The Impact of the Novel Coronavirus Pneumonia Epidemic on the Green Bond Market: A Perspective on Yield and Issuance Size

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Abstract. This study aims to empirically analyze the impact of COVID-19 on credit spreads and issue size of corporate green bonds and explores the role of factors such as bond type, issue duration and issue timing. The study empirically analyzed the COVID-19 epidemic using the least squares (OLS) method, and conducted multicollinearity and heteroskedasticity tests using the VIF test, the White test, and the Robust model, and enhanced the explanatory power of the model by introducing a dummy variable (bond category). It is found that COVID-19 significantly reduces the issuance cost of green bonds. Moreover, the issuance size of green bonds decreased after COVID-19, but this trend is no longer significant after controlling for bond category. It indicates that different types of green bonds are affected by the epidemic to different degrees. In addition, longer issuance maturities are associated with larger issuance sizes. Moreover, large-scale issuance helps to reduce credit spreads. This study reveals the complex impact of COVID-19 on the green bond market and provides empirical evidence for the development of issuance strategies for green financial products.

Keywords: Green bonds; COVID-19; Credit spread; Issuance size

1 Introduction

Since the outbreak of COVID-19, there has been an unprecedented shock to economic activities globally, especially to the financial markets (Albuquerque et al, 2020; Arellano et al., 2019)[1,2]. The government has taken action to minimize the impact of COVID-19 shocks on the economy (Cui et al., 2022)[7]. However, COVID-19 led to increased price volatility and reduced trading liquidity in global bond markets. Credit spreads widened to record levels, signaling heightened investor risk concerns about corporate bonds. In addition, COVID-19 led to a 14% decline in the issuance of such bonds at the beginning of the crisis, compared to the first quarter of 2019 (Cicchiello et al., 2022)[6]. As an important green financial product, Green bonds are designed to provide financial support for further financing or refinancing of projects with environmental benefits (Flammer, 2021)[8]. Green bonds are an important driver of green financing

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and help companies to demonstrate their green commitment while influencing national development in renewable energy (Nguyen et al., 2020; Flammer, 2021)[16,8].

How did credit spreads on green bonds change during the epidemic? Did the epidemic affect the scale of green bond issuance by firms? What is the role of different types, issuance maturities, and issuance timing in this? Despite the growing body of research in the field of green finance and sustainable investment, pervious literature on the specific impacts of the epidemic on the green bond market is still relatively scarce, especially in terms of empirical data and analyses. By exploring these issues, this study aims to empirically analyze the impact of COVID-19 on credit spreads and issuance size of corporate green bonds, and to explore the role of factors such as bond type, issuance maturity and issuance time.

On the one hand, this study helps to understand the impact of the epidemic on the green finance sector and provides a theoretical basis for risk management and policy formulation of green financial products. On the other hand, by analysing the changes in credit spreads and issue size, it can provide investors with important information about the value and risk of green bond investments. This dual perspective analysis provides a more comprehensive and detailed picture of the market impact and reveals more layers of market dynamics compared to a one-dimensional study. In addition, up-to-date data from the epidemic period for the analysis makes the findings highly current.

The paper is organized as follows: chapter one presents the background, purpose, significance, and methodology of the study. Chapter 2 conducts a literature review, reviewing research results and theoretical foundations in related fields. Chapter three constructs the model, including the research model, empirical methods, and data sources. Chapter four presents the results of the empirical analysis. Chapter 5 discusses the research findings and compares them with existing studies, and proposes a mechanism explanation for the impact of the epidemic on the green bond market. Chapter 6 summarizes the findings.

2 Literature Review

As a new instrument in the financial market, green bonds aim to provide financial support for environmentally friendly projects and promote sustainable development. With the COVID-19 pandemic causing unprecedented impact on the global economy and financial markets, the performance of green bonds in the epidemic and its implications for the future financial markets have become a hot topic for academic and industry research. Academics delve into the impact of macroeconomic factors on green bonds and the performance of green bonds under COVID-19.

Regarding the impact of macroeconomic factors on green finance, Zhou et al. (2019)[18] comparatively analyze the determinants of bond credit spreads between China and the United States using multivariate linear regression and vector autoregressive (VAR) models, and found that factors such as GDP and stock market volatility were significantly related to credit spreads. Broadstock et al. (2021)[4] point out that the financial market volatility, energy price volatility and economic stability are the main influences on the green bond market. Kumar et al. (2022)[10] discuss the challenges and opportunities for the financial sector in the post-epidemic era, particularly for developing countries, and how economic resilience can be enhanced through green financial instruments. Moreover, Summarizing previous research, COVID-19 has had a multifaceted impact on the green bond market in terms of market efficiency, market risk, market participants' reactions and strategic adjustments, credit spreads and issuance size (Cicchiello et al., 2022; Intorti et al., 2023; Mensi et al., 2021; Naeem et al., 2021)[6,9,13,15].

Firstly, COVID-19 has had an impact on the efficiency and risk of the green bond market. On the one hand, the market efficiency and risk of the green bond market were severely tested during COVID-19. Mensi et al. (2021)[13] reveal the main drivers of market inefficiency, including macroeconomic risks, financial conditions, and COVID-19. Cui et al. (2022)[7] confirm that green bonds were more affected by COVID-19. Naeem et al. (2021)[15] show that the green bond market is more efficient than the traditional bond market during COVID-19, demonstrating its risk diversification potential to extreme markets. Naeem et al. (2021)[15] further analyzes the risk spillover effect between green bonds and other sectors and finds that there are asymmetric risk spillovers. Moreover, this dynamic volatility spillover effect intensified during COVID-19. On the other hand, the green bond market exhibited greater volatility during COVID-19. Liu (2022)[11] study that the green bond market experienced large volatility and significant negative abnormal returns in response to the COVID-19 shocks, with its volatility suffering mainly from uncertainty in traditional fixed income markets. Moreover, Mensi et al. (2023)[14] claim that green bonds are net senders of systemic risk in the short run and net receivers in the long run. Moreover, during COVID-19, green bonds and gold became safe-haven assets for American equity investors.

Secondly, the impact of COVID-19 on the green bond market is also reflected in market participants' reactions and strategic adjustments. Based on the European green bond market, Cicchiello et al. (2022)[6] assert that credit spreads initially increase but then decrease in response to the vaccine news. Intorti et al. (2023)[9] claim that, although green bonds are effective in combating climate change, they typically involve higher risks and higher returns.

Finally, COVID-19 had a significant impact on credit spreads and issue size of green bonds. From a credit spread perspective, Cicchiello et al. (2022)[6] present that credit spreads on green bonds increased significantly in the early years of COVID-19, which may reflect market participants' concerns about the economic and financial uncertainty associated with the epidemic. However, as the vaccine became more widespread and the market adapted to COVID-19, the credit spreads of green bonds gradually decreased and were even lower than those of conventional bonds. This indicates a gradual recovery of investor confidence in green bonds and reflects the market's positive assessment of green assets. Regarding the size of issuance, Löffler et al. (2021)[12] observe a decrease in the size of green bonds after COVID-19. This trend may be related to the global recession caused by COVID-19, a change in investors' risk appetite, and increased volatility in financial markets. Corporations and individuals may reduce their investments in the face of economic uncertainty, leading to a contraction in the size of green bond issuance. However, with the gradual recovery of the economy and renewed market interest in climate change issues, the scale of green bond issuance is expected to resume growth.

In summary, previous research has been conducted that has made significant contributions to understanding the market performance of green bonds under COVID-19. Scholars have analyzed the credit spreads of green bonds in depth through different models and methodologies and revealed the impact of macroeconomic factors, market turbulence, energy price volatility, and economic policy uncertainty. However, there is still a research gap in the existing literature on the performance of green bonds in different market environments, especially their behaviour during extreme events such as the COVID-19 pandemic. In order to fill these gaps, this study will combine theoretical analyses and empirical data to delve into the impact of the COVID-19 pandemic on the credit spreads and issue size of green bonds.

3 Model

This study selects corporate green bonds issued by Chinese companies from 2016 to 26 March 2024 as the research object. This paper selects 3,366 green bonds issued in China from 2016 to 26 March 2024 as the original samples. After manually screening and deleting the missing value samples and duplicate samples, the paper finally obtains 2758 samples. Duplicate samples refer to the samples where two bonds have the same bond code and issuer but different market codes. Bond ID, Symbol, short name, issue date, full name, exchange code, issuer, bond nature, bond term, issue scale, par value rate of each bond is collected. Moreover, this study collects the same sample as this 2758 green corporate bonds with the same issue date as the 10-year Treasury bond yields. The green bond data for this study was obtained from the CSMAR database, while the ten-year Treasury bond yields were obtained from the investing.com database.

To examine the impact of COVID-19 on the green bond market in terms of issue size and credit spreads, this paper constructs models (1) and (2).

$$\text{CS} = \beta_0+\beta_1 COVID_{it} + \beta_2 TERM_{it} + \beta_3 SIZE_{it} + \beta_4 TIME_{it} + \varepsilon_{it} \tag{1}$$

$$\text{SIZE}= \beta_0+\beta_1 COVID_{it} + \beta_2 TERM_{it} + \beta_3 CS_{it} + \beta_4 TIME_{it} + \varepsilon_{it} \tag{2}$$

In Table 1, the explanatory variables are green bond credit spreads (CS) and issue size (SIZE). cs represents the credit spread of corporate green bonds. Ideally, green bond credit spreads represent the difference in yield between green bonds and other comparable conventional bonds. Drawing on the approach of Cicchiello et al. (2022)[6], this paper understands the green bond credit spread as the spread used to compensate investors above the risk-free rate of return. Therefore, the difference between the green bond coupon rate and the yield to maturity of a 10-year Treasury bond over the same period is used to measure the credit spread. The formula is: CS=R-Rf, where R refers to the par value rate of the green corporate bond at maturity refers to the risk-free yield to maturity on the same issue date.

The explanatory variable is COVID, which refers to whether COVID-19 has occurred on the issue date of green bond issuance by firm i, t. Referring to Albuquerque et al. (2020)[1] and Cui et al. (2022)[7], on 24th January 2020, COVID-19 is in full force in the financial market. Therefore, if after 24 January 2020 (including 24 January 2020), the value is 1. If before 24 January 2020, the value is 0. The control variables for model (1) are TERM, TIME, and SIZE, and for model (2) are TERM, TIME, and CS. where TERM denotes the maturity of the green bond. TIME denotes the number of days from the issuance date of the green bond to the date of COVID-19. TIME is negative before 24 January 2020, while positive thereafter. The value indicates the number of days between it and 24th January 2020 where ε_{it} is the random error term.

Table 1. Overview of variables

Variables		Description	Description
Dependent Variable	CS	Credit spread of Green Bond	CS =R-Rf
	SIZE	Issue size of Green Bond	Issue scale
Independent variable	COVID	Whether COVID-19 has occurred on the issue date	After 24 January 2020, the value is 1, while Before 24 January 2020, the value is 0.
Control variable	TERM	Issuance term of Green Bond	Bond term
	TIME	Days from COVID-19 to the issue date	Negative before 24 January 2020, while positive thereafter.

The summary statistics are shown in Table 2. For the 2758 samples, the average credit spread (CS) was 0.965%. The minimum value was -3.722 % while the maximum value was 7.303%. The average value of issue size (SIZE) was ¥1.255 billion. The minimum value was ¥1 million while the maximum value was ¥30 billion. 74.7% of all green bonds were issued after COVID-19. Moreover, the average maturity (TERM) of corporate green bonds was only 3.976 years. The shortest maturity was 0.03 years while the longest maturity was 30 years. In addition, the mean of TIME was 862.349 days. The minimum value was -1115 days, i.e., the earliest green bond in the sample was issued on 2016-01-05. The maximum value was 1889 days, i.e., the latest green bond in the sample was issued on 2024-03-27.

Table 2. Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CS(%)	2758	0.965	1.185	-3.722	7.303
SIZE(¥billion)	2758	1.255	2.706	0.001	30.000
COVID	2758	0.747	0.435	0.000	1.000
TERM(years)	2758	3.976	3.514	0.030	30.000
TIME(days)	2758	862.349	711.387	-1115	1889

4 Empirical Analysis

4.1 Correlation Analysis

This paper implements Pearson coefficient analysis for the main variables. According to Table 3, on the one hand, the correlation coefficient between corporate green bond credit spread (CS) and COVID-19 (covid) is -0.349. This indicates that there is a negative correlation between cs and covid, i.e., the issuance cost of corporate green bonds is reduced after covid. On the other hand, the correlation coefficient between issue size (SIZE) and COVID-19 (covid) is -0.007, which indicates that size is also negatively correlated with covid, i.e., the issuance size of corporate green bonds is reduced after covid, although the coefficient is small. In addition, the correlation coefficient between term and credit spread (CS) is 0.299, while the correlation coefficient with size is 0. This implies that term is positively correlated with credit spread, while there is almost no correlation with the size of issuance. time has a correlation coefficient of -0.336 with credit spread (CS) and -0.007 with size. The correlation coefficient of time with credit spread (CS) is -0.336, while the correlation coefficient with issue size (SIZE) is -0.005. This indicates that time has a negative correlation with both credit spread and issue size. After COVID-19, the issue size decreases, and the credit spread decreases. However, the correlation coefficient of COVID-19 (COVID) with issue term (TERM) is -0.159, which indicates that the issue term of corporate green bonds decreases after covid.

Table 3. Correlation matrix

Variables	CS	SIZE	COVID	TERM	TIME
CS	1				
SIZE	-0.214	1			
COVID	-0.349	-0.007	1		
TERM	0.299	0.000	-0.159	1	
TIME	-0.336	-0.005	0.836	-0.148	1

4.2 Regression Analysis

The regression results of model (1) are shown in Table 4, which examines the effect of COVID-19 on the issuance cost of corporate green bonds. The regression coefficient of COVID-19 (COVID) is -0.549 and is significant at 1% level (p=0.000). This implies that the issuance cost of green bonds is significantly lower after COVID-19 after controlling for issue size, issue term, and days from covid-19. The coefficient of issue term (TERM) is 0.083 and is significant at 1% level (p=0.000). This indicates that the term of issuance has a significant positive effect on the cost of issuance. That is, the longer the issuance period, the lower the issuance cost. The coefficient of issue size (SIZE) is -0.095 and significant at 1% level (p=0.000). This indicates that issue size has a significant negative effect on issue cost. The larger the issue size, the smaller the credit spread. time has a coefficient of 0 and is significant at the 1% level (p=0.000). This suggests that the number of days to COVID-19 has a negligible effect on the cost of issuance. The R-squared of the whole model is 0.235, which means that the result explains 23.5% of the variance in the sample data and the F-test is significant.

Table 4. Regression results (model (1))

CS	Coef.	St. Err.	t-value	p-value
COVID	-0.549	0.083	-6.620	0.000
TERM	0.083	0.006	14.640	0.000
SIZE	-0.095	0.007	-12.950	0.000
TIME	0.000	0.000	-4.350	0.000
Constant	1.352	0.050	27.170	0.000
R-squared	0.235			
F-test	211.143(P=0.000)			
Number of obs	2758			

The regression results of model (2) are shown in Table 5, which examines the effect of COVID-19 on the size of green bond issuance. The regression coefficient of COVID-19 (COVID) is -0.379, and it is significant at the 10% level (p=0.074<0.1). This implies that green bond issuance is significantly reduced after COVID-19 after controlling for credit spreads, term of issuance, and number of days from covid-19. The coefficient of issue term (TERM) is 0.050 and is significant at 1% level (p=0.001<0.01). This indicates that issue tenure has a significant positive effect on issue size. That is, the longer the term of the issue, the larger the issue size. The coefficient of credit spread (cs) is -0.607 and significant at 1% level (p=0.000<0.01). This indicates that credit spread has a significant positive effect on issue size. The larger the credit spread, the larger the issue size. The coefficient of the number of days (TIME) from covid-19 is 0 and insignificant, which means that this variable has no significant effect on the issue size. The R-squared of the whole model is 0.057, which means that the result explains 5.7% of the variation in the sample data and the F-test is significant.

Table 5. Regression results (model (2))

SIZE	Coef.	St. Err.	t-value	p-value
COVID	-0.379	0.212	-1.790	0.074
TERM	0.050	0.015	3.320	0.001
CS	-0.607	0.047	-12.950	0.000
TIME	0.000	0.000	-1.010	0.311
Constant	2.040	0.137	14.930	0.000
R-squared	0.057			
F-test	41.976(P=0.000)			
Number of obs	2758			

4.3 Robustness Testing

This paper uses VIF test and white test to ensure that the regression results in this paper are robust. This study uses Variance Inflation Factor (VIF) to carry out the multicollinearity test for this model. Table 6 shows that the mean value of VIF for the independent variables of model (1) and model (2) is less than 10. therefore, there is no multicollinearity in both models.

Table 6. VIF results

Model	Variable	VIF	1/VIF
Model (1)	COVID	3.330	0.300
	TERM	1.030	0.971
	SIZE	1.000	1.000
	TIME	3.320	0.301
	Mean VIF	2.17	
Model (2)	COVID	3.380	0.296
	TERM	1.100	0.909
	CS	1.230	0.813
	TIME	3.340	0.299
	Mean VIF	2.26	

For the problem of heteroskedasticity, the White test is used in this paper. As shown in Table 7, Prob>chi2= 0.000. this means that both models reject the original hypothesis of homoskedasticity, i.e., there is heteroskedasticity in both models. One of the common methods to solve the heteroskedasticity problem is Robust Standard Error Regression.

Table 7. White results

Model	Source	chi2	df	p
Model (1)	Heteroskedasticity	140.95	13	0.000
	Skewness	59.38	4	0.000
	Kurtosis	14.41	1	0.001
	Total	214.74	18	0.000
Model (2)	Heteroskedasticity	70.85	13	0.000
	Skewness	42.04	4	0.000
	Kurtosis	15.91	1	0.001
	Total	128.80	18	0.000

The Robust regression results of the two models are shown in Table 8&9. In model (1), COVID, TERM, SIZE, TIME still have significant effect on credit spread (CS) at 1% level. In model (2), COVID has a significant negative effect on issue size at the 5% level. TERM and CS still have a significant effect on issue size at the 1% level. The effect of TIME on issue size remains insignificant. In summary, the robust model is basically consistent with the above model.

Table 8. Robust regression results (model (1))

CS	Coef.	St. Err.	t-value	p-value
COVID	-0.549	0.097	-5.640	0.000
TERM	0.083	0.007	12.220	0.000
SIZE	-0.095	0.010	-9.820	0.000
TIME	0.000	0.000	-4.110	0.000
Constant	1.352	0.056	24.020	0.000
R-squared	0.235			
F-test	155.779(P=0.000)			
Number of obs	2758			

Table 9. Robust regression results (model (2))

SIZE	Coef.	St. Err.	t-value	p-value
COVID	-0.379	0.173	-2.190	0.028
TERM	0.050	0.010	4.850	0.000
CS	-0.607	0.050	-12.030	0.000
TIME	0.000	0.000	-1.010	0.314
Constant	2.040	0.171	11.910	0.000
R-squared	0.057			
F-test	40.697(P=0.000)			
Number of obs	2758			

4.4 Heterogeneity Test: Bond Category

To further explore the impact of bond category on issuance cost and issuance size, this study introduced a dummy variable for bond type in 2 models, setting up models (3) and (4). Moreover, Table 10 coded the types of Green Bonds, and there were 19 categories in the 2758 samples. Asset-Backed Securities and Green Debt Financing Instrument have the largest share of 26.72% and 15.34%, respectively.

$$CS = \beta_0 + \beta_1 COVID_{it} + \beta_2 TERM_{it} + \beta_3 SIZE_{it} + \beta_4 TIME_{it} + \beta_5 CATEGORY_{it} + \varepsilon_{it} \tag{3}$$

$$SIZE = \beta_0 + \beta_1 COVID_{it} + \beta_2 TERM_{it} + \beta_3 CS_{it} + \beta_4 TIME_{it} + \beta_5 CATEGORY_{it} + \varepsilon_{it} \tag{4}$$

Table 10. Category codes

CATEGORY	Frequency	Percent	Cumulative
General Financial Debt	197	7.14	7.14
Medium Term Note	164	5.95	13.09
Corporate Bonds	240	8.7	21.79
General Corporate Bonds	244	8.85	30.64
Exchangeable Corporate Bonds	2	0.07	30.71
Commercial Banks' General Financial Bonds	59	2.14	32.85
International Development Agency Bonds	1	0.04	32.89
Local Government Bonds	14	0.51	33.39
Foreign Sovereign Government RMB Bonds	2	0.07	33.47
Policy Financial Bonds	30	1.09	34.55
Short-term Financing Bills	10	0.36	34.92
Green Debt Financing Instrument	423	15.34	50.25
Asset-Backed Notes	252	9.14	59.39
Asset-Backed Securities	737	26.72	86.11
Chain Nitrogen Financing Instrument	87	3.15	89.27
Financial Leasing Company Financial Debt	6	0.22	89.49
Non-Publicly Issued Corporate Bonds	268	9.72	99.2
Non-public Directed Debt Financing Instruments	21	0.76	99.96
Project Revenue Bonds	1	0.04	100
Total	2758	100	

In this study, regression analyses of models (3) and (4) with the inclusion of a dummy variable (CATEGORY) were conducted using the areg command. Table 11 shows that the regression coefficient of COVID-19 (COVID) is -0.530 and is significant at the 1% level (p=0.000). This implies that the issuance cost of green bonds is still significantly lower after COVID-19 with the inclusion of the bond category. In addition, the coefficients of issue term (TERM), issue size (SIZE) and TIME remain significant. In addition, the R-squared of model (3) rises from 0.235 to 0.423 compared to model (1), which means that the model fit is almost doubled.

Table 11. AREG regression results (model (3))

CS	Coef.	St. Err.	t-value	p-value
COVID	-0.530	0.074	-7.220	0.000
TERM	0.053	0.006	9.330	0.000

SIZE	-0.059	0.007	-7.930	0.000
TIME	0.000	0.000	-3.700	0.000
Constant	1.371	0.045	30.560	0.000
R-squared	0.423			
F-test	127.837(P=0.000)			
F-test of absorbed indicators	49.616(P=0.000)			
Number of obs	2758			

Table 12 shows that the regression coefficient of COVID-19 (COVID) is -0.008 and insignificant at 1% level (p=0.968). This means that the coefficient on the issue size of green bonds after COVID-19 is not only reduced but the coefficient is also insignificant after adding the bond category. This means that the effect of COVID-19 on issue size is not significant anymore for different categories of bonds. The coefficients of issuance term (TERM), credit spread (CS) and TIME are consistent with model (2). In addition, the R-squared of model (4) improves from 0.057 to 0.278 compared to model (2), which implies that the model fit is better considering the bond category.

Table 12. AREG regression results (model (4))

SIZE	Coef.	St. Err.	t-value	p-value
COVID	-0.008	0.190	-0.040	0.968
TERM	0.063	0.015	4.280	0.000
CS	-0.383	0.048	-7.930	0.000
TIME	0.000	0.000	0.280	0.778
Constant	1.353	0.130	10.390	0.000
R-squared	0.278			
F-test	20.097(P=0.000)			
F-test of absorbed indicators	46.311(P=0.000)			
Number of obs	2758			

5 Results and Discussion

The occurrence of COVID-19 significantly reduces the credit spreads of green bonds, which is not in line with Cicchiello et al. (2022)[6] and Intonti et al. (2023)[9]. This may be related to the difference in their study population. Cicchiello et al. (2022)[6] focuses on the European market while Intonti et al. (2023)[9] focuses on the Asian market. This study focuses on the Chinese market. This phenomenon may be related to the changes in market environment, policy support and market demand in China before and after the epidemic. First, changes in the market environment may be a key factor affecting the cost of green bond issuance. During the epidemic, green bonds may have received more attention as a relatively safe investment vehicle (Cicchiello et al., 2022)[6].

In addition, the social value of green bonds has been more recognised as people become more aware of sustainable development and environmental protection. This is consistent with Tang & Zhang (2020)[17]. Issuing green bonds can help companies attract investors who are concerned about environmental issues, thus expanding their investor base. This suggests that green financial instruments are not only beneficial for advancing sustainable projects, but may also open up new sources of funding for firms and enhance the diversity of their financing channels. This may have led to a reduction in their issuance costs (Cicchiello et al., 2022)[6]. In addition, policy support may also be an important factor. During the epidemic, China introduced policy measures to stimulate its economy, including support for green finance. These policies may have directly or indirectly reduced the issuance costs of green bonds.

After COVID-19, the size of green bond issuance has decreased significantly. This is consistent with Löffler et al. (2021)[12]. However, the reduction in the size of green bond issues after COVID-19 declines after considering the bond type and is not statistically significant. This finding may suggest that there are differences in the changes in the issue size of different types of green bonds after the epidemic, and that these differences may have influenced the overall trend in issue size. The COVID-19 epidemic led to great uncertainty in the global economy, and many firms and industries were hit. In this environment, companies may reduce the size of their investments, including reducing investment and financing in environmental projects. This curtailment may directly lead to a reduction in the scale of green bond issuance. Moreover, following COVID-19, investors and businesses may adopt more conservative strategies, favoring holding cash or investing in less risky assets. As green projects tend to require long-term investments and higher initial costs, this may have led to a decrease in the attractiveness of green bonds, thus reducing the size of their issuance.

In addition, COVID-19 may have changed the financing needs of businesses. Initially, many firms faced liquidity pressures and prioritized short-term debt financing over long-term green project investments. This shift in demand may have affected the scale of green bond issuance. In sum, a combination of economic uncertainty, risk-averse behaviour, and changes in financing needs around COVID-19 led to a reduction in the scale of green bond issuance. However, the green bond market includes many types of bonds, such as green corporate bonds, green government bonds, and green financial bonds. These different types of green bonds may be affected by the epidemic to different degrees. For example, green bonds issued by the government may be less affected because of the government's invisible guarantee, while green bonds issued by corporations may be more affected because of the corporations' own business risks (Baldacci & Possamaï, 2022)[3].

Longer issuance periods reduce issuance costs and accompany larger issuance sizes. This is in line with risk compensation theory, consistent with Brugler et al. (2022)[5]. On the one hand, longer issuance periods imply that investors need to bear the risk of interest rate changes for a longer period of time. To compensate for this risk, issuers usually need to offer lower interest rates, which reduces the cost of issuance. Long-term bonds are usually favored by long-term investors (e.g. pensions, insurance companies, etc.) because they offer stable cash flows and a long-term investment match. This stable demand can help reduce issuance costs. On the other hand, longer issuance maturities are usually associated with large capital projects that require long-term funding to support their construction and operation. As a result, longer issuance maturities may be associated with larger issuance sizes.

There is an inverse relationship between credit spreads and issue size. Larger credit spreads imply that investors need higher ret urns to compensate for the credit risk taken (Brugler et al., 2022)[5]. When a bond has larger credit spreads, it usually means that the bond has a lower credit rating, or the market has higher concerns about its default risk. In this case, in order to attract investors to buy it, it may be necessary to reduce the size of the issue in order to reduce the supply, which in turn increases the bond price and lowers the yield. Moreover, from an investor's point of view, higher credit spreads may result from illiquidity or increased credit risk. In the case of increased credit risk, investors may demand higher yields as compensation, which could lead to a decrease in demand for bonds, thus limiting the size of the issue.

6 Conclusion

The outbreak of COVID-19 has had a profound impact on the global economy and has brought new challenges and opportunities for green finance. In this context, this study empirically analyses the impact of COVID-19 on corporate green bond credit spreads and issuance size, taking into account the roles of different bond categories, issuance maturities, and issuance times. Moreover, the model was tested for multicollinearity and heteroskedasticity through VIF test, White test, and Robust model. In addition, the inclusion of a dummy variable (bond category) further improves the explanatory effect of the model.

The study shows that, on the one hand, the occurrence of COVID-19 significantly reduces the issuance cost of green bonds, a result that may be related to changes in the market environment, policy support, and growth in market demand during the epidemic. In particular, the longer issuance term contributed to a further reduction in issuance costs. These results on issuance costs do not change after considering the bond type. In addition, large-size issuance narrows credit spreads, reflecting market recognition of issuer credit risk. On the other hand, the size of green bond issuance decreases significantly after COVID-19, but this decrease is no longer significant after considering bond type. This suggests that there are differences in the extent to which different types of green bonds are affected by the post-epidemic period. Longer issuance maturities are associated with larger issuance sizes, possibly because longer-term bonds are more aligned with the financing needs of large capital projects. In addition, higher credit spreads are accompanied by larger issue sizes, while the number of days to COVID-19 has no significant effect on either issuance costs or issue size. These findings reveal the complex impact of COVID-19 on the green bond market and provide empirical references for the issuance strategies of green financial products.

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