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Research on the Change of Bond Credit Spread of Manufacturing Enterprises Empowered by Digital Economy

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Abstract: With the rapid development of information technology, the digital economy has become a key force driving economic growth and innovation. Manufacturing acts as a core component of the real economy, it holds a pivotal position in the national economy. Bond financing is the most common financing channel for enterprises. The credit spread is an important indicator for evaluating the credit quality and credit risk of corporate bonds, it is also crucial for the bond market's stable operation and developmen. This paper studies the impact of the digital economy on the credit spread of bonds of manufacturing enterprises. By constructing an econometric model and using the regression analysis, the finding is that the digital economy can reduce the bond credit spread of manufacturing enterprises siginificantly. Furthermore by conducting robustness tests, endogeneity analysis, and heterogeneity analysis the result still holds.

Keywords: Digital economy; Manufacturing; Bond financing; Credit spread; Bond market.

1. Introduction

1.1. Research Background

In the era when the digital wave of the global economy is sweeping across, the digital economy is booming at an unprecedented speed that has become a key component in promoting economic development. In detail, the digital economy is conducive to optimizing resource allocation for enterprises, and it has a non-negligible impact on the operating performance of enterprises.

The development of manufacturing enterprises is of extremely great significance for promoting economic prosperity and social harmony and stability. The development level of the manufacturing industry can reflect a country's economic strength. So for a long time, the scale of manufacturing industry in different countries keeps growing.

Corporate bonds is the main financing tool for enterprises in the bond market. Bond financing is usually the most common financing method for many enterprises, because comparing with equity financing, the cost of bond financing is relatively low, and it does not dilute the control rights of existing shareholders, enabling the decision-making and operation of enterprises to maintain relative independence.

Credit spread is an important indicator for evaluating the credit risk of corporate bonds, it is the difference between the bond yield and the risk-free interest rate. It also reflects the additional compensation demanded by investors due to their assumption of credit risk. So it can be concluded that there is a positive relationship between bond credit spread and bond default risk. When the default risk of bonds increases, investors will demand higher yields which promotes the expansion of credit spreads. Conversely, if the default risk of bonds decreases, the credit spreads will narrow accordingly.

The development of the digital economy has brought new opportunities and challenges to which may have an impact on the credit risk of manufacturing enterprises and then affect the credit spread of its corporate bonds indirectly. The research on the impact of the digital economy on the credit spreads of corporate bonds was relatively scarce. Therefore, studying the impact of the digital economy on the credit spread of bonds of manufacturing enterprises has important theoretical and practical significance.

1.2. Research Significance

In the past, the research on the impact of the digital economy on the credit spreads of corporate bonds was scarce. This study aims to deeply explore the impact of the digital economy on the credit spreads of bonds of manufacturing enterprises. By constructing an empirical model to analyze the quantitative relationship between the development level of the digital economy and the credit spread of manufacturing enterprises' bonds. Identifying the specific paths and transmission mechanisms through which the digital economy affects corporate bonds' credit spreads will improve the theoretical research on the digital economy and corporate bonds' credit spreads, and provide new perspectives and methods for subsequent research.

This research is of great significance for enterprises and investors. For enterprises, understanding the impact of the digital economy on corporate bonds' credit spread in detail can help them accelerate the pace of digital transformation, enhance their production efficiency and and strengthen their market competitiveness, thereby increase their profitability to reduce credit risks and their bonds' credit spread. For investors, the research result can provide them with more accurate bonds' credit spread prediction methods, and help them assess the investment value and risk level of corporate bonds, then make more scientific and reasonable investment decisions, and optimize their resource allocation.

2. Literature Review

2.1. Research Related to The Digital Economy

The digital economy is a new economic form, which has received extensive attention from the academic community in recent years. However at present there is still no standard definition of digital economy. The research by Abbos, Shermukhamedov explained that due to digital economy's

multifaceted and dynamic nature, and the transformational power of digital technologies, the concept of digital economy keeps evolving all the time [1]. In Sorescu Alina and Martin Schreier's research, it mentioned specifically that the concept of the digital economy was first proposed by Don Tapscott in 1995, since then various definitions of digital economy have emerged [2]. In the research conducted by Kolesnikov A.V, various understandings of the digital economy held by developed countries were collected and got the conclusion that the digital economy aims at increasing public access to information, including purchasing goods and services. However the digital economy is more important for corporations, because the digital economy is an important tool for expanding their presence in the market, and thereby increasing the profitability of production [3].

When talking about the histroy of the digital economy's development. Shi Yong from Bulletin of Chinese Academy of Sciences has conducted detailed research, in which it introduced that the evolution of digital economy has experienced three stages, the first was the preparation stage (1950s-2000) when there were just some simple innovative products provided technical support for the prosperity of digital economy. The second stage was the rapid development stage (2000-2012) when new business models like e-commerce, search engines and social media existed. The third stage started after 2012 when the era of big data and artificial intelligence developed that made digital industrialization accelerated. Then it showed that the developed countries in Europe and America have leadership in digital economy, this is because in the past few decades, they had promulgated many sound legal policies to regulate the development of the digital economy. Especially, the United States which possesses world-leading technologies and conducts technological innovations constantly that has greatly promoted the leapfrog development of the digital industry. Those developed countries also have sound market form that can provide comprehensive market consulting services for the transaction and circulation links of the digital economy. When discussing the current situation of China's digital economy development, it introduced that the digital economy has become a key driving force for China's high-quality economic development. It can be attributed to a series of reasons, such as the expansion of the scale of digital industrialization, where many manufacturing, agricultural and service enterprises have achieved digital transformation [4].

As mentioned before, the digital economy leads economic growth, the manufacturing holds a pivotal position in the national economy. So the impact of the digital economy on manufacturing industry is a key area of research. Generally speaking, the digital economy helps manufacturing enterprises improve production efficiency and product quality. However some scholars may have more detailed discoveries. The empirical analysis done by Jiaqi Chang showed the development of digital economy has positive impact on manufacturing industry by increasing the total factor productivity [5]. As we know manufacturing enterprises cannot operate without the application of technology, therefore the digital economy can promote the development of manufacturing through technological innovation, this is proved by Qiong Wang and Yihan Wei's research, in which it reached the conclusion that the digital economy has a double-promotion effect on technological innovation by improving the output quantity and quality of technological innovation in manufacturing enterprises. In addition their research also concluded that the digital economy has increased the number of patent applications of manufacturing enterprises effectively [6].

Moreover, there is no doubt that traditional manufacturing industries are bound to generate a large amount of carbon emissions, which will exacerbate global climate change and environmental pollution problems. Therefore, manufacturing industries need to respond to the global call for sustainable development. In Yi Liu's research, the empirical analysis showed that the digital economy can be helpful in the green transformation of traditional manufacturing industries by digital innovation, industrial upgrading and human capital [7]. In China, manufacturing industry's Green total factor productivity (GTFP) growth has been enhanced by the digital economy siginificantly, and digital economy levels in the surrounding areas have significant spatial spillover effects on green productivity growth [8].

2.2. Research on Credit Spreads of Corporate Bonds

Credit spread is a key indicator for measuring the risks and returns of corporate bonds, which have attracted much attention from scholars in the financial field. Collin Dufresne's research pointed that the fundamental reason for the emergence of bonds' credit spread is that there is a risk of bond default, then in the event of default bondholders can only receive a portion of the promised payment or even no payment [9]. Then Campbell Rachel's research explained that credit spread can be defined as the difference between the risky bond and a risk-free alternative, it is also a measure of the amount of credit risk faced. And it also suggested that credit spread of corporate bonds keeps changing over time for plenty of reasons [10]. For the factors influencing corporate bonds' credit spread, the research done by Si-Si Li and Mu Zhang concluded that the influencing factors of credit spreads are at both the macro level and the micro level [11].

At the micro level, it should be started from the perspective of the enterprise itself. Haiyang Wang's research found that there is an inverse relationship between the liquidity of corporate bonds and the credit spread [12]. For an enterprise, the stronger the liquidity is, other financial indicators such as current ratio, quick ratio, cash-to-short-term debt ratio, and net cash flow from operating activities would be affected positivly that lowers the default risk of enterprises' bond and the credit spread would be narrowed. In contrast the weaker the liquidity is, the higher the default risk is and the credit spread is larger.

At the macro level, it should be started from the perspective of economic environment and market condition. Dragon Yongjun Tang and Hong Yan's research found that GDP growth is usually inversely related to credit spread. At the market level, investor sentiment is the most important determinant of credit spread [13]. It is clear that the GDP growth means the economic expansion, enterprises have better profit conditions, lower default risks, and relatively smaller credit spreads. Conversly, during an economic recession, it is difficult for enterprises to make profits, the risk of default rises, and the credit spread will be greater. Investors' sentiment will change along with the changes in the market environment. As we know that investors' sentiment usually depends on their attitude towards the market, investors with optimistic attitude tend to invest in bonds with high risk and return, the credit spread will be increased. When investors are pessimistic, their investment will shift to safe-haven assets,

resulting in a decrease of credit spread.

2.3. Research on the Relationship Between Digital Economy and Credit Spread

At present, the studies on the direct impact of digital economy on the credit spreads of bonds of enterprises are relatively few. However, some studies have provided us with some ideas that digital economy may affect corporate bonds' credit spread indirectly.

As mentioned before there is a positive relationship between credit spread and bond default risk. The digital economy may help an enterprise reduce its bond credit spread by lowering the bond default risk. Fu Min's research introduced a new credit bond default risk measurement model (GST-GRU) established based on the digital economy to predict bond risks accurately. Through this model the bond default risk will be predicted correctly [14]. It is useful for investors, through this model constructed based on the digital economy, if an enterprise is predicted to have a high risk of bond default, investors will abandon their investment, and the enterprise will also take measures to reduce the risk of bond default and thereby lower the bonds' credit spread indirectly.

It is known that digital economy promotes enterprises' digital transformation. In Huijie Cui's research the empirical result showed that digital transformation can reduce credit spread significantly by increasing total factor productivity, reducing information asymmetry, and strengthening internal control [15]. So the ditigal economy reduces corporate bonds' credit spread through digital transformation.

Similarly, the development of digital economy can promote digital finance, thereby impact corporate bonds' credit spread. Weijing Kang's research on the impact of digital finance on corporate bonds' credit spread in China indicated that digital finance reduces corporate bonds' credit spread significantly. In detail, the reducing effect is determined by financial usage, coverage breadth and overall level of digitalization [16]. Therefore the ditigal economy reduces the credit spread of corporate bonds through digital finance.

3. Methodology

This study puts forward research hypothesis firstly, then the empirical analysis is used in order to analyze the impact of the digital economy on the credit spread of bonds of manufacturing enterprises in depth to ensure the scientific nature and reliability of the research.

As mentioned before many scholars' research show that the digital economy has had a positive impact on manufacturing enterprises, and this impact may be transmitted to the credit spread of corporate bonds indirectly. In theory, the application of digital economy can also help enterprises expand market channels and enhance their market competitiveness, which enable enterprises to increase profitability and debt-paying ability, thereby reduce the possibility of bond default and narrow the credit spread of bond. In this case, the hypothesis is proposed, the development of digital economy lowers the credit spread of bonds of manufacturing enterprises.

In terms of empirical analysis, this study constructs the econometric model based on the basic financial panel data of A-share listed enterprises from 2010 to 2023 for regression analysis. By constructing econometric model, the quantitative relationship between the development level of the digital economy and the credit spread of manufacturing enterprises' bonds can be revealed clearly, which provides strong empirical support for the research result. To further verify the robustness of the research result, this study further employs robustness test, endogeneity analysis, and heterogeneity analysis to verify the research result from different perspectives, ensuring the reliability of the research conclusion.

4. Analysis

4.1. Data

The data used to measure the development level of the digital economy in this study are all sourced from the statistical yearbooks of various regions. The data for calculating corporate bonds' credit spreads are from the China Securities Depository and Clearing Corporation Limited (CSDCC). The data of other control variables of listed enterprises are all sourced from the China Stock Market & Accounting Research Database (CSMAR). To make the data more representative, the following processes are carried out on the original data collected. Firstly, the control values of all variables are eliminated. Secondly, considering the particularity of the financial industry, all enterprise data of the financial industry are eliminated. Finally, a total of 1370 observations of listed manufacturing enterprises in China from 2010 to 2023 were obtained.

4.2. Econometric Model

Based on the data above, the following model is constructed

$$Cs_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \beta_2 controls_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

In model (1) above, β_0 is the intercept term, also known as the constant term. $\beta_1, \beta_2, \beta_3$ are the variable regression coefficients. i represents the enterprise and t represents the time. $Dig_{i,t}$ represents the development level of digital economy in enterprise i during period t, and $Cs_{i,t}$ represents the bond's credit spread of enterprise i during period t. $\text{controls}_{i,t}$ represents some control variables that may affect the credit spreads of corporate bonds, including enterprise size (Size), cash flow ratio (Cashflow), the proportion of independent directors (Indep), return on assets (ROA), the growth rate of operating income (Growth), and the shareholding ratio of the largest shareholder (Top1). γ_i represents the individual fixed effects that cannot be observed by the company. δ_i is the time-fixed effect. $\varepsilon_{i,t}$ is the random interference term.

4.3. The Variables' Definition and Calculation

$Cs_{i,t}$ is the explained variable which means corporate bonds' credit spread, it is the difference between the yield to maturity of a corporate bond and the yield of a Treasury bond with the same remaining maturity. In detail, it is calculated as the difference between the yield to maturity of a national bond with the same issuance time and maturity as the corporate bond in year t and the yield to maturity of the corporate bond in year t.

$Dig_{i,t}$ is the explanatory variable which means digital economy. For the measurement of the digital economy in prefecture-level cities, this study refers to the approach of Zhao Tao et al. (2020), by calculating the digital economy development index using the entropy weight method based on five indicators which are internet penetration rate, the number of internet-related practitioners, internet-related output, the

number of mobile internet users, and the inclusive development index of digital finance.

For the control variables this study selected a series of factors that might have an impact on the credit spread of corporate bonds, such as enterprise size (Size), cash flow ratio (Cashflow), the proportion of independent directors (Indep), return on assets (ROA), the growth rate of operating income (Growth), and shareholding ratio of the largest shareholder (Top1).

The detailed definition and calculation methods of the key variables are shown in Table 1.

Table 1. The definition and calculation methods of the key variables

Type	Name	Symbol	Calculation method
Explained variable	Credit spread	Cs	The difference between the yield of corporate bonds and that of national bonds
Explanatory variable	Digital economy	Dig	By Entropy Weight method
Control variable	Enterprise size	Size	The logarithm of total assets
	Cash flow ratio	Cashflow	Cash flow generated from operating activities divided by total assets
	The proportion of independent directors	Indep	The number of independent directors divided by the total number of the board of directors
	Return on assets	ROA	Net profit divided by total assets
	The growth rate of operating income	Growth	The ratio of the current year's operating income to that of the previous year substracts one
	Shareholding ratio of the largest shareholder	Top1	The shareholding ratio of the largest shareholder

5. Results

5.1. Descriptive Statistics

The basic descriptive statistics of each variable in this study are shown in Table 2 below.

Table 2. Basic Statistical Characteristics of the variables

Name	Obs	Mean	SD	Min	Median	Max
Cs	1370	2.0040	1.1874	-0.4159	1.9326	13.5727
Dig	1370	0.1985	0.2329	0.0000	0.1089	0.9400
Size	1370	24.0061	1.3548	20.9766	23.8877	27.6126
Cashflow	1370	0.2543	0.1323	-0.1281	0.2404	1.4425
Indep	1370	38.0066	6.3483	25.0000	36.3600	66.6700
ROA	1370	0.0347	0.0467	-0.2926	0.0301	0.2777
Growth	1370	0.1538	0.3498	-0.6527	0.1020	7.2923
Top1	1370	0.1361	0.1962	-0.9277	0.1216	0.7782

Table 2 shows that the maximum value of the explanatory variable which is digital economy (Dig) is 0.9400, the minimum value is 0.0000, and the standard deviation is 0.2329, indicating that there are significant differences in the development level of the digital economy among various regions in China in different years. The maximum value of the explained variable which is the credit spread of corporate bonds (Cs) is 13.5727, its minimum value is -0.4159, and the standard deviation is 1.1874, indicating that there are some differences in the bond yields issued by different enterprises. At the same time, the credit spread of bond exists negative value, suggesting that some enterprises have yields lower than the level of national bonds in the same period due to their excellent credit. The basic descriptive statistics of the remaining control variables were also in line with expectations.

5.2. Correlation Analysis

In order to identify the strength and direction of the linear association among variables, avoid the interference of multicollinearity on the regression results, and provide a preliminary verification for theoretical hypothesis, a correlation test on the variables is conducted. The results are shown in Table 3 below. As Table 3 shows, the maximum correlation among the variables occurs between the Cashflow and Cs variables is 0.894, this coefficient is significantly positive at the 1% level, indicating that there is a positive relationship between the cash flow ratio and the credit spread of corporate bonds, it is higher than the threshold 0.8, indicating a strong correlation among the variables. The correlation coefficient of the digital economy and the credit spread of corporate bonds is -0.242, which is significantly negative at the 1% level, preliminarily verifying the initial hypothesis that the development of the digital economy will reduce the credit spread of corporate bonds significantly. The correlation coefficients among the remaining variables were all lower than the threshold of 0.8, indicating that there was no strong correlation among the variables.

Table 3. Correlation analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Cs	1.000							
(2) Dig	-0.242***	1.000						
(3) Size	0.231***	-0.103***	1.000					
(4) Cashflow	0.894***	-0.151***	0.262***	1.000				
(5) Indep	0.047*	0.023	0.170***	0.074***	1.000			
(6) ROA	-0.017	0.037	-0.036	0.155***	-0.021	1.000		
(7) Growth	-0.056**	0.057**	-0.038	-0.033	-0.041	0.279***	1.000	
(8) Top1	-0.618***	0.103***	-0.032	-0.530***	0.054**	0.003	0.014	1.000
*** p<0.01, ** p<0.05, * p<0.1								

5.3. Multicollinearity Analysis

In order to identify and handle the high correlation among explanatory variables, the variance inflation factor (VIF) is used to conduct multicollinearity tests on the variables. The results are shown in Table 4. It shows that the variable with the largest VIF value is Cashflow, which is 1.62. That of the rest variables are all lower than 1.5, which are far below the threshold of 10. Meanwhile, the minimum value of 1/VIF is 0.617, and the mean VIF is 1.216, indicating that there is no multicollinearity among the variables.

Table 4. Multicollinearity analysis

	VIF	1/VIF
Cashflow	1.62	0.617
Top1	1.449	0.69
ROA	1.142	0.876
Size	1.131	0.884
Growth	1.095	0.913
Indep	1.043	0.958
Dig	1.036	0.966
Mean VIF	1.216	

5.4. Basic Regression Result (OLS)

By using the model (1) constructed before, the direct impact results of the digital economy on the credit spread of corporate bonds can be obtained. To avoid the situation where the reduction of the credit spread of corporate bonds is caused by the control variable and leads bias in the result, this study conducts the regression without the control variable firstly and adds the control variables later. The results are shown in the first and second column of Table 5.

Table 5 above shows the OLS results, in which we can find that regardless of whether the control variables are included or not, the coefficient is significantly negative at the 1% level, indicating that the development of the digital economy has significantly reduced the bond credit spread of the manufacturing enterprises, which proves the hypothesis. This is because the digital economy enhances the transparency and traceability of enterprises' financial and operational information by using the technologies such as big data and blockchain. Reducing the information asymmetry between investors and enterprises, therefore it enables investors to assess enterprises' risks more accurately, then they may demand a lower credit risk premium which leads a reduction in the risks of bonds issued by enterprises. From the perspective of control variables, the growth of them will lead the expansion of the credit spread of corporate bonds. The reason is that when enterprises expand, they need a large amount of funds, resulting in increased risks, and investors will demand more returns. The increase in both return on assets and the shareholding ratio of the largest shareholder will reduce the credit spread of corporate bonds. This is because the higher the profit of an enterprise, the stronger its ability to repay principal and interest, and the lower the bond risk is.

Table 5. Basic regression results

	(1)	(2)
Variables	Cs	Cs
Dig	-0.5912***	-0.4332***
	(-3.9289)	(-5.2427)
Size		0.2675***
		(5.1572)
Cashflow		4.1909***
		(9.2437)
Indep		0.0016
		(0.6455)
ROA		-1.6556***
		(-3.8118)
Growth		0.0059
		(0.2265)
Top1		-2.2000***
		(-6.9508)
Constant	1.6487***	-4.9440***
	(37.3941)	(-3.9887)
Time fixed	Yes	Yes
Individual fixed	Yes	Yes
Observations	1,370	1,370
R-squared	0.6171	0.8856
*** p<0.01, ** p<0.05, * p<0.1		

5.5. Robustness Test

5.5.1. Adding control variables

Considering that the asset-liability ratio can affect the credit spread of corporate bonds, and if in a company the chairman and the general manager are held by the same person, the corporate bonds' credit spread can be affected as well. In this case, the study adds the asset-liability ratio (Lev) and the indicator whether the company's chairman and the general manager are held by the same person (Dual) to the control variables for the robustness test. The regression results are shown in the first two columns of Table 6. We can find that comparing with Table 5, regardless of whether the two control variables are added or not, the coefficients of Dig are significantly negative at the 1% level. It means that the development of the digital economy will significantly reduce the credit spread of corporate bonds, which is consistent with the basic regression results.

Table 6. Robustness test

	(1)	(2)	(3)	(4)
Variables	Cs	Cs	Cs	Cs
Dig	-0.5912***	-0.4386***	-0.7388***	-0.4750***
	(-3.9289)	(-5.3543)	(-4.3342)	(-4.8338)
Size		0.2770***		0.2584***
		(4.9794)		(4.4958)
Cashflow		4.1789***		4.1936***
		(9.3611)		(8.3328)
Indep		0.0015		0.0007
		(0.6006)		(0.2315)
ROA		-1.7757***		-1.7775***
		(-3.7264)		(-3.7266)
Growth		0.0100		0.0047
		(0.3802)		(0.1686)
Top1		-2.1953***		-2.1613***
		(-6.8887)		(-6.5334)
Lev		-0.1558		
		(-0.7996)		
Dual		0.0100		
		(0.2077)		
Constant	1.6487***	-5.0726***	1.6629***	-4.6881***
	(37.3941)	(-3.9377)	(34.7903)	(-3.4105)
Time fixed	Yes	Yes	Yes	Yes
Individual fixed	Yes	Yes	Yes	Yes
Observations	1,370	1,370	1,258	1,258
R-squared	0.6171	0.8857	0.6317	0.8886
*** p<0.01, ** p<0.05, * p<0.1				

5.5.2. Reducing the sample size

As we know some extreme public health event can impact China's macroeconomy and further affect the credit spreads of corporate bonds, for example the COVID-19 pandemic. The COVID-19 pandemic was a major global public health event that had a profound impact on the economy, society, environment and other aspects of all countries. To prevent the possible impact of the COVID-19 pandemic in 2020 from deteriorating the results, this study eliminates the data of 2020 for robustness tests. The regression results are shown in the column (3) and (4) in Table 6 above, what we can find is that comparing with Table 5, the coefficient of Dig is still significantly negative at the 1% level. It is demonstrated that the digital economy will reduce the credit spread of corporate bonds, which is consistent with the regression result before, the robustness of the regression result in this study is verified again.

5.6. Endogeneity Analysis

Although we have tried our best to avoid endogeneity problems when selecting variables, it is inevitable that endogeneity problems will arise due to omitted variables, selection bias or reverse causality. In order to control the possible endogeneity problems, this study uses the instrumental variable method to solve the endogeneity problem.

Generally, the disclosure of an enterprise's annual report is in April of the following year. Therefore, the impact of the development of the digital economy on the credit spread of corporate bonds may not be reflected in the annual report until the following year. Thus, this study uses the digital economy which lags by one period as the instrumental variable for endogeneity analysis. By using the Two-stage Least Squares (2SLS) for analysis, the results are shown in Table 7 below.

Table 7. Endogeneity analysis

	(1)	(2)
Variables	Dig	Cs
IV	0.4599***	
	(7.7756)	
Dig		-0.4879***
		(-3.5483)
Size	0.0463**	-0.0024
	(1.9736)	(-0.0914)
Cashflow	-0.0683	7.3632***
	(-0.6127)	(24.2952)
Indep	-0.0015	0.0002
	(-1.0211)	(0.0718)
ROA	0.0860	-4.1024***
	(0.6051)	(-6.1604)
Growth	-0.0259	0.0852
	(-1.5528)	(1.1447)
Top1	0.1392*	-0.8984***
	(1.7748)	(-5.4996)
Constant	-0.8431	0.6456
	(-1.5402)	(1.1313)
Time fixed	Yes	Yes
Individual fixed	Yes	Yes
Observations	1150	1150
R-squared	0.6754	0.8829
F	17.96	
*** p<0.01, ** p<0.05, * p<0.1		

The column (1) shows the result of the first stage of 2SLS, the coefficient of the IV to Dig is 0.4599, which is significantly positive at the 1% level, verifying the correlation between the instrumental variable and explanatory variable, moreover the F value in the first stage is 17.96, indicating that there is no weak instrumental variable problem. The column (2) shows the result of the second stage of 2SLS, we can find that after solving the endogeneity problem, the the coefficient of Dig is still significantly negative at the 1% level, which is consistent with the basic regression. Table 7's results indicate that after considering the endogeneity, the result of the impact of digital economy on the credit spread of corporate bonds remains robust.

5.7. Heterogeneity Analysis

5.7.1. Based on regions

Due to the vast land area and uneven distribution of regional resources in our country, there are significant differences in the economic development levels among regions. There are some considerable differences in economic development conditions, policy factors, and industrial agglomeration among different regions. Therefore, in order to deeply examine the differences in the impact of digital economy on the credit spread of corporate bonds among different regions, This study divides the sample into the eastern, central and western regions for sub-sample research according to the provinces where the enterprises are located.

The regression results are shown in the first three columns of Table 8. The coefficient of the digital economy is significant at the levels of 1% in the eastern, western regions and 5% in the central region, which indicate that in any region the development of the digital economy will significantly reduce the credit spread of enterprises' bond. In terms of significance, the digital economy is significant at the 1% level in both the eastern and western regions, and that is significant at the 5% level in the central region, this is mainly due to the differences in the development level of the digital economy, industrial structure, and policy support among regions. The eastern region has mature digital infrastructure, high market-oriented financial environment and policy synergy that enhanced the transparency of enterprises' information and operational efficiency dramatically, resulting in the most obvious compression of credit spreads. The western region has benefited from policy dividends such as the national "East Data West Computing" initiative and the rapid penetration of digital finance, which alleviated the problem of insufficient coverage by traditional finance effectively , and the marginal improvement of credit spreads has been significant. However, in the central region, there exists some problems such as the industrial structure dominated by traditional manufacturing, the slow digital transformation and the lack of policy inclination, the credit risk mitigation effect from the digital economy is limited relatively.

Table 8. Heterogeneity analysis results

	(1)	(2)	(3)	(4)	(5)
	Eastern	Central	Western	State-owned	Non-state-owned
Variables	Cs	Cs	Cs	Cs	Cs
Dig	-0.4595***	-1.4387**	-0.8997***	-0.5832***	-0.2183*
	(-4.4326)	(-2.3359)	(-2.6948)	(-5.7430)	(-1.7805)
Size	0.2236***	0.3081***	0.3338***	0.2721***	0.2711***
	(3.6101)	(4.4642)	(3.0935)	(4.6014)	(3.5247)
Cashflow	4.0897***	3.5059***	4.9232***	3.4144***	4.6434***
	(7.2180)	(5.3321)	(5.3519)	(9.4471)	(7.9119)
Indep	0.0016	0.0017	-0.0060	0.0025	0.0056
	(0.5090)	(0.4773)	(-0.9380)	(0.8573)	(1.1222)
ROA	-1.4449***	-1.3035	-3.4683**	-1.0403**	-2.2301***
	(-3.0323)	(-1.6180)	(-2.3481)	(-2.5153)	(-3.3023)
Growth	0.0229	0.0288	-0.0829	0.0144	-0.0311
	(0.8135)	(0.3664)	(-0.8281)	(0.5637)	(-0.4757)
Top1	-2.3261***	-1.7131***	-2.3648***	-1.6627***	-2.8785***
	(-5.3140)	(-3.5676)	(-3.4060)	(-5.7206)	(-5.8643)
Constant	-3.9832***	-5.8620***	-5.8668**	-5.1145***	-5.0834***
	(-2.6750)	(-3.5932)	(-2.2269)	(-3.7114)	(-2.7979)
Time fixed	Yes	Yes	Yes	Yes	Yes
Individual fixed	Yes	Yes	Yes	Yes	Yes
Observations	894	264	212	762	608
R-squared	0.8810	0.9056	0.9282	0.8869	0.9102
*** p<0.01, ** p<0.05, * p<0.1					

5.7.2. Based on the nature of the enterprise

In order to examine the differences in the impact of the digital economy on the credit spread of corporate bonds among different types of enterprises, this study divides the samples into state-owned enterprises and non-state-owned enterprises for heterogeneity test. The regression results are shown in the last two columns of Table 8 above. In the state-owned enterprises, the effect of the digital economy on the credit spread of corporate bonds is significantly negative at the 1% level, while in the non-state-owned enterprises, the impact of the digital economy on the credit spread of corporate bond is significantly negative at the 10% level. This indicates that no matter whether the enterprise is state-owned or not, the digital economy will reduce the credit spread of corporate bonds, however its reducing effect is more

significant in the state-owned enterprises. This is because state-owned enterprises usually enjoy stronger government support, more complete digital infrastructure and more stable financing channels. Their digital transformation often receives policy preferences and financial subsidies, that enable them to utilize digital technologies more efficient to enhance information transparency and operational efficiency, thereby significantly reducing investors' premium requirements for credit risks. In contrast, the non-state-owned enterprises are usually constrained by capital, technology and management capabilities, they also have a slower process of digital transformation and find it difficult to fully enjoy the policy dividends of the digital economy, resulting in a relatively limited mitigating effect of the digital economy on credit risks.

6. Discussion

6.1. Research conclusions

This study focuses on the impact of the digital economy on the credit spreads of bonds of manufacturing enterprises. Through research hypotheses and empirical tests, the conclusions are drawn.

The development level of the digital economy can reduce the credit spread of bonds of manufacturing enterprises significantly. The empirical test was conducted by constructing a model based on the basic financial panel data of A-share listed enterprises from 2010 to 2023, then it was concluded that the higher the level of digital economy development, the lower the credit spread of bonds of manufacturing enterprises. After controlling for a series of factors that may affect credit spread, such as enterprise size, cash flow ratio, the proportion of independent directors, return on assets, the growth rate of operating income, and the shareholding ratio of the largest shareholder, the result remains consistent.

In the robustness test, after considering asset-liability ratio and whether the chairman and the general manager are held by the same person in the company, digital economy's development still reduces the credit spread of bonds of manufacturing enterprises significantly. Considering the impact of the COVID-19 pandemic, after deleting the data of 2020, the negative relationship remains stable. It is inevitable that the endogeneity problem may arise, using the digital economy which lags by one period as the instrumental variable for endogeneity analysis, through the 2SLS method, the result of the impact of digital economy on the credit spread of bonds of manufacturing enterprises remains robust.

In addition, in the heterogeneity analysis, it is concluded that the development of the digital economy can reduce the credit spreads of manufacturing enterprises' bonds significantly in any region of China, but the reducing effect is relatively weak in the central China. For the manufacturing enterprises, the development of the digital economy can not only reduce the credit spread of bonds of state-owned enterprises but also that of non-state-owned enterprises, however, the reducing effect in the state-owned enterprises is stronger.

6.2. Policy suggestions

Based on the conclusion of this study, in order to promote the deep integration of the digital economy and manufacturing thereby reducing the credit spread of bonds of manufacturing enterprises, the joint efforts of the government, manufacturing enterprises and financial institutions are required. So some policy suggestions can be put forward for them.

6.2.1. For government

The government should increase investment in the construction of digital economy infrastructure and enhance research and development investment in the digital economy field. The manufacturing enterprises should be provided with a more efficient and stable digital environment, more advanced digital solutions should be offered, and reduce the cost and threshold of digital transformation.

At the same time, the government should improve relevant policies and regulations, establish and improve the data security guarantee system to reduce the data security risks of enterprises during the process of digital transformation. In detail, the supervision of data security should be strengthened, and a data security monitoring and early warning mechanism need to be established, in order to identify and handle data security issues, so that data leakage and abuse can be prevented.

In addition, the government can support the digital transformation of enterprises by providing a series of policy measures. For instance, providing special fund support to manufacturing enterprises that actively promote digital transformation. Tax reduction and exemption can be granted to enterprises for carrying out digital projects. Providing interest subsidies for loans related to the digital transformation of enterprises to reduce their digital transformation costs. In particular, some small and medium-sized enterprises are usually facing more difficulties and challenges in the process of digital transformation. The government can strengthen its support for the digital transformation of small and medium-sized enterprises by providing technical training, consulting services and so on.

6.2.2. For manufacturing enterprises

Manufacturing enterprises themselves should respond to the trend of digital transformation actively. But under normal conditions, manufacturing enterprises are limited by their own conditions, it is difficult for them to complete digital transformation independently. In such case, it is necessary to cooperate with third parties. For instance, they can enhance the effectiveness of digital transformation by cooperating with digital economy enterprises and fully using their technological and resource advantages. In terms of marketing, they can cooperate with internet enterprises to carry out digital marketing and services, expand online channels, and enhance customer satisfaction. It is also possible to cooperate with big data enterprises to utilize big data analysis technology and enhance production quality and efficiency, and inventory costs and logistics costs can be reduced.

Manufacturing enterprises should also focus on cultivating and introducing digital talents. Firstly, internal training within the enterprise can be strengthened. By organizing employees to participate in digital technology training to enhance their digital skills regularly. Secondly, they can cooperate with universities and research institutions to cultivate professional talents that meet the needs of enterprises' digital transformation. In addition, introducing outstanding digital talents from outside is also a good way. By offering competitive salary and good career development opportunities, excellent digital talents from home and abroad can be attracted.

6.2.3. For financial institutions

For financial institutions, on one hand, they need to assess the credit risks during the digital transformation of manufacturing enterprises accurately by leveraging digital technology. Strengthening the monitor and analysis of the credit spreads of corporate bonds, and adjust the credit spreads of bonds reasonably, providing investors with more accurate risk compensation.

On the other hand, financial institutions should enhance cooperation with government and manufacturing enterprises to promote the integrated development of the digital economy and manufacturing enterprises jointly. To cooperate with the government, financial institutions should participate in government-led digital transformation projects and provide financial support for enterprises. Financial institutions should also cooperate with enterprises by gaining a deep understanding of their digital transformation needs and providing customized financial services for them.

In addition, each financial institution needs to work together to carry out digital financial innovation jointly and improve the efficiency and quality of financial services.

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