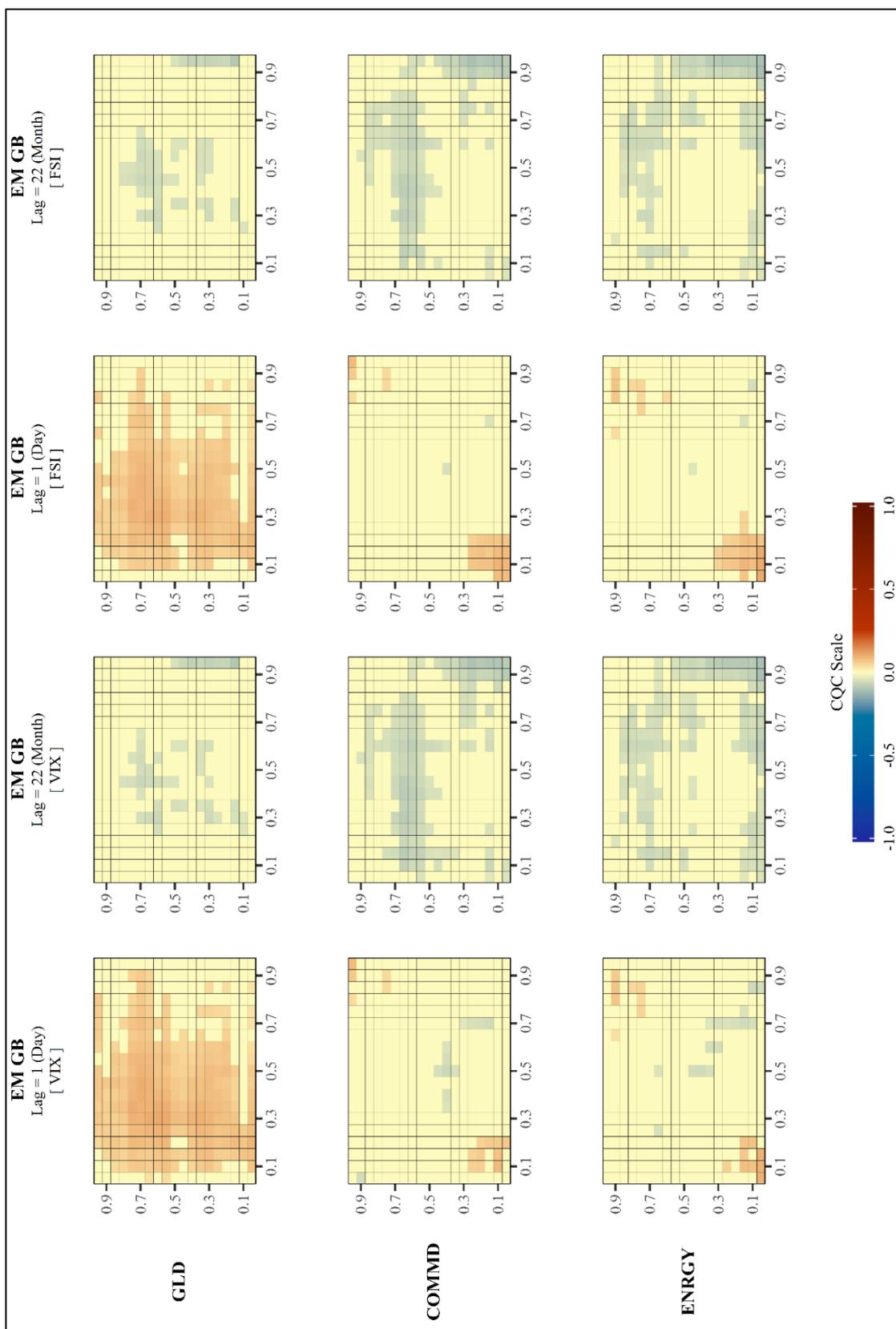
Figure 11. Dependency of EM GB on Gold, Commodity, and Energy Markets After Controlling for Market Conditions

5. Conclusion

The total amount of GSS Bonds exceeded USD 4 trillion in the first half of 2023. Although the issuance of GBs has increased rapidly in developing countries, it has not exceeded one in five of the cumulative issuances of GBs.

Some problems related to sustainability and GBs, such as transparency, accounting, and auditing, persist. In the GBs of developing countries, the lack of clarity on risk, return, and portfolio value, because these instruments are not yet widespread, poses an additional problem for investors. It is foreseeable that the GB markets of emerging economies will grow in line with current market trends and international policies. Therefore, eliminating uncertainties regarding these instruments will be beneficial for both investors and issuers.

Although there is a large body of literature analyzing the relationship between GBs and other asset classes, studies on GBs generally use global GB indices, particularly the S&P GB index and the Barclays Bloomberg GB index, as representatives of GBs. These global indices cover investment-grade GBs in both developed and developing countries. The fact that these instruments are mostly issued in DMs has led DMs to dominate global GB indices. Thus, global GB indices do not reflect the performance of GBs issued in EMs.

To find an answer to this gap in the literature, the J.P. Morgan GB Emerging Markets 10% Country Cap index, which covers only GBs issued in EMs, is taken as an indicator of the EM GB market, and the relationship between this market and other asset classes is investigated. Using daily price data for the period between 2015 and 2022, the relationship between EM GBs and global GBs; EM and global debt instruments, developed and EM equity instruments, and gold, commodity, and energy markets is tested using the CQ method.

The current results contribute to the literature and provide important implications for both financial market regulators and international portfolio investors. In the findings, high contagion, which poses a threat to financial stability in terms of regulatory and supervisory institutions, has been found, while results of interest to international portfolio investors in terms of risk and portfolio diversification have been reached.

The findings are of considerable significance for regulators in emerging markets. The high and instantaneous contagion risk from global markets to EM Green Bonds fundamentally challenges the perception of these instruments as isolated or inherently safer. Consequently, authorities should refrain from perceiving the "green" label as a mitigator of financial risk. It is imperative to integrate green financial instruments fully into systemic risk monitoring and mainstream financial stability frameworks. Proactive measures such as enhanced capital buffers may be implemented to shield against external shocks. These measures should be considered in lieu of managing them as a separate, lower-risk asset class.

For portfolio managers and international investors, the ramifications are both strategic and multifaceted. Our analysis indicates that EM Green Bonds offer limited diversification benefits within a fixed-income portfolio, acting more as a substitute for conventional EM debt due to high correlation. Nevertheless, they offer a significant opportunity for medium-term diversification against the volatility of EM equities. Moreover, their negative correlation with broader commodity markets suggests that they can serve as an effective hedging instrument against commodity price fluctuations, thereby adding a distinct value to a multi-asset portfolio.

Financial market regulators should consider the high degree of pass-through between the one-day short-term EM GB and other markets. This contagious risk pass-through between the EM GB and almost all other markets poses a problem for regulators who aim to reduce the total risk in the market and prevent financial crises. High contagion across markets, especially when panic prevails, may jeopardize financial stability. Therefore, the risk transmission mechanisms of EM GB instruments discussed in this study, which are expected to continue to grow in the future, should be further investigated, and the threats posed by these transmission mechanisms on financial stability should be identified and minimized.

Regarding portfolio diversification, the findings regarding EM GB can be summarized under three headings: debt instruments, equities, and commodities. Among debt instruments, the fluctuations observed in the total debt instruments of EMs and global GBs are reflected in the EM GB in a directly proportional manner, and this effect disappears as maturity increases. While this result shows that these instruments cannot be used to hedge against each other, the disappearance of the dependency relationship in the long run requires further investigation. Although basic economic and financial logic assumes that the dependence between these assets will continue to some extent in the long run, the analysis shows a weak relationship in the long run. This leaves a gap in the literature that needs to be addressed.

There is a dynamic dependence relationship between EM GBs and EM equity. In the very short term, there is generally a positive spillover from EM equity to the EM GB, but this turns into an inverse and more limited effect in the one-week term. This negative relationship persists after one month.

After controlling for market conditions, there is no significant change in the CQC between equity instruments and EM GBs with a one-day lag, but the negative relationship strengthens with a one-month lag. These findings indicate that there is a medium-term negative correlation between EM GBs and equity instruments, but this relationship weakens during periods of uncertainty. There is a negative correlation between EM GBs and equity instruments in the medium term under normal market conditions. When excessive volatility exists in the market, the negative relationship weakens and becomes more neutral.

This result suggests that investors holding equities in their medium-term portfolios can diversify and reduce portfolio risk by investing in the GBs of EMs. This is particularly true for equity instruments in EMs. Thus, investors who invest in equities in these markets reduce their portfolio risk while making additional investments in these countries without reducing their equity investments.

Usually, there is a positive correlation between gold and EM GBs in the very short term of one day. When market conditions are controlled for, the positive effect of gold in the very short term increases slightly. In the one-month term, there is no significant change. The gold–EM GB relationship does not change significantly according to market conditions. This result points to a diversification potential between gold and EM GBs, but this relationship needs to be further investigated.

As for the dependence of EM GBs on commodity markets, in the short term, the pass-through from other markets to EM GBs is minimal in commodity markets. In the medium term, there is an open and dynamic dependence on market conditions. This is because the CQ test does not reveal a significant relationship, whereas a significant negative relationship emerges

when controlling for market conditions. Slight to moderate positive price movements in the energy and general commodity markets are generally negatively correlated with GBs. Similarly, while GBs are positive, depreciation in these assets is reflected in EM GBs in the opposite direction and supports their positive volatility.

These findings on the dependence of EM GBs on commodity instruments shed light on important diversification potential and may have positive implications for GB investors and EM GB issuers in EMs. This study leaves several research topics for future research. First, as mentioned above, the risk transfer mechanisms related to EM GB instruments should be analyzed in more detail, and the possible negative effects on financial stability should be investigated.

Second, some uncertainty remains in the medium- and long-term relationships of EM GBs with other debt instruments. Therefore, unanswered questions remain until the interdependent relationships between these assets are tested with other methods and more comprehensive inputs. The third research issue is that although the methodology used in this study provides some advantages in testing interdependence relationships, it does not include risk–return performance indicators in the analysis; therefore, comparative performance analysis with interdependence relationships should be performed in studies aiming at portfolio optimization. Finally, the growth of GB markets in EMs may eliminate some of the study limitations, and it would be useful to retest the relationships discussed in this study with more favorable inputs.

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APPENDIX

Table A1. Dates of "J.P. Morgan Green Bond Emerging Markets 10% Capped Index" price data interruptions.

19/01/2015	18/01/2016	16/01/2017	19/02/2018	18/02/2019	17/02/2020	15/02/2021
16/02/2015	15/02/2016	20/02/2017	30/03/2018	19/04/2019	10/04/2020	02/04/2021
03/04/2015	25/03/2016	14/04/2017	28/05/2018	27/05/2019	25/05/2020	31/05/2021
25/05/2015	30/05/2016	29/05/2017	04/07/2018	04/07/2019	03/07/2020	05/07/2021
03/07/2015	04/07/2016	04/07/2017	03/09/2018	02/09/2019	07/09/2020	06/09/2021
07/09/2015	05/09/2016	04/09/2017	08/10/2018	14/10/2019	12/10/2020	11/10/2021
12/10/2015	10/10/2016	09/10/2017	12/11/2018	11/11/2019	11/11/2020	11/11/2021
11/11/2015	11/11/2016	23/11/2017	22/11/2018	28/11/2019	26/11/2020	25/11/2021
26/11/2015	24/11/2016	25/12/2017	25/12/2018	25/12/2019	25/12/2020	24/12/2021
25/12/2015	26/12/2016	01/01/2018	01/01/2019	01/01/2020	01/01/2021	17/01/2022
01/01/2016	02/01/2017	15/01/2018	21/01/2019	20/01/2020	18/01/2021	21/02/2022