

Article

Research on the Impact of Green Bonds on Credit Risk of Manufacturing Enterprises

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Abstract: This article takes 30 listed enterprises in the manufacturing industry as samples, uses the KMV model to measure the default distance, and tests the validity of the measurement results to investigate whether issuing green bonds has a potential impact on the credit risk of enterprises. The results show that the KMV model has a better ability to predict corporate credit risk; and enterprises that have issued green bonds generally have lower credit risk due to signaling effects and other effects. Finally, this article puts forward relevant recommendations such as policy support and database construction based on the research results. This article provides a basis for enterprises to broaden financing channels and strengthen credit risk management.

Keywords: Green Bonds; Credit Risk; KMV Model; Manufacturing Enterprises; Listed Companies

1. Introduction

China's economic development has made world-renowned achievements in recent years, but ecological and environmental problems are becoming increasingly serious, and the contradiction between limited resources and unlimited demand becoming more apparent, highlighting the need for China to pursue a green development path.

China made a solemn promise to the world in September 2020 to aim for peak CO₂ emissions by 2030 and carbon neutrality by 2060. This "double carbon" target is not only a strategic deployment to promote the development of ecological civilization in China, but it also means that the green and low-carbon development model of China's real economy is undergoing a major transformation, bringing new opportunities for the development of green finance. Green bonds, as an essential component of the green financial system, can not only provide necessary financial support for green and low-carbon industries, but also assist relevant green projects in overcoming financing constraints, thereby promoting the sustainable development of green and low-carbon industries. Manufacturing enterprises currently account for a significant portion of China's high pollution and energy consumption, and because their industrial chains are more intricate and their risk tolerance is lower than those of other industries, their credit risk is higher than that of other sectors. Therefore, some manufacturing enterprises try to optimize the financing structure and reduce credit risk by issuing green bonds. Previous research on green bonds by scholars mainly focuses on the influencing factors of green bonds, the benefits brought by green bonds, etc. Research on corporate credit risk mainly focuses on the negative impacts brought by credit risk, and the measures on how

to curb credit risk are mainly carried out from the external environment and internal management. Few scholars have researched whether the issuance of green bonds will affect corporate credit risk.

Based on previous research, this paper uses 30 manufacturing enterprises as research objects, with enterprises that issued green bonds before 2021 serving as the experimental group and enterprises that did not issue green bonds serving as the control group. The KMV model (or Credit Monitor Model) is then used to calculate the enterprises' default distance, and the application value of the KMV model is determined through validity tests. Finally, the paper studies whether issuing green bonds has a potential impact on the credit risk of enterprises. The main contributions of this article are as follows: first, it adds to the research on the relationship between green bonds and corporate credit risk; second, it demonstrates the applicability of the KMV model to measure the default distance, which can effectively predict credit risk; and third, it validates the view that enterprises that have issued green bonds generally have lower credit risk. The following is the article's structure: the second section is literature review; the third section is the research design of the KMV model; the fourth section is empirical analysis; and the fifth section is conclusions and recommendations.

2. Literature Review

Green bonds are a significant form of corporate financing, and numerous parties are releasing various bond variants, with state-owned firms and banks dominating the market. However, throughout the investment and financing process, companies are vulnerable to the problem of credit risk, which if not averted in time may lead to a significant catastrophe, thus it is critical for enterprises to assess and warn about credit risk in real time. Domestic and international research on green bonds and corporate credit risk is most evident in the following areas.

2.1. Green Bonds

Hyun et al. (2020) [1] found through their study that green bonds just account for just approximately 3% of the worldwide bond market and that there are still several impediments to the development of the green bond market due to higher issuance costs and information asymmetry. Yang and Shi (2020) [2] conducted an empirical study with data from a sample of 170 green bonds in China and discovered that public green bonds have a more prominent advantage in terms of financing costs, policy support can have a significant impact on financing, and third-party green certification has not yet played a significant role in reducing financing costs. Zhang et al. (2021) [3] demonstrated that when corporations issue green bonds, their cost of capital is dramatically decreased if they can reduce the issuer's perceived risk, improve safe liquidity, and eliminate information asymmetry. Based on panel data of 1775 listed companies, Ma et al. (2020) [4] used a double difference model to find that the cost of financing and individual investor sentiment has significant mediating effects on green bond issuance and increase in firm value. Wu et al. (2022) [5] showed that the issuance of green bonds by businesses can have a positive industry spillover effect, encouraging other businesses in the same sector to undertake more green projects. Additionally, other companies have significantly improved their financial performance and environmental benefits after implementing green and low-carbon behaviors. Zhang et al. (2022) [6] found that companies' ability to innovate green was considerably enhanced after issuing green bonds, mainly due to improved information transparency and easing of financing constraints, both of which together contributed to the green development of companies.

2.2. Bonds and Credit Risk

Zhang et al. (2019) [7] demonstrated that credit risk arising from bond defaults has a pricing effect in the primary market after industry contagion. Based on the default scenario in the Chinese bond market, Hu and Peng (2023) [8] discovered that bond defaults can have a detrimental impact on the broader regional credit climate. Yang et al. (2021) [9] used a sample of A-share listed companies from 2001-2019 and showed that changing the regulatory environment and increasing internal governance construction can mitigate the detrimental impact of bank rivalry on corporate credit risk. Sheng et al. (2019) [10] built a logistic model to investigate the influencing elements of default of bond issuers in China and discovered that default risk can be greatly decreased by maximizing profitability and reducing leverage and enhancing asset liquidity. Dräger et al. (2021) [11] presented new guarantees to manage commercial banks' credit risk, arguing that creative guarantees can assist control banks' credit risk. Zhang and Lv (2022) [12] found that by establishing a basic model based on company financial statements and extending it by introducing textual information, banks can reduce information asymmetry, which has a major effect on the improvement of credit risk identification.

2.3. Measuring Credit Risk Using the KMV Model

A substantial inverse association between a company's credit risk and its carbon emissions and carbon intensity was found by Capasso et al. (2020) [13], who utilized the KMV model to quantify the firm's credit risk and analyze its relationship with climate change. Lu and Gao (2021) [14] used the KMV model to measure the credit default risk of 36 listed companies, and found that the KMV model can effectively measure the credit default risk of listed companies, and has a certain early warning effect through empirical analysis. Wang et al. (2019) [15] selected 94 credit asset securitization products in China, and after empirical analysis of the improved KMV model, they found that these products have higher credit ratings and lower default probability, so they can be regarded as a stable investment channel. Chen et al. (2019) [16] applies the modified KMV model to identify the credit risk level of customers in factoring business and finds that it can identify the credit risk of enterprises more accurately and provide reference for the decision-making of factors, which has high application value. Wang and Cao (2022) [17] constructed a jump-diffusion KMV model and analyzed it at different levels. The results showed that the greater the default distance and the lower the credit risk of a company when its jump risk is low, its own solvency is solid, and its performance is good during the economic boom. Zhang and Li (2018) [18] chose six Chinese commercial banks engaged in carbon financing as the study's subject matter. They measured their credit risk and market risk using the KMV model and generalized autoregressive conditional heteroskedasticity model, respectively, and used the factorial Copula model to analyze the correlation between them. Based on data from 36 listed banks in China, Guo and Zhou (2022) [19] used the KMV model and random forest model to calculate the default distance and demonstrated that the internal factors (such as business structure and management) have a greater impact on commercial banks' credit risk than the external environment. Song et al. (2020) [20] applied the KMV model to the block chain financial market, due to the existence of a particle swarm optimization method in the MATLAB software, and its application to the modified KMV model can be found that the coefficients of the long and short-term liabilities can be effectively corrected. And through the ROC curve, ST stocks and non-ST stocks in the market are finally distinguished successfully, which proves that this optimization method can effectively identify the credit risk of listed companies in the block chain financial market.

In summary, from the combing of domestic and foreign academic literature, there are many researches on green bonds and corporate credit risk, and many academics use the KMV model to measure credit risk, but there are still some areas that need to be improved. Firstly, there are limited researches on risks in the existing literature on green bonds, which mostly focuses on the assessment of financing costs and benefits. Secondly, research on the effects of green bonds issued by micro-enterprises is less common than research on banks and other financial institutions. Thirdly, the existing literature mainly focuses on the factors affecting enterprise credit risk from the external environment and internal management, but the relationship between the issue of green bonds and the credit risk of the companies themselves is rarely researched. The correlation between the issuance of green bonds and enterprises' own credit risk is rarely studied. As a special industry, the manufacturing industry is less able to resist risks, so it is necessary to further investigate if green bonds influence the credit risk of manufacturing enterprises based on previous scholars' studies in this article.

3. Research Design

3.1. Sample Selection

Table 1. Basic characteristics of the sample companies in the experimental group.

Experimental Group	Subsectors	Size	Business History	Credit Rating
X ₁	Chemical fiber manufacturing	large-scale	25 years	A-
X ₂	Metalwork industry	large-scale	26 years	AAA
X ₃	Electrical machinery and equipment manufacturing	large-scale	28 years	AA
X ₄	General equipment manufacturing	large-scale	22 years	AAA
X ₅	Comprehensive utilization of waste resources	large-scale	17 years	AA
X ₆	Metalwork industry	large-scale	28 years	A+
X ₇	Chemical fiber manufacturing	large-scale	16 years	AA
X ₈	automobile manufacturing	large-scale	21 years	AAA
X ₉	Comprehensive utilization of waste resources	large-scale	24 years	AA+
X ₁₀	Electrical machinery and equipment manufacturing	large-scale	26 years	AA
X ₁₁	Ferrous metal smelting and rolling	large-scale	23 years	AA
X ₁₂	Non-metallic mineral products	large-scale	24 years	AA-
X ₁₃	Chemical raw materials and chemical products manufacturing	large-scale	25 years	AA
X ₁₄	Non-metallic mineral products	large-scale	12 years	AA
X ₁₅	Non-ferrous metal smelting and rolling	large-scale	21 years	AA-

According to the Securities and Futures Commission's (SFC) 2012 industry categorization, this paper takes the manufacturing industry as an example and selects the enterprises that have issued green bonds before 2021 as the experimental group. Because the KMV model is only applicable to the assessment of credit risk of listed enterprises, the unlisted enterprises are excluded from the sample selection, and enterprises with suspended trading and some missing data are excluded to ensure the comprehensiveness of the data and the accuracy of the calculation. Fifteen enterprises were finally screened to meet the conditions.

The control group consists of 15 listed enterprises that have not issued green bonds before 2021. The control group is selected by the following steps: first, enterprises in the manufacturing industry are screened according to the SEC industry classification standards, which are the same as the experimental group, covering 10 subsectors under the manufacturing classification. And unlisted enterprises, enterprises that had experienced suspension and some missing data were excluded among them. Secondly, firms that have not issued green bonds before 2021 are selected among them. Finally, 15 listed enterprises with similar asset size, similar main business, and similar years of operation as the sample companies in the experimental group were screened out according to the 1:1 criterion. The basic characteristics of the 30 sample enterprises are shown in Tables 1 and 2. The data used in this paper are obtained from the China Stock Market Accounting Research Database, and the calculation of indicators in this database is based on the annual reports published by listed enterprises.

Table 2. Basic characteristics of the sample companies in the control group.

Control Group	Subsectors	Size	Business History	Credit Rating
Y ₁	Electrical machinery and equipment manufacturing	large-scale	23 years	AA
Y ₂	Electrical machinery and equipment manufacturing	large-scale	31 years	AA
Y ₃	Non-metallic mineral products	large-scale	37 years	AA
Y ₄	Non-metallic mineral products	large-scale	21 years	AA+
Y ₅	Comprehensive utilization of waste resources	medium size	17 years	A+
Y ₆	Ferrous metal smelting and rolling	large-scale	30 years	AA-
Y ₇	Ferrous metal smelting and rolling	large-scale	24 years	AAA
Y ₈	Chemical fiber manufacturing	large-scale	30 years	AA+
Y ₉	Chemical fiber manufacturing	large-scale	23 years	AA
Y ₁₀	Chemical raw materials and chemical products manufacturing	large-scale	21 years	AA
Y ₁₁	Metalwork industry	large-scale	29 years	A+
Y ₁₂	Metalwork industry	large-scale	19 years	AA
Y ₁₃	automobile manufacturing	large-scale	24 years	AA+
Y ₁₄	General equipment manufacturing	large-scale	22 years	AA
Y ₁₅	Non-ferrous metal smelting and rolling	large-scale	31 years	A+

3.2. Model Design

The KMV model was proposed by American KMV company and is widely recognized worldwide. The KMV model is based on the B-S option pricing theory. It means that when valuing a company's stock, the market price of its assets is used as the underlying, and real-time stock price data from the capital market is used to forecast the actual future default probability of the enterprise, and then this result is compared with the expected default probability to derive the credit standing of enterprise. In the KMV model, the equity of the enterprise is considered as a call option, and the liabilities of the enterprise are considered as the strike price, with the enterprise's asset value serving as the underlying. If the asset value is lower than the liability, the firm will choose to default; on the contrary, if the asset value is higher than the liability, the firm will pay the debt as promised. The KMV model involves many parameters, of which three variables, debt value, risk-free rate and time parameter are known, but asset value and its volatility are unknown.

3.2.1. Market Value of Equity " V_E "

In the KMV model, all shares of a business are freely circulating and unrestricted, therefore the equity market value may be determined easily using the stock price and quantity. However, there are still many listed companies in the domestic stock exchange market that have both outstanding and non-floating shares, so this paper employs a method commonly used by scholars, which is to use net assets per share as the price of non-floating shares, and then add the two together to arrive at the following equation:

$$\text{Equity market value } "V_E" = \text{number of outstanding shares} \times \text{stock price} + \text{number of non-marketable shares} \times \text{net asset per share} \quad (1)$$

3.2.2. Annual Volatility of Equity Value " σ_E "

KMV calculates equity value volatility using the historical data method, assuming that all the company's stocks are freely available and that stock prices follow a normal distribution with stable variance, so the log-return method is used to first calculate the daily stock price return " u_i ", and then the daily equity value volatility σ is derived using the standard deviation, calculated as follows:

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (u_i - \bar{u})^2} \quad (2)$$

Where " u_i " denotes the daily stock return. " \bar{u} " denotes the average return of the stock over a specific period.

The equity value volatility is the product of the daily equity value volatility and the actual number of trading days in a year. " n " denotes the actual number of trading days of the stock in the year, and finally the annual equity value volatility " σ_E " is obtained, then the equation is calculated as follows:

$$\sigma_E = \sigma * \sqrt{n} \quad (3)$$

3.2.3. Value of Debt " D "

The book value of the debt is obtained from the financial statements of the enterprise, and its value is equal to the sum of short-term liabilities plus long-term liabilities.

3.2.4. Risk-free Interest Rate " r "

The one-year time deposit rate announced by the People's Bank of China is adopted as the risk-free interest rate, that is, 1.5%.

3.2.5. Debt Maturity " t "

The debt repayment period is assumed to be one year.

3.2.6. Asset Value " V_A " and Its Volatility " σ_A "

Since the asset value is consistent with geometric Brownian motion, according to the B-S model, "N(d)" represents the standard cumulative normal distribution function and the asset value equation is:

$$V_E = V_A N(d_1) - D e^{-rt} N(d_2) \quad (4)$$

$$d_1 = \frac{\ln\left(\frac{V_A}{D}\right) + \left(r + \frac{1}{2}\sigma_A^2\right)t}{\sigma_A\sqrt{t}} \quad (5)$$

$$d_2 = d_1 - \sigma_A\sqrt{t} \quad (6)$$

The expression for the volatility of corporate equity value " σ_E " is obtained by taking partial derivatives of both sides of equation (4) and then deforming it by simplification:

$$\sigma_E = \frac{V_A}{V_E} \times N(d_1) \times \sigma_A \quad (7)$$

By combining the above equations, the asset value " V_A " and the asset value volatility " σ_A " can be determined.

3.2.7. Distance to Default "DD"

The debt structure of a company includes short-term liabilities "STD" and long-term liabilities "LTD". Theoretically, default occurs if the value of a company's assets is lower than the book value of its liabilities, while long-term liabilities can ease the pressure of debt repayment. Through extensive observation and empirical analysis, KMV found that the threshold where defaults occur most frequently, or the default point "DP", is at the sum of short-term liabilities plus half of long-term liabilities, resulting in the following equation:

$$DP = STD + 0.5 \times LTD \quad (8)$$

According to the default point "DP", the default distance "DD" can be calculated, and the default distance is inversely proportional to the default probability, then the equation is as follows:

$$DD = \frac{E(V_A) - DP}{E(V_A)\sigma_A} \quad (9)$$

In this equation, " $E(V_A)$ " is expressed as the value of the firm's assets at the end of the debt maturity.

3.2.8. Expected Default Rate "EDF"

Expected Default Rate "EDF" refers to the magnitude of the probability of a firm's default risk over time. The KMV model assumes that the asset value follows a normal distribution, and the theoretical expected default rate is:

$$EDF = N \times \left[\frac{DP - E(V_A)}{E(V_A)\sigma_A} \right] = N(-DD) \quad (10)$$

Where "DD" indicates the default distance for companies.

3.3. Calculation of Indicators

3.3.1. Calculation of Market Value of Equity " V_E " and Volatility of Equity Value " σ_E "

From the above, the equity value of an enterprise = stock price \times number of outstanding shares + net assets per share \times number of non-circulating shares. The volatility of the enterprise's stock price is calculated as the average of the daily volatility of the enterprise's stock price, and the daily closing prices of the sample enterprises from January 1, 2019 to December 31, 2021 are collected to calculate the market value of equity " V_E " and the volatility of equity value " σ_E " using MATLAB software.

3.3.2. Calculation of Enterprise Asset Value and Its Asset Value Volatility

Through relevant studies, it is shown that the asset value of the enterprise can be regarded as satisfying the lognormal distribution, then according to the previous formula, the MATLAB software can be used to calculate the asset value and the asset value volatility of the experimental group and the control group enterprises in 2019-2021.

3.3.3. Calculation of Default Point and Default Distance

According to the study, the default point = short-term liabilities + 0.5 \times long-term liabilities. The default distance refers to the distance between an enterprise's expected asset value and its default point, which reflects the enterprise's expectation of its financial position and operating capacity when the default event occurs and is directly related to the financial indicators in the balance sheet. The larger the default distance is, the faster the expected asset value of the enterprise declines and the lower the risk of default. Then, according to the equations described in the previous section, the default points and default distances of the experimental and control group enterprises in 2019-2021 are calculated using MATLAB software.

4. Empirical Analysis

4.1. Credit Risk Indicator Selection

KMV firm creates a massive historical information database to collect whether a firm has defaulted, and uses different default distances as the standard for judging default. Based on this standard, the proportion of the number of defaulting enterprises in the total number of enterprises is studied. KMV model is based on these data to construct the empirical mapping between default distance and default probability. As a result, the empirical default probability is used as the credit risk measurement index in the KMV model.

However, the data on real bond defaults in China are few and not very comprehensive, and there is not a strong and perfect database, so there are certain shortcomings in the statistics about corporate default information, and the empirical " EDF " cannot be constructed, and the theoretical " EDF " can only be calculated based on the assumption of normal distribution of corporate asset value, but the mapping relationship between " EDF " and " DD " shows that the two must be negatively correlated. Therefore, this paper adopts the default distance " DD " as the credit risk index of the enterprises.

According to the aforementioned calculation, the smaller the default distance " DD ", the bigger the expected default probability " EDF ", which also shows the greater the enterprise's default risk. Table 3 shows the calculation results of the experimental and control groups' default distances for the years 2019-2021.

Table 3. Default distance of experimental group and control group.

Experimental Group	2019	2020	2021	Control Group	2019	2020	2021
X ₁	-3.9685	-2.9551	-0.9201	Y ₁	-2.7268	-2.5423	-1.4284
X ₂	-0.6255	-1.8023	-0.4123	Y ₂	0.0468	-0.1638	-1.1648
X ₃	0.7549	1.1333	1.1819	Y ₃	-6.5075	-6.3564	-6.7154
X ₄	0.1780	0.5086	0.5011	Y ₄	-2.4824	-1.7105	0.5626
X ₅	1.3214	1.4096	1.3230	Y ₅	1.4627	1.7466	1.2650
X ₆	0.0676	0.2969	1.4501	Y ₆	-7.8031	-7.2883	-4.4720
X ₇	-0.7681	0.9074	0.3802	Y ₇	-11.3232	-6.0466	-2.4758
X ₈	0.1582	1.3368	1.4247	Y ₈	-1.0611	-1.6782	-0.6330
X ₉	1.6837	1.5022	1.4421	Y ₉	-4.9647	1.3304	0.9202
X ₁₀	-1.6573	0.0763	0.5942	Y ₁₀	-5.1289	-7.9165	-7.1659
X ₁₁	-2.7163	-2.3964	-1.1472	Y ₁₁	0.5065	0.4440	0.7454
X ₁₂	2.3121	1.8563	1.5625	Y ₁₂	-2.6489	-2.4947	-1.8187
X ₁₃	1.9308	1.8798	2.1500	Y ₁₃	0.1853	1.0926	0.7338
X ₁₄	1.5365	1.1913	0.8182	Y ₁₄	-8.7798	-6.6657	-1.3628
X ₁₅	1.4287	1.4782	1.1712	Y ₁₅	0.4901	0.6160	0.9508

Data source: calculated according to MATLAB software.

4.2. Risk Identification Ability Test

4.2.1. Descriptive Statistical Test

Table 4. Descriptive statistics of default distance in the experimental group.

Year	Sample Size	Average Value	Standard Deviation	Minimum Value	Maximum Value
2019	15	0.1091	1.8001	-3.9685	2.3121
2020	15	0.4282	1.5595	-2.9551	1.8798
2021	15	0.7680	0.9524	-1.1472	2.1500

Data source: calculated and organized according to SPSS software.

Table 5. Descriptive statistics of default distance in the control group.

Year	Sample Size	Average Value	Standard Deviation	Minimum Value	Maximum Value
2019	15	-3.3823	3.8941	-11.3232	1.4627
2020	15	-2.5089	3.4622	-7.9165	1.7466
2021	15	-1.4706	2.7238	-7.1659	1.2658

Data source: calculated and organized according to SPSS software.

Table 3 lists the particular default distance data of the two groups of samples, and the following data test analysis is required to better understand the differences between the two groups of samples. Data descriptive statistical analysis can be performed initially, based on the sample grouping. First, the data in Table 3 were entered into SPSS software, and then the statistical function was used to analyze the data of the two groups specifically, from which the statistical results are shown in Tables 4 and 5.

It is generally believed that the greater the default distance, the lower the probability of corporate default. By conducting the descriptive statistical analysis of the default distance of 30 companies, it can be seen that the mean value of default distance of the issued green bond group in

2019, 2020 and 2021 is 3.4914, 2.9371 and 2.2386 higher than that of the unissued green bond group, respectively, with a more noticeable difference, indicating that the credit risk of listed companies in the green bond issuance group is lower than that of the non-issued green bond group. From the perspective of standard deviation, the standard deviation of the unissued green bond group is larger and its change is more unstable, reflecting that the volatility of credit risk of listed companies in the unissued green bond group is higher than that of the issued green bond group.

4.2.2. Mann-Whitney U test

To determine if the KMV model properly measures a firm's default risk, the validity of the KMV model measurements must be verified by comparing the data of the two sample groups and determining whether there is a statistically significant difference between them.

Statistically, there are many ways to test whether there is a significant difference between the two groups of samples. Before choosing the method of testing significant differences, it is necessary to test whether the data are normally distributed. The amount of data in the experimental and control groups was not large, so the Shapiro-Wilk (S-W) test was used to test whether the data are normally distributed. First, the data in Table 3 were entered into SPSS software, and then the statistical function was used to analyze the data of the two groups specifically, from which the statistical results are shown in Tables 6 and 7.

Table 6. S-W test for the experimental group.

Year	Sample Size	Test Statistics	Sig.
2019	15	0.918	0.177
2020	15	0.800	0.004
2021	15	0.904	0.109

Data source: calculated and organized according to SPSS software.

Table 7. S-W test for the control group.

Year	Sample Size	Test Statistics	Sig.
2019	15	0.928	0.254
2020	15	0.886	0.059
2021	15	0.847	0.016

Data source: calculated and organized according to SPSS software.

The significance of the data in 2020 in the experimental group and in 2021 in the control group is less than 0.05 by the Shapiro-Wilk (S-W) test, which does not conform to a normal distribution, so this article selects the Mann-Whitney U test in the nonparametric method to measure the KMV model results for analysis of variance.

Table 8. Results of Mann-Whitney U test.

Year	Mann-Whitney U	Z-Value	Sig.
2019	48.000	-2.675	0.007
2020	51.000	-2.551	0.011
2021	42.000	-2.924	0.003

Data source: calculated and organized according to SPSS software.

The Mann-Whitney U test is mainly to test whether the means between two independent sample groups are significantly different from each other. The original hypothesis is that there is no

significant difference between the means of two independent sample groups. The following Mann-Whitney U test was used to compare the default distances of the two sample groups in different years. The data in Table 3 were entered into SPSS software, and then the statistical function was used to analyze the data of the two groups specifically, from which the statistical results are shown in Table 8.

The Mann-Whitney U test results show that the Z statistic values for different years are -2.675, -2.551, and -2.924, corresponding to p-values of 0.007, 0.011, and 0.003, which are all less than 0.05. It indicates that the original hypothesis can be rejected by the test results at a significance level of 0.05, which means that it is concluded that the two independent conclusions that there is a significant difference in the mean values between the sample groups. According to the aforementioned results, there is a substantial difference in the default distance between the two sample groups, indicating that the KMV model has stronger discriminative ability for assessing credit risk and has a broad application potential in credit risk management.

4.3. Analysis of Empirical Results

4.3.1. The Analysis of Default Distance

Because Chinese scholars' research on credit risk is relatively late, and a perfect database has yet to be established, the default distance of listed company bonds calculated above cannot be used for one-to-one correspondence with foreign databases to determine the probability of default. There, this paper only confirms that the default distance can be used as an indicator of credit risk of corporate bonds to measure the credit status of the target company.

It is often assumed that the greater a company's default distance, the lower its default chance and credit risk. As a result, in this research, 15 manufacturing firms that issued green bonds before 2021 and 15 firms that did not issue green bonds before 2021 are chosen, and the default distance is calculated using the KMV model to investigate whether issuing green bonds has a potential impact on the credit risk of enterprises. According to the study results, there is a considerable difference in the default distance between the two groups, indicating that the issuance of green bonds will have a certain impact on corporate credit risk.

4.3.2. The Reason Analysis of Default Distance Difference

First, the calculation of the default distance is a complicated process. The data such as the value of the assets of the company and rate of change, the book value of the liabilities of the company, the value of the equity and its rate of change, etc. must be counted, and then the distance to default can be further calculated according to the formula.

In addition, as a tool to raise funds from the market, the funds of green bonds are mainly used to support green environmental protection projects, while the default behavior of the issuing body is closely related to the total asset status of the company. According to relevant theories, the issuance of green bonds will have a certain potential impact on corporate credit risk.

1) Based on the theory of resource compensation, governments at all levels have introduced a series of incentives to promote the development of green bonds, including tax cuts and interest rate reductions and cash incentives, which make the issuance cost of green bonds relatively low and bring the advantage of policy dividends. And the issuance of green bonds has a long financing

period and a large issuance scale compared with bank borrowings, which can provide enterprises with medium- and long-term funds and alleviate the plight of manufacturing enterprises with large capital demand, long cycle and high financing constraints. As a direct financing method for enterprises, issuing green bonds also saves the indirect financing cost spent by enterprises through borrowing from third parties, eases the financing pressure of enterprises, and thus indirectly reduces credit risk.

2) By the signaling theory, enterprises are more aware of their capabilities and development than their investors, and this information asymmetry will increase the transaction costs incurred in identifying enterprises. The issuance of green bonds is subject to more stringent review and disclosure of environmental information, which has a signaling effect and will help to improve the transparency of corporate information from the perspective of information transmission. Meanwhile, third-party certification will help to improve the reliability of the information and enhance the trust of investors and consumers in the company. In addition, the issuance of green bonds by enterprises and the practice of environmental protection will convey positive information about the company's strong strength and excellent operating conditions, which will help enterprises obtain more and more favorable credit support, reduce the cost of corporate financing, and have a potential impact on risk reduction.

3) According to the theory of social responsibility, the issuance of green bonds by listed companies is a manifestation of actively undertaking social responsibility. At present, China is in a period of economic transformation and is committed to taking the road of green development, and the state has corresponding policy support for enterprises carrying out green projects. In addition, with the depth of the concept of sustainable development, investors are beginning to pay attention to and emphasize the green reputation of enterprises and incorporate the environmental performance of enterprises into investment considerations. A company's green behavior can create a good public image, bring green reputation, attract investors' attention, and help to get the support of green investors.

5. Conclusions and Recommendations

5.1. Conclusions

To realize the "dual-carbon" goal, in recent years, the Chinese Government has repeatedly and clearly proposed the construction of a market-oriented green financial system and the vigorous development of green finance. This article takes listed enterprises in the manufacturing industry as example and selects 15 enterprises that have issued green bonds before 2021 as the experimental group and 15 enterprises that have not issued green bonds as the control group. And it measures the default distance according to the KMV model and conducts empirical analysis. The research results show that the KMV model has good predictive ability in measuring the default distance and can effectively identify the credit risk; due to the influence of signaling effect and other effects, enterprises that have issued green bonds usually have lower credit risk. This article encourages the development of green bonds based on the research results, which is a response to China's advocacy of the development of green financial policies and helps to realize the national strategic goal of "green financial system". In addition, this article encourages more enterprises to issue green bonds,

broaden financing channels, and carry out risk identification and prevention in time, which is of great practical significance for practitioners.

Through the study, the above conclusions are drawn, but there are some shortcomings due to the limited time: on the one hand, the sample size is not large enough, which may have an impact on the accuracy of the results; on the other hand, the study of this article is limited to specific manufacturing industries, although the conclusions obtained are quite correct, it is still necessary to further test whether the industry factors have an impact on the recognition ability of the model. Therefore, we make the following outlooks for future research: first, explore the impact of green bond issuance in different industries on corporate risk. Second, further explore the mechanism through which green bonds affect credit risk. Third, extend the observation period of the sample firms to investigate the long-term effect of green bonds affecting credit risk.

5.2. Recommendations

5.2.1. Increase the Policy Support for Green Bonds

First, lower the issuing cost, encourage the issuance of green bonds, and offer listed firms that issue green bonds more policy preferential treatment. Second, for green bonds issued for specific green projects, credit enhancement measures such as bond certification by third-party professional institutions and the provision of guarantees can be implemented to effectively reduce financing costs and increase their attractiveness to high-quality projects. Non-financial firms are encouraged to seek financial support using market-based measures such as issuing green debt financing instruments and green asset securitization under the conditions of conformity with laws and regulations. Third, to meet the financing needs of various types of enterprises, financial institutions should actively issue innovative green bond products, investigate the formation of several green bond varieties with unique characteristics, provide diversified financing options for enterprises, and effectively respond to financing problems that may arise during the process of enterprise transformation and upgrading.

5.2.2. Accelerate the Construction of the Credit Risk Database

Because China's credit system was built late, issues such as insufficient credit risk data and incomplete data sets have hindered the adoption and promotion of the KMV model to some extent. As a result, financial institutions should focus more on data collection and collation, as well as speed the development and upgrading of enterprise credit risk databases. Simultaneously, based on relevant data from Chinese enterprises, the mapping relationship function between default distance and default probability should be established by combining default history and financial data, significantly improving the KMV model's applicability in the financial market.

5.2.3. Regular Disclosure of Green Bond Information

Enterprises issuing green bonds should strictly comply with the issuance system and information disclosure requirements, conduct strict due diligence and information disclosure to eliminate "green-washing" behaviors. Enterprises should fully disclose the financing process of green bonds, regularly and timely disclose the construction progress of green projects, the destination of funds raised and the use of project funds, etc., to enable investors to obtain open and

transparent information and reduce information asymmetry. At the same time, the credibility and persuasiveness of the information can be further improved through third-party certification, which sends a credible signal of lower risk to investors and enhances their confidence.

5.2.4. Integrating Green Bond Programs with ESG Strategies

Enterprises can integrate green bond programs with broader ESG and sustainable development strategies. Enterprises actively assume social responsibility and practice environmental protection, which helps to enhance corporate reputation, strengthen soft power and achieve sustainable business objectives. Actively carry out diversified green projects to improve environmental and economic performance and enhance the investment value of the enterprise. Comprehensively strengthen the company's risk governance and build an early warning mechanism to prevent risks in time.

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References

- [1] Hyun S, Park D, Tian S. The price of going green: the role of greenness in green bond markets[J]. *Accounting & Finance*, 2020,60(1):73-95. DOI: <https://doi.org/10.1111/acfi.12515>.
- [2] Yang X Y, Shi B F. The factors affecting the pricing of green bond issuance[J]. *Finance Forum*, 2020,25(1):72-80. DOI: <https://doi.org/10.16529/j.cnki.11-4613/f.2020.01.009>.
- [3] Zhang R, Li Y, Liu Y. Green bond issuance and corporate cost of capital[J]. *Pacific-Basin Finance Journal*, 2021,69:101626. DOI: <https://doi.org/10.1016/j.pacfin.2021.101626>.
- [4] Ma Y M, Hu C Y, Liu X L. Green bond issuance and corporate value promotion: based on the mediation effect test of DID model[J]. *Finance Forum*, 2020,25(9):29-39. DOI: <https://doi.org/10.16529/j.cnki.11-4613/f.2020.09.005>.
- [5] Wu Y H, Tian Y N, Chen Y Y, et al. The spillover effect, mechanism and performance of green bond issuance[J]. *Management World*, 2022,38(6):176-193. DOI: <https://doi.org/10.19744/j.cnki.11-1235/f.2022.0086>.
- [6] Zhang X Y, Wu D W, Wang Y. The impact of green bonds on corporate green innovation[J]. *Modern Economic Science*, 2022,44(5):28-38.
- [7] Zhang C Q, Bao Q, Sheng M Q. Study on the effect of credit risk contagion caused by corporate bond defaults: evidence from credit spread of corporate bonds issuing by the same industry[J]. *Business Management Journal*, 2019,41(1):174-190. DOI: <https://doi.org/10.19616/j.cnki.bmj.2019.01.011>.
- [8] Hu X N, Peng S C. On the impact of corporate bond default on regional credit environment: evidence from the primary bond market[J]. *Credit Reference*, 2023,41(2):57-63. DOI: <https://doi.org/10.3969/j.issn.1674-747X.2023.02.009>.
- [9] Yang G, Wang R, Wang S N, et al. Research on the effect of bank competition on credit risk of listed companies[J]. *China Soft Science*, 2021,(10):103-114. DOI: <https://doi.org/10.3969/j.issn.1002-9753.2021.10.011>.
- [10] Sheng L R, Chen H H, Hu S C, et al. Credit risk forecasting model of corporate bond issuers and its practical applications[J]. *Review of Investment Studies*, 2019,38(6):25-35.
- [11] Dräger V, Heckmann-Draisbach L, Memmel C. Interest and credit risk management in German banks[J]. *German Economic Review*, 2021,22(1):63-95. DOI: <https://doi.org/10.1515/ger-2019-0114>.
- [12] Zhang M, Lv Z Y. A signaling game model of credit risk recognition for technological SMEs based on text information[J]. *Soft Science*, 2022,36(5):131-136. DOI: <https://doi.org/10.13956/j.ss.1001-8409.2022.05.19>. DOI: <https://doi.org/10.54560/jracr.v13i3.382>

- [13] Capasso G, Gianfrate G, Spinelli M. Climate change and credit risk[J]. *Journal of Cleaner Production*, 2020,266:121634. DOI: <https://doi.org/10.1016/j.jclepro.2020.121634>.
- [14] Lu X, Gao L. Research on credit default risk measurement of listed enterprises based on KMV model[J]. *Science & Technology and Economy*, 2021,34(4):106-110. DOI: <https://doi.org/10.3969/j.issn.1003-7691.2021.04.022>.
- [15] Wang X Y, Yu L X, Yang X M. Research on the credit risk of commercial bank credit asset securitization: a study based on the modified KMV model[J]. *Financial Regulation Research*, 2019,(3):54-66. DOI: <https://doi.org/10.3969/j.issn.2095-3291.2019.03.004>.
- [16] Chen Z Y, Liu C K, Chen W. Identification of factoring's credit risk in China— —Based on modified KMV model[J]. *Academic Research*, 2019,(2):96-102. DOI: <https://doi.org/10.3969/j.issn.1000-7326.2019.02.014>.
- [17] Wang J, Cao Q Y. Credit risk evaluate of listed companies based on Jump-Diffusion KMV model[J]. *Journal of Technology Economics*, 2022,41(1):160-168. DOI: <https://doi.org/10.3969/j.issn.1002-980X.2022.01.015>.
- [18] Zhang X, Li J. Credit and market risks measurement in carbon financing for Chinese banks[J]. *Energy Economics*, 2018,76:549-557. DOI: <https://doi.org/10.1016/j.eneco.2018.10.036>.
- [19] Guo L L, Zhou S Q. Is commercial bank credit risk mainly affected by internal or external factors? An empirical test based on KMV and Random Forest model[J]. *Accounting and Economics Research*, 2022,36(1):105-124. DOI: <https://doi.org/10.16314/j.cnki.31-2074/f.2022.01.009>.
- [20] Song Y, Zhang F, Liu C. The risk of block chain financial market based on particle swarm optimization[J]. *Journal of Computational and Applied Mathematics*, 2020,370:112667. DOI: <https://doi.org/10.1016/j.cam.2019.112667>.



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