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Debt Financing Cost and Green Innovation: The Conditioning Role of Financing Dependence Structure in Chinese Manufacturing Firms

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Abstract

Debt-financing costs are generally considered to be restrictive for corporate innovation; however, their role in green innovation may be conditional rather than uniformly negative. Based on a sample of A-share listed companies from 2012 to 2023, this study examines whether this cost is related to green patenting and, more importantly, how this relationship varies with firms' financing dependence structure. Green innovation can be reflected in the scale of total green patent applications and the depth of green invention applications. Based on the estimates, both indicators are positively correlated with the cost of debt, and the impact is relatively stronger for total applications. Higher debt costs do not necessarily hinder firms' green transition. However, the moderation analysis indicates that this positive effect is not uniform either. It is weaker when the company uses more equity financing, but this evidence is limited; by contrast, it becomes stronger when firms rely more heavily on debt financing, especially for green invention patent applications. The evidence suggests that debt financing cost is not only a financial burden but may also play a conditional role in firms' green innovation decisions. The novelty of this study is that it distinguishes between dependence on equity and debt financing and finds that the debt-cost-green innovation relationship differs between the two types of financing dependence. Therefore, the cost of debt financing may act as either a constraint or a form of external pressure, depending on how firms obtain external funds.

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1.0 Introduction

Green innovation helps enterprises meet environmental protection requirements, reduce resource consumption and achieve industrial decarbonisation. This issue is especially relevant to manufacturing enterprises in China. Manufacturing accounted for roughly a quarter of the country's GDP in recent years and remains one of China's main sectors. In 2023, industry accounted for 48% of the country's final energy consumption (International Energy Agency, 2024; World Bank, 2024). In the same year, China recorded 101,000 green and low-carbon invention patent applications, accounting for more than half of the world's total (State Council of the People’s Republic of China, 2024). These facts indicate that, given the manufacturing industry's significant economic contribution, high energy consumption, and strong pressure for low-carbon technological innovation, it should be a particular focus for green innovation. Green innovation is usually relatively expensive. Given the constraints on internal funds, firms may need to raise external funds to cover the expenses of green research and development (R&D). Brown et al. (2009), Giebel and Kraft (2024), and Hall and Lerner (2010) show that R&D investment is sensitive to external funding conditions because innovation projects are uncertain, intangible, and difficult to use as collateral. The problem is more serious for green innovation; that is, the expected commercial benefits may not appear until later. Therefore, manufacturing enterprises face a practical problem: how to continue investing in green technology over the long term as external funding becomes more expensive.

Many previous studies have investigated the relationships among several financing conditions and corporate innovation, such as financing constraints, leverage, debt maturity, and green credit policies (Aivazian et al., 2005; Hao & Wu, 2024; Hu et al., 2021; Mitkov, 2024). Based on the above studies, financing conditions have impacted innovation behaviour. However, it is unclear whether the two types of financing dependence structures respond differently to the same level of debt financing cost. This matters because debt financing costs may operate through competing channels. Due to institutional pressures, environmental regulations and carbon reduction goals have increased the demands on enterprises to demonstrate credible green transformation efforts (DiMaggio & Powell, 1983; Suchman, 1995). Agency and signalling theory suggest that a higher cost of debt financing may reflect greater pressure from the debt market, reduced managerial discretion, more stringent creditor oversight, and the need for companies to issue clearer signals to capital suppliers (Diamond, 1991; Jensen, 1986; Spence, 1973). Therefore, although the cost of debt financing will reduce the funds available for green innovation due to increased financial pressure, it may also motivate enterprises to undertake green innovation to signal technological investment and long-term financial stability.

This tension can be seen as a Green Paradox of Financing. Environmental R&D requires substantial funds over an extended period and is subject to uncertainty in technological outcomes. At the same time, high interest burdens limit near-term liquidity and increase lenders' external oversight. In China's bank-led financial system, high debt-cost pressure may not affect all firms in the same way. Therefore, its effect may vary depending on whether the firm relies more on debt financing or equity financing. The first unresolved problem is whether the cost of debt financing has the same effect on equity-dependent and debt-dependent firms. Static leverage cannot address this problem because it captures the stock of debt at a particular point in time, whereas financing dependence reflects the extent to which a firm relies on external funds when internal cash flows are insufficient (Chen et al., 2025; Rajan & Zingales, 1998; Wu et al., 2025). Equity financing dependence may reduce debt-cost pressure because equity financing does not involve fixed repayment obligations. However, debt financing dependence may increase creditor risk concerns, refinancing pressure, and debt-market signals. Therefore, this study treats financing dependence structure as a boundary condition in the relationship between debt financing cost and corporate green innovation.

Total green patent applications and green invention patent applications are used to measure green innovation, with the latter capturing more invention-oriented outcomes. This distinction is useful because green finance and environmental regulation may affect different types of green innovation in different ways (Huang et al., 2023; Xiong et al., 2023; Zhang et al., 2022). Using Chinese A-share-listed manufacturing firms from 2012 to 2023, this paper examines the relationship between debt financing costs and green innovation and investigates whether this relationship differs across levels of equity and debt financing dependence. This paper has the following two contributions. First, it shows that the impact of debt costs on green innovation depends on the enterprise's financing-dependence structure rather than solely on the size of borrowing costs. Second, by separating equity financing dependence from dependence on debt financing, it explains how different external financing structures shape firms' responses to debt-market pressure. The analysis also separates total green patent applications from green invention patents to compare general patenting with invention-based green innovation.

2.0 Literature Review and Hypotheses Development

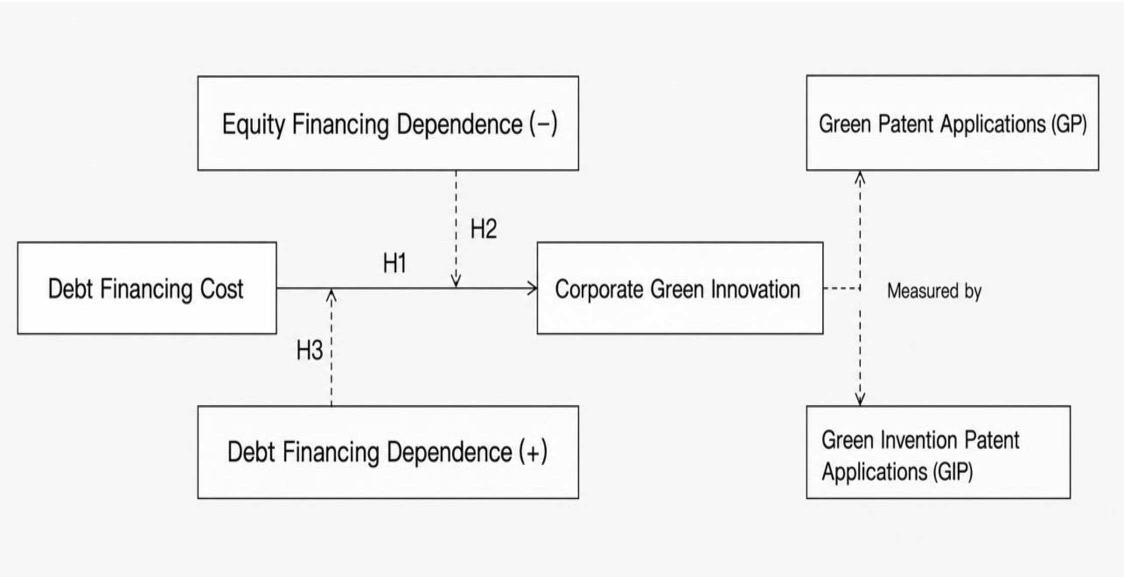

Figure 1: Research Framework

2.1 Debt Financing Cost and Green Innovation

Environmental R&D typically has a long cycle and uncertain returns, thus demanding continuous funding. Green initiatives are not always high-tech innovations; sometimes they involve investments in pollution-reduction facilities, regulatory compliance, or changes driven by policy adjustments. These characteristics make it difficult to fund environmental programmes only with internal funds. Previous studies show that R&D expenses are highly exposed to external financial frictions; this vulnerability stems from their high uncertainty, non-physical characteristics, and limited collateral value (Brown et al., 2009; Giebel & Kraft, 2024; Hall & Lerner, 2010). When internal cash flow is insufficient to fund investment, firms may need to raise external funds to support new research and development and technological upgrades (Fazzari et al., 1988; Rajan & Zingales, 1998).

Many routes have been employed in previous research to study the impact of financing conditions on innovation, including financing constraints, leverage, debt maturity, and credit policy (Aivazian et al., 2005; Hao & Wu, 2024; Mitkov, 2024). Although these studies have provided useful evidence, each shows only part of the financing environment. Financing constraints refer to restricted access to external funds; leverage is the proportion of total debt; maturity structure refers to the repayment schedule of this debt; and credit policy studies investigate changes in loan allocation under regulatory reforms. The cost of debt capital for the firm is not shown directly in the above indicators. Debt financing cost is a more direct index of the price a company pays for debt financing. This distinction is important because Chinese banks remain a major source of funds for listed manufacturing firms, and debt financing is still an important external funding source.

The net impact of borrowing costs on environmental innovation is theoretically divided into two opposite channels (Diamond, 1991; Jensen, 1986). Therefore, this paper focuses on two channels: the cost-of-capital penalty and the monitoring-and-signalling channel. On the one hand, according to the cost-of-capital penalty, an increase in interest expense will reduce available funds and limit funds for the initial R&D investment in green projects. At the same time, the monitoring-and-signalling channel suggests that a high financing cost may reflect increased external supervision or pressure from debt markets, and thus managers may employ green patenting as a credible signal of long-term competitive advantage. Therefore, a positive correlation between the cost of debt financing and green innovation does not mean that a high cost of debt financing promotes green innovation. Rather, firms may make more efforts in green innovation to reassure the debt market.

Recent studies on green finance and green credit have also indicated that credit allocation and financing pressure affect a company's green innovation; however, most of these studies have focused on policy-induced changes in credit conditions rather than the firm-level cost burden of debt financing (Gao et al., 2022; Hu et al., 2021). Both total green patent applications and green invention patent applications will be used in the analysis because financing pressure may affect broader patenting activity and invention-oriented outcomes differently (Chen et al., 2025; Dong et al., 2025; Huang et al., 2023; Zhang et al., 2022). The first hypothesis is therefore proposed at the overall level of corporate green innovation, while green patent applications (GP) and green invention patent applications (GIP) are reported separately in the empirical tests:

Hypothesis 1: Debt financing cost is positively associated with corporate green innovation.

2.2 Equity Financing Dependence, Debt Financing Cost and Green Innovation

Financing dependence captures the degree to which firms repeatedly use external capital when internally generated funds cannot meet investment needs. Rajan and Zingales (1998) proposed the idea of external financing dependence and measured firms' need for outside funds beyond internal cash flow. Unlike leverage, this concept does not refer to the level of liabilities reported on the balance sheet in the current period. This distinction is useful here because the effect of debt financing costs may depend not only on the size of the costs themselves but also on the external financing channel primarily used by the firm (Chen et al., 2025; Wu et al., 2025). Equity financing dependence reflects the importance of equity capital as a source of external funds for a firm. Equity financing can support innovation because it does not require fixed repayment schedules and better accommodates long-term uncertainty. Innovation activities are high-risk, long-term investments that may not yield returns for an extended period (Brown et al., 2009; Hall & Lerner, 2010). Previous studies have also found that external equity plays an important role in financing innovation and growth, especially when firms have strong R&D needs but limited internal funds (Hsu et al., 2014).

Pfeffer and Salancik's (1978) resource-dependence theory can be applied to this case. At the centre of this proposition is the idea that firms' decision-making is influenced by external stakeholders who provide necessary resources; therefore, debt-market signals may not affect firms that rely more on non-debt financing channels in the same way. If a firm has a larger proportion of debt financing, creditors will be its main source of funds.

By contrast, if a firm relies more on equity financing, debt providers become less central to its external resource base. Therefore, changes in debt financing cost may have a relatively weaker effect on the firm's financing capacity and investment decisions.

Another reason for this moderating effect is the presence of a non-debt funding alternative. Firms that rely more on equity financing are less exposed to increases in borrowing costs because they rely less on interest-bearing debt. For these firms, an increase in the cost of debt may have a relatively small negative impact on financing capacity and investment plans for green innovation. Equity financing dependence is not a direct cause of reduced green innovation. Rather, equity-dependent firms may be less affected by higher debt-cost pressure because they have a stronger non-debt financing channel. This argument is based on the substitution between external financing channels. According to financing-choice theory, firms adjust their external financing sources based on financing costs, information asymmetry, and funding needs (Myers & Majluf, 1984). With rising debt financing costs, firms with greater reliance on equity financing may have greater flexibility to continue green innovation without relying heavily on debt capital. Equity financing may also reduce firms' repayment pressure, refinancing risk, and creditor monitoring related to debt financing. As a result, debt financing cost may become a weaker signal and a less binding constraint for firms that depend more on equity financing. Therefore, the positive association between debt financing cost and green innovation is expected to weaken as equity financing dependence increases:

Hypothesis 2: Equity financing dependence negatively moderates the relationship between debt financing cost and corporate green innovation.

2.3 Debt Financing Dependence, Debt Financing Cost and Green Innovation

The second moderating variable captures the degree of recurrent reliance on borrowed capital. This idea is not the same as leverage; rather than a static stock measure, it refers to the frequent issuance of new debt instruments to finance continuous investment in the enterprise. Therefore, companies with the same debt-to-asset ratios may differ in their actual reliance on new debt financing. Debt financing dependency shows how a company is exposed to changes in the debt market more dynamically (Chen et al., 2025; Rajan & Zingales, 1998).

Aivazian et al. (2005), Hao and Wu (2024), Liu et al. (2019), Mitkov (2024) and Shi et al. (2022) have shown that leverage, green credit allocation and debt maturity are related to corporate investment horizons and environmental behaviour. Most of the above studies have focused on stock-based indebtedness, debt maturity and policy-driven credit shifts. They do not fully explain whether firm-specific reliance on repeated debt financing changes firms' response to debt financing cost. This point is important because similar increases in debt cost may create different levels of pressure across firms depending on how strongly they rely on debt financing. Pfeffer and Salancik's (1978) resource-dependence framework offers a coherent rationale for this predicted amplification. Their core tenet holds that organisational autonomy is constrained by the preferences of external suppliers of critical resources. For highly debt-dependent enterprises, banks and other creditors are key providers of external funds. These firms are therefore more sensitive to creditor assessments, refinancing risk, and changes in debt-market conditions. As a result, the cost of debt financing may become a relatively large and direct source of pressure for debt-dependent enterprises compared with debt-independent enterprises.

Debt financing cost reflects how external creditors assess a firm's risk and future prospects. If debt financing costs are relatively high, firms with high dependence on debt financing may need to enhance trust among creditors and improve future borrowing conditions. Green innovation may serve as one response to this pressure. It can signal to creditors and other external stakeholders that the firm is environmentally responsible, technologically capable, and oriented towards long-term development. Given the above reasons, lenders will likely take environmental, social, and governance factors into account when assessing whether to extend credit facilities (Eliwa et al., 2021). Therefore, increased reliance on debt financing is expected to amplify the positive effect of debt financing costs on green innovation by increasing creditor monitoring and debt-market evaluation.

The moderating effect may be more pronounced if the indicator of green innovation is invention patents. Green invention patent applications generally have higher technological newness and are subject to more stringent examination than total green patent applications. For enterprises with relatively high dependence on debt financing, creditors will pay more attention to whether green innovation reflects actual technological improvements rather than simply an increase in the number of patents. However, the hypothesis has been proposed at the level of overall corporate green innovation, and the empirical analysis will separately report green patent applications and green invention patent applications. Therefore, the third hypothesis is as follows:

Hypothesis 3: Debt financing dependence positively moderates the relationship between debt financing cost and corporate green innovation.

3.0 Methodology

3.1 Sample Selection

The sample is the manufacturing enterprises listed on the A-share market in China from 2012 to 2023. Manufacturing enterprises have been selected due to their direct connection to China's green transition and the need for external funding for green innovation projects. Industry affiliation is determined in accordance with the Guidelines for the Industry Classification of Listed Companies issued by the China Securities Regulatory Commission (2012). The financial data are taken from the CSMAR database. Green patent information is obtained from the CNIPA database via CNRDS. The sample is filtered in several stages. Firms in ST or *ST status are excluded because their financial conditions may be irregular and thus interfere with the analysis. Observations with missing key variables are excluded. All continuous variables have been winsorised at the 1st and 99th percentiles to limit the effect of extreme values. After the above filters, there are 14,058 firm-year observations with complete financial and green patent data.

3.2 Variable Selection

The dependent variable is corporate green innovation. In line with patent-based innovation studies, the two green patent indicators are used to measure different aspects of green innovation (Cornaggia et al., 2015; Hall & Lerner, 2010; Xiang et al., 2022). The first index is GP, which is the natural logarithm of 1 plus the number of green patent applications. It is the general quantity of green innovation output. The second indicator is GIP, which is defined as the natural logarithm of 1 plus the number of green invention patent applications. It is a higher-quality result because invention patents are generally more novel and subject to stricter examination. The logarithmic transformation is applied because patent counts are usually right-skewed and contain many zero values. Ln(1 + patent count) is used to mitigate skewness and extreme values, and firm-year observations without green patents are retained (Cornaggia et al., 2015; Xiang et al., 2022).

This study defines the firm's interest burden, Debtcost, as financial expenses divided by total liabilities at the end of the period. A higher value generally indicates a higher borrowing cost. Since financial expenses are presented net, Debtcost may be negative in a small number of observations due to interest income, exchange gains, or other accounting adjustments. Equityfindep and Debtfindep are the moderating variables, representing the enterprise's dependence on equity financing and debt financing, respectively. According to the measurement system put forward by Rajan and Zingales (1998) and later adapted in more recent studies (Wu et al., 2025), this study begins by calculating the external finance deficit as capital expenditures less internally generated operating cash flows, divided by the former.

$$\mathrm{ExtFindep}_{\mathrm{it}} = \frac{\mathrm{Capital\ Expenditure}_{\mathrm{it}} - \mathrm{Operating\ Cash\ Flow}_{\mathrm{it}}}{\mathrm{Capital\ Expenditure}_{\mathrm{it}}} \tag{1}$$

Equity financing dependence and debt financing dependence are then constructed by weighting external financing dependence by the relative share of equity financing and debt financing in total external financing:

$$\mathrm{EFD}_{\mathrm{it}} = \mathrm{ExtFindep}_{\mathrm{it}} \times \frac{\text{Net Equity Financing}_{\mathrm{it}}}{\text{Total External Financing}_{\mathrm{it}}} \tag{2}$$

$$\mathrm{DFD}_{\mathrm{it}} = \mathrm{ExtFindep}_{\mathrm{it}} \times \frac{\text{Net Debt Financing}_{\mathrm{it}}}{\text{Total External Financing}_{\mathrm{it}}} \tag{3}$$

Where Net Equity Financing and Net Debt Financing represent annual net financing flows from equity and debt sources, respectively. EFD captures the extent to which firms rely on equity financing, while DFD captures the extent to which firms rely on debt financing. This flow-based construction reflects firms' actual financing dependence behaviour more directly than static balance-sheet ratios. Several firm-level control variables are added. Xiang et al. (2022) and Guo and Zhao (2024) have done similar studies, and this study controls for the above firm-level factors that may affect both financing conditions and green innovation performance: ROA, Firmage, Cashflow, Indep, and Sharebalance. Dual, Loss and SOE are added as extra control variables for the robustness tests.

Table 1: Variable Definition

Variable Type	Variable Name	Variable Symbol	Definition
Dependent Variables	Green Innovation	GP	Ln(1 + number of green patent applications)
		GIP	Ln(1 + number of green invention patent applications)
Alternative Dependent Variable		GPG	Ln(1 + number of granted green patents)
		GIPG	Ln(1 + number of granted green invention patents)
Independent Variables	Debt Financing Cost	Debtcost	Financial expenses divided by end-of-period total liabilities
Moderating Variable	Equity Financing Dependence	Equityfindep	Flow-based measure of firms' reliance on equity financing
	Debt Financing Dependence	Debtfindep	Flow-based measure of firms' reliance on debt financing
Control Variables	Return On Assets	ROA	Net income divided by average total assets

Variable Type	Variable Name	Variable Symbol	Definition
	Firm Age	Firmage	The log-transformed value of the years elapsed since the company's original date of incorporation
	Cash Flow Ratio	Cashflow	The net cash generated from core business activities, normalised by the firm's total assets at the beginning of the year
	Board Independence	Indep	Independent directors divided by total board members
	Ownership Balance	Sharebalance	Shareholding of the second-largest shareholder divided by that of the controlling shareholder
Additional Control Variables	Ceo Duality	Dual	Indicator equal to 1 when the chairperson also holds the CEO position, and 0 otherwise
	Loss Status	Loss	Indicator equal to 1 for loss-making firms, and 0 otherwise
	State Ownership	SOE	Indicator equal to 1 for state-owned firms, and 0 otherwise
Fixed Effect	Industry Fixed Effects	Industry FE	Industry dummies included to absorb industry-specific differences
	Year Fixed Effects	Year FE	Year dummies included to absorb common time shocks

3.3 Model Design

The baseline model is used to test whether debt financing cost is associated with corporate green innovation:

$$\begin{aligned} \mathrm{GI}_{it} = {} & \alpha_0 + \alpha_1 \mathrm{Debtcost}_{it} + \alpha_2 \mathrm{ROA}_{it} + \alpha_3 \mathrm{Firmage}_{it} + \alpha_4 \mathrm{Cashflow}_{it} + \alpha_5 \mathrm{Indep}_{it} \\ & + \alpha_6 \mathrm{Sharebalance}_{it} + \gamma_{\mathrm{industry}} + \gamma_{\mathrm{year}} + \varepsilon_{it} \end{aligned} \tag{4}$$

In the model, $\mathrm{GI}_{i,t}$ refers to the green innovation outcome of the firm i in year t. GP and GIP are used separately as dependent variables. GP captures green innovation quantity, while GIP captures quality-oriented green innovation. $\mathrm{Debtcost}_{i,t}$ is the main independent variable, measured as financial expenses divided by end-of-period total liabilities. The baseline control variables include ROA, Firmage, Cashflow, Indep, and Sharebalance. Industry and year fixed effects are included, and standard errors are clustered at the firm level. Equation (4) tests Hypothesis 1. Two additional models are estimated to examine whether the association between debt financing cost and green innovation depends on firms' financing dependence structure. The first model tests the moderating effect of equity financing dependence:

$$\begin{aligned}\mathrm{GI}_{it} = {} & \beta_0 + \beta_1 \mathrm{Debtcost}^{c}_{it} + \beta_2 \mathrm{EFD}^{c}_{it} + \beta_3 (\mathrm{Debtcost}^{c}_{it} \times \mathrm{EFD}^{c}_{it}) + \beta_4 \mathrm{ROA}_{it} \\ & + \beta_5 \mathrm{Firmage}_{it} + \beta_6 \mathrm{Cashflow}_{it} + \beta_7 \mathrm{Indep}_{it} + \beta_8 \mathrm{Sharebalance}_{it} \\ & + \gamma_{\mathrm{industry}} + \gamma_{\mathrm{year}} + \varepsilon_{it} \end{aligned} \tag{5}$$

The second model tests the moderating effect of debt financing dependence:

$$\begin{aligned}\mathrm{GI}_{it} = {} & \delta_0 + \delta_1 \mathrm{Debtcost}^{c}_{it} + \delta_2 \mathrm{DFD}^{c}_{it} + \delta_3 (\mathrm{Debtcost}^{c}_{it} \times \mathrm{DFD}^{c}_{it}) + \delta_4 \mathrm{ROA}_{it} \\ & + \delta_5 \mathrm{Firmage}_{it} + \delta_6 \mathrm{Cashflow}_{it} + \delta_7 \mathrm{Indep}_{it} + \delta_8 \mathrm{Sharebalance}_{it} \\ & + \gamma_{\mathrm{industry}} + \gamma_{\mathrm{year}} + \varepsilon_{it} \end{aligned} \tag{6}$$

In Equations (5) and (6), $\mathrm{Debtcost}^{c}_{it}$, EFD^{c}_{it}, and DFD^{c}_{it} denote mean-centred variables. Mean-centring is applied before constructing the interaction terms to reduce potential multicollinearity. In Equation (5), β_3 captures the moderating effect of dependence on equity financing. This model is used to test Hypothesis 2. In Equation (6), δ_3 captures the moderating effect of debt financing dependence. This model is used to test Hypothesis 3. Several robustness tests are conducted. Industry-year fixed effects are first added to absorb time-varying industry shocks. Additional firm-level controls, including CEO duality, loss status, and state ownership, are then included to reduce omitted-variable concerns. Third, GP and GIP are replaced with grant-based green innovation measures, namely GPG and GIPG. Finally, one-period and two-period lagged Debtcost are used to reduce concerns about potential reverse causality.

4.0 Results and Discussion

4.1 Descriptive Statistics

Table 2 reports the descriptive statistics for the final sample of 14,058 firm-year observations. The mean of GP is 1.0959, higher than the mean of GIP at 0.7390, and the median of GIP is 0.00. This suggests that green invention patenting is less common than total green patenting in the sample. Debtcost has a mean of 0.0072 and a standard deviation of 0.032, indicating cross-firm variation in borrowing cost. The minimum value of -0.15 reflects negative net financial expenses in a few observations rather than negative borrowing interest rates. Equityfindep and Debtfindep also vary substantially across firms, which supports the use of the financing dependence structure in the moderation analysis.

Table 2: Descriptive Statistics

Variable	Obs	Mean	SD	Min	Median	Max
GP	14058	1.0959	1.273	0.00	0.69	5.08
GIP	14058	0.7390	1.081	0.00	0.00	4.67
Debtcost	14058	0.0072	0.032	-0.15	0.01	0.06
Equityfindep	14058	-0.4342	3.227	-21.69	0.00	9.62
Debtfindep	14058	-0.6243	4.448	-24.67	0.00	17.22
ROA	14058	0.0376	0.065	-0.26	0.04	0.21
Firmage	14058	2.0990	0.759	0.69	2.20	3.33
Cashflow	14058	0.0535	0.065	-0.12	0.05	0.25
Indep	14058	0.3769	0.054	0.33	0.36	0.57
Sharebalance	14058	0.7518	0.593	0.04	0.59	2.77

4.2 Multicollinearity Diagnosis

Based on the correlation results, the explanatory variables are not highly correlated. Table 3 further investigates this issue using VIF values. The largest VIF is 1.52, and the mean VIF values are in the range of 1.14 to 1.17. Since all VIF values are well below the typical limit of 10, multicollinearity is not expected to affect the stability of the regression results. Based on the above results, the mean-centred interaction terms in the moderation model do not exhibit severe multicollinearity.

Table 3: Variance Inflation Factor Results

Model	Variables included	Maximum VIF	Mean VIF	Conclusion
Baseline Model	Debtcost and control variables	1.37	1.14	No serious multicollinearity
Equity Financing Dependence Moderation Model	Debtcost, Equityfindep, Debtcost × Equityfindep, and control variables	1.37	1.16	No serious multicollinearity
Debt Financing Dependence Moderation Model	Debtcost, Debtfindep, Debtcost × Debtfindep, and control variables	1.52	1.17	No serious multicollinearity

Note: This table presents the variance inflation factor results for the baseline and moderation specifications. Interaction terms are based on mean-centred variables. The reported VIF values are all lower than the commonly used benchmark of 10

4.3 Baseline Regression Results

Table 4 reports the baseline regression results. Columns (1) and (2) use GP and GIP as the dependent variables, respectively. The estimated coefficients are positive in both specifications. For the aggregate green patent measure (GP), the coefficient is statistically significant at the 1% level. For the invention-based measure (GIP), the corresponding effect is smaller but remains statistically significant at the 5% level. According to the above analysis, a higher cost of debt financing is associated with greater green innovation output. The economic magnitude is also worth noting. A one-standard-deviation increase in Debtcost corresponds to a 0.068 log-point increase in GP, which is approximately a 7.0 per cent relative increase. The corresponding increase in GIP is about 0.026 log units, which is approximately a 2.6 per cent rise. GP has a larger estimated economic effect than GIP. Debt financing cost is more strongly related to the scale of green patenting than to quality-oriented green invention patenting. The baseline results support Hypothesis 1.

According to the above, there is a tension between cost-of-capital pressure and the monitoring-and-signalling channel of debt financing cost. Although the cost of debt financing for the company will be relatively high, it may also expose the firm to stronger creditor scrutiny and external market evaluation. In light of the above, some enterprises may use green innovation to show social responsibility and demonstrate long-term transformation potential. A relatively larger effect of GP than of GIP indicates that this signalling response is more pronounced on the scale of green patent applications than in quality-oriented green invention patents. Therefore, the positive coefficient should not be viewed as evidence that a higher cost of debt financing is unconditionally advantageous.

Table 4: Baseline Regression Results

Variables	(1) GP	(2) GIP
Debtcost	2.127*** (4.478)	0.815** (1.987)
ROA	1.458*** (5.879)	1.069*** (5.062)
Firmage	0.309*** (10.133)	0.263*** (9.664)
Cashflow	0.002 (0.009)	0.050 (0.227)
Indep	0.051 (0.124)	0.313 (0.859)
Sharebalance	0.014 (0.343)	0.019 (0.517)
Industry FE	Yes	Yes
Year FE	Yes	Yes
Cluster at Firm Level	Yes	Yes
Constant	-0.715*** (-3.845)	-0.751*** (-4.582)
R-squared	0.161	0.128
Observations	14,058	14,058

Note: *** and ** indicate significance levels at the 1% and 5% levels, respectively, and T-values are reported in parentheses.

4.4 Moderating Effects of Financing Dependence

Table 5 presents the moderation results. Columns (1) and (2) are about Equityfindep, and Columns (3) and (4) are about Debtfindep. The interaction term between Debtcost and Equityfindep is negative and statistically significant at the 10% level in both the GP and GIP specifications. Therefore, firms with higher equity financing dependence are less sensitive to debt financing cost pressure in relation to green innovation.This pattern is consistent with the substitution mechanism discussed above. Equity-dependent firms may have greater flexibility to reduce their exposure to debt-cost pressure because equity financing does not involve fixed repayment obligations in the same way as debt financing. As a result, debt financing cost may become a weaker constraint and a weaker external signal for firms that have stronger access to equity-based external capital. However, because the significance is only at a weak level, this evidence should be interpreted with caution. Therefore, the results provide limited but directionally consistent support for Hypothesis 2.

The interaction term between Debtcost and Debtfindep is positive in both specifications, but it is statistically significant only in the GIP model. This indicates that debt financing dependence strengthens the relationship between debt financing cost and green innovation, although the statistically significant evidence appears only for quality-oriented green innovation. This finding supports the view that firms with stronger debt dependence face greater exposure to creditor monitoring and debt-market evaluation. For these firms, green invention patent applications may be a more credible signal of substantive technological upgrading than an increase in patent quantity alone. This may explain why the moderating effect of Debtfindep is clearer for GIP than for GP. Overall, the results provide limited evidence for Hypothesis 2 and partial evidence for Hypothesis 3. The evidence for Hypothesis 3 is stronger in the green invention patent model.

Table 5: Moderating Effects of Financing Dependence

Variables	(1) GP	(2) GIP	(3) GP	(4) GIP
Debtcost	1.875***	0.623	2.143***	0.833**
	(3.873)	(1.495)	(4.522)	(2.038)
Equityfindep	0.013***	0.009***		
	(3.507)	(2.974)		
Debtcost × Equityfindep	-0.131*	-0.113*		
	(-1.705)	(-1.804)		
Debtfindep			0.010***	0.008***
			(3.068)	(2.782)
Debtcost × Debtfindep			0.119	0.150**
			(1.512)	(2.160)
ROA	1.457***	1.067***	1.370***	0.994***
	(5.882)	(5.061)	(5.481)	(4.647)
Firmage	0.312***	0.265***	0.313***	0.266***
	(10.203)	(9.712)	(10.261)	(9.768)
Cashflow	0.177	0.175	0.329	0.321

Variables	(1) GP	(2) GIP	(3) GP	(4) GIP
	(0.686)	(0.771)	(1.169)	(1.312)
Indep	0.046	0.308	0.051	0.311
	(0.112)	(0.849)	(0.123)	(0.856)
Sharebalance	0.014	0.019	0.013	0.018
	(0.350)	(0.524)	(0.312)	(0.492)
Constant	-0.712***	-0.753***	-0.725***	-0.764***
	(-3.823)	(-4.587)	(-3.897)	(-4.659)
Observations	14,058	14,058	14,058	14,058
R-squared	0.163	0.129	0.162	0.129
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Cluster at Firm Level	Yes	Yes	Yes	Yes

Note: ***, ** and * indicate significance levels at the 1%, 5% and 10% levels, respectively, and T-values are reported in parentheses.

4.5 Robustness Checks

Table 6 reports the robustness checks for the baseline relationship. Debtcost remains positive and significant after including industry-year fixed effects and additional control variables. When grant-based patent measures are used, Debtcost remains significant in the GPG model but becomes insignificant in the GIPG model. The tests using lagged Debtcost provide similar evidence, mainly for the GP models. The foregoing robustness exercises collectively suggest that the primary association exhibits greater persistence when innovation is measured in volumetric terms, as opposed to quality-weighted invention counts. This pattern may be explained by the difference between patent applications and granted invention patents. Debt-cost pressure may encourage firms to increase green patent applications as a visible signalling response, but granted green invention patents require stronger technological novelty, stricter examination, and a longer approval process. Therefore, higher debt financing cost may not be sufficient to lead to granted green invention patents within the same observation window.

Table 7 is the robustness check results of the moderation models. The Debtcost × Equityfindep interaction remains negative, but its significance becomes weaker after additional controls and grant-based measures are introduced. Therefore, the evidence for Hypothesis 2 should be considered directionally consistent but not strong. Therefore, although equity financing dependence may alleviate debt-cost pressure for firms, this reduction is not universal. The Debtcost × Debtfindep interaction is still positive, as shown in the GIP and GIPG models. Therefore, debt financing dependence may have a more stable moderating effect on quality-oriented green innovation. A possible reason is that debt-dependent firms are more exposed to creditor evaluation and refinancing pressure. Quality-oriented green innovation by these enterprises may offer creditors a more reliable signal of reduced credit risk than a high number of patents. In summary, the robustness tests still support Hypothesis 1. They provide weak support for Hypothesis 2, and the evidence for Hypothesis 3 is relatively stronger, primarily found in models of quality-oriented green innovation.

Table 6: Robustness Checks for Baseline Models

Test	DV	Key Variable	Coef.	t-stat	Controls	FE	Cluster	Obs.	R^2
Industry-Year FE	GP	Debtcost	2.075***	4.340	Yes	Industry-Year	Firm	14,058	0.163
Industry-Year FE	GIP	Debtcost	0.742*	1.803	Yes	Industry-Year	Firm	14,058	0.130
Additional controls	GP	Debtcost	2.137***	4.686	Yes	Industry, Year	Firm	13,351	0.173
Additional controls	GIP	Debtcost	0.889**	2.302	Yes	Industry, Year	Firm	13,351	0.143
Alternative DV	GPG	Debtcost	1.735***	4.297	Yes	Industry, Year	Firm	14,054	0.157
Alternative DV	GIPG	Debtcost	0.221	0.854	Yes	Industry, Year	Firm	14,054	0.086
Lagged Debtcost	GP	L1_Debtcost	1.524***	2.828	Yes	Industry, Year	Firm	11,766	0.162
Lagged Debtcost	GIP	L1_Debtcost	0.265	0.570	Yes	Industry, Year	Firm	11,766	0.130
Lagged Debtcost	GP	L2_Debtcost	1.559***	2.719	Yes	Industry, Year	Firm	10,026	0.159
Lagged Debtcost	GIP	L2_Debtcost	0.210	0.423	Yes	Industry, Year	Firm	10,026	0.130

Note: Baseline controls include ROA, Firmage, Cashflow, Indep, and Sharebalance. Additional controls include Dual, Loss, and SOE. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 7: Robustness Checks for Moderating Effects

Test	DV	Int. term	Coef.	t-stat	Controls	FE	Cluster	Obs.	R^2
Industry-Year FE	GP	Debtcost × Equityfindep	-0.134*	-1.743	Yes	Industry-Year	Firm	14,058	0.164
Industry-Year FE	GIP	Debtcost × Equityfindep	-0.115*	-1.844	Yes	Industry-Year	Firm	14,058	0.131
Industry-Year FE	GP	Debtcost × Debtfindep	0.116	1.475	Yes	Industry-Year	Firm	14,058	0.164
Industry-Year FE	GIP	Debtcost × Debtfindep	0.148**	2.133	Yes	Industry-Year	Firm	14,058	0.131
Additional controls	GP	Debtcost × Equityfindep	-0.124	-1.529	Yes	Industry, Year	Firm	13,351	0.174

Test	DV	Int. term	Coef.	t-stat	Controls	FE	Cluster	Obs.	R²
Additional controls	GIP	Debtcost × Equityfindep	-0.103	-1.554	Yes	Industry, Year	Firm	13,351	0.144
Additional controls	GP	Debtcost × Debtfindep	0.124	1.583	Yes	Industry, Year	Firm	13,351	0.174
Additional controls	GIP	Debtcost × Debtfindep	0.150**	2.155	Yes	Industry, Year	Firm	13,351	0.145
Alternative DV	GPG	Debtcost × Equityfindep	-0.087	-1.292	Yes	Industry, Year	Firm	14,054	0.159
Alternative DV	GIPG	Debtcost × Equityfindep	-0.027	-0.651	Yes	Industry, Year	Firm	14,054	0.087
Alternative DV	GPG	Debtcost × Debtfindep	0.095	1.499	Yes	Industry, Year	Firm	14,054	0.159
Alternative DV	GIPG	Debtcost × Debtfindep	0.085**	2.064	Yes	Industry, Year	Firm	14,054	0.087

Note: Baseline controls include ROA, Firmage, Cashflow, Indep, and Sharebalance. Additional controls include Dual, Loss, and SOE. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5.0 Conclusion and Future Research

5.1 Conclusion

Panel data on A-share manufacturing companies from 2012 to 2023 were used in this paper to explore the relationship between debt financing costs and corporate green innovation, as well as to investigate the moderating effect of the financing dependence structure. Green innovation is measured by green patent applications and green invention patent applications, which capture quantity-oriented and invention-oriented dimensions of green innovation, respectively. The results show that the cost of debt financing is positively associated with both green innovation measures, and the estimated effect is stronger for green patent applications than for green invention patent applications. Therefore, the cost of debt financing should not be considered solely as an expense. It may also reflect creditor monitoring, debt-market pressure, and firms' incentives to signal green transformation capabilities. In line with previous studies by Gao et al. (2022), Hu et al. (2021), Shi et al. (2022) and Yao et al. (2022), changes in financing conditions and green credit policies can affect corporate green innovation behaviour. The weak effect of green invention patent applications also suggests that debt pressure is more closely linked to the expansion of green patenting than to difficult-to-achieve, high-quality invention-based innovation.

Based on the moderation results, the structure of financing dependence is also different. Equity financing dependence reduces the positive impact of high debt financing costs on green innovation, but the corresponding evidence is relatively weak and should be interpreted cautiously. Another way to think about it is that equity-dependent firms have other sources of external financing and are less exposed to pressure from fixed debt repayments, refinancing risk, and creditor monitoring. Debt financing dependence, on the other hand, strengthens the relationship between debt financing cost and green innovation, especially when green invention patent applications are used as the dependent variable. Therefore, it can be seen from resource dependence theory that debt-dependent firms rely more heavily on creditors for essential external resources (Pfeffer & Salancik, 1978). These enterprises' substantial green innovation can serve as a credible signal of technological upgrades and long-term transition ability.

Collectively, the above studies show that the impact of debt financing cost on green innovation varies by enterprise. It also depends on the source of the company's external funds and its use of debt markets. This is the result of a financing-related green innovation paradox. Debt financing costs may create short-term financial pressure, but they can also encourage the company to demonstrate long-term green transformation potential. This does not mean that a higher cost of debt is inherently beneficial. Therefore, the research indicates that debt-market pressure can be linked to green innovation when firms use innovation to respond to creditor evaluation and external financing requirements.

5.2 Implications

The results offer implications for both research and practice. First, this study contributes to the literature on financing conditions and green innovation by focusing on debt financing cost rather than only on financing constraints, leverage, debt maturity, or green credit policy. By using a financing dependence structure, the study moves beyond static leverage measures and provides a more dynamic explanation of why firms respond differently to similar debt-cost pressure. The distinction between equity financing dependence and debt financing dependence shows that external financing structure is not only a background firm characteristic, but also a boundary condition that shapes the debt cost–green innovation relationship.

A further contribution lies in the distinction between the quantity and quality-oriented dimensions of green innovation. The results suggest that debt financing costs are more strongly associated with the scale of green patenting, whereas debt financing dependence plays a clearer moderating role in green invention patent applications. This distinction supports the view that different types of green innovation may respond differently to financing pressure and external evaluation (Huang et al., 2023; Zhang et al., 2022). The findings also have practical implications. The decisions made by company management regarding green innovation should be considered alongside the firm's financing structure. Firms with a high proportion of debt financing may be more exposed to creditor evaluation and refinancing risk; therefore, credible green innovation can be seen as progress in technological upgrading and long-term transformation capacity. Managers should not assume that debt pressure is inherently beneficial, because excessive financing costs may still undermine financial flexibility and weaken long-term support for innovation.

Green credit risk assessment should be differentiated for financial institutions. Banks and other lenders should not apply the same interest-rate policy to all green projects and should consider the firm's overall financing-dependence structure when setting credit terms. Debt-dependent enterprises with high-quality green invention activities may require a different credit assessment than those whose primary source of green patents is increased volume. Government-issued green finance policies should promote genuine green innovation while avoiding excessive financial pressure on financially weaker enterprises. Thus, the financing dependence structure can be used to inform the design of targeted green credit support and innovation incentives.

5.3 Limitations and Future Research

This study has several limitations. First, the sample includes only Chinese A-share-listed manufacturing companies. Manufacturing enterprises are highly relevant to the green transition due to the industry's high environmental pressures and substantial investment needs for technological upgrading. However, the results may not be directly applicable to unlisted companies, small and medium-sized enterprises, service companies or companies with different institutional conditions. Other studies may also explore whether similar mechanisms apply to other sectors, ownership types, pollution levels, or financial systems. Second, the green innovation indicators in this study are based on patents. Green patent applications and green invention patent applications are observable and comparable indicators, but they may not cover all types of green innovation, such as process optimisation, energy-saving measures, unpatented technologies, or commercialised environmental products. Future studies may add more indicators to distinguish between symbolic green patenting and genuine green innovation more clearly, such as patent citations, patent value, renewal status, commercialisation outcomes and environmental performance.

Thirdly, although this study uses lagged debt financing cost and several robustness tests, the results should still be considered associations rather than conclusive proof of causality. Future research could employ more identification strategies to provide stronger causal evidence, such as policy shocks and quasi-natural experiments. Finally, this study focuses on equity financing dependence and debt financing dependence as moderators. Future studies may further examine how regional green finance development, local environmental enforcement, technology intensity and decision-making mechanisms for financial investment play a role. With the increasing connection between the green transition and financing decisions, the role of the Chief Financial Officer is changing; now, they need to be responsible for both financial control and the long-term strategic coordination of financing costs, debt-market discipline, liquidity pressure, and green innovation.

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