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The impact of entrepreneurial innovation spirit on digital technology innovation: text analysis based on chairmen's statements in annual reports

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Article

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Abstract: Entrepreneurial innovation spirit is the core of entrepreneurship and a potential internal driver of corporate digital technology innovation. Using sample data on China's A-share listed companies that disclosed chairmen's statements in their annual reports from 2016 to 2023, this paper examines the impact of entrepreneurial innovation spirit on digital technology innovation and its underlying mechanisms. The results show that entrepreneurial innovation spirit significantly promotes the digital technology innovation of listed companies; this conclusion remains valid after a battery of endogeneity and robustness tests. Mechanism tests reveal that entrepreneurial innovation spirit promotes corporate digital technology innovation by increasing the allocation of digital assets, digital human resources and external R&D knowledge. Heterogeneity analysis indicates that the positive effect is more pronounced in firms with lower agency costs, no internal control deficiencies, stronger chairman compensation and equity incentives, and chairmen who are younger and have higher educational attainment. This study contributes a text-based quantitative measurement of entrepreneurial innovation spirit, enriches the literature on the economic consequences of entrepreneurship and on the determinants of digital technology innovation, and offers empirical evidence and practical guidance for fostering entrepreneurial innovation spirit to advance digital technology innovation.

Keywords: Entrepreneurship; Entrepreneurial innovation spirit; Digital technology innovation; Innovation performance

Introduction

The report of the 20th National Congress of the Communist Party of China points out the need to "accelerate the development of the digital economy and promote the deep integration of the digital economy and the real economy." It is thus evident that the integrated development of the digital economy and the real economy has become the new pattern for the development of contemporary enterprises, and that digital technology innovation is the key to advancing this integration. Through digital technology innovation, firms can embed emerging technologies such as artificial intelligence and the Internet of Things into their R&D processes, so that new products, new processes, new technologies and new services are enriched with digital elements to meet the new needs of firms and of human development in the new era (Tumbas et al., 2018). Against the backdrop of a new-type modern industrial system, accelerating the development of digital technology innovation is therefore an important measure for firms to foster new quality productive forces and achieve high-quality development. However, compared with traditional technological innovation, digital technology innovation places higher demands on firms' innovation conditions and requires strong financial support to build up the reserves of digital technology personnel, equipment and related knowledge that such innovation demands.

Moreover, digital technology innovation focuses more on applying modern digital technologies to innovation in invention patents and utility model patents while paying less attention to design patents, which makes its innovation output more uncertain than that of traditional technological innovation. Consequently, although the economic benefits of digital technology innovation are highly promising, most firms conservatively choose not to pursue it—even falling into a situation of "not daring to innovate" or "being unwilling to innovate"—given its high input requirements and low output efficiency (Yoo et al., 2010).

However, for firms seeking to break this impasse in digital technology innovation, appropriate innovation leadership is the key. In particular, entrepreneurs headed by the chairman should fully play the role of the "bellwether" and pool the innovative forces of the management team. Entrepreneurial innovation spirit is the internal driving force of corporate innovation and development; it is therefore highly likely to be internalized into firms' digital technology innovation strategies, forming a powerful innovation drive that accelerates the digital technology innovation of listed companies. Yet, because such entrepreneurial innovation spirit reflects the cognition and capability of entrepreneurs as individuals in innovation and entrepreneurship, rather than the implementation of a concrete firm-level innovation strategy, whether it can translate into an effective innovation drive in a complex market environment remains in doubt. In summary, entrepreneurial innovation spirit embodies entrepreneurs' cognition and capability with respect to innovation knowledge and innovation concepts. Can such entrepreneurial innovation spirit generate a powerful innovation drive that promotes the digital technology innovation of listed companies? This is a question that deserves in-depth analysis, yet the existing literature lacks corresponding inquiry.

Against this background, this paper conducts a text analysis of chairmen's statements in annual reports to quantify entrepreneurial innovation spirit, and then examines its impact on corporate digital technology innovation, striving to provide suggestions and feasible measures for how to foster entrepreneurial innovation spirit and accelerate corporate digital technology innovation. Our contributions are threefold. First, the paper defines and measures entrepreneurial innovation spirit using chairmen's statements in annual reports. Entrepreneurial innovation spirit should focus on the entrepreneur as the innovation subject while emphasizing the assessment of innovation elements. Although a few studies have tentatively measured entrepreneurial innovation spirit through R&D investment (Wiklund and Shepherd, 2005) or questionnaire surveys (Antoncic and Hisrich, 2001), the subject of R&D investment is the firm, so using R&D investment as a proxy makes it difficult to highlight the innovation leadership of the entrepreneur as the innovation subject; questionnaire-based measurement, while focusing on the entrepreneur, can hardly reflect the characteristics of innovation elements. To capture both the entrepreneur as the spiritual subject and the innovation elements, this paper draws on the textual information of chairmen's statements, thereby achieving an organic unity of the subject and the innovation elements of entrepreneurial innovation spirit and a more systematic measurement of it. Second, this study broadens the literature on the determinants of corporate digital technology innovation. Among the existing studies on the influencing factors of corporate digital technology innovation,

Jin and Jiang (2024) tentatively defined entrepreneurship from the perspective of the urban innovation atmosphere and examined its impact on corporate digital technology innovation. However, that study measures entrepreneurship through the innovation atmosphere of the city outside the firm, which can hardly depict entrepreneurship within the firm organization; moreover, it focuses on entrepreneurship in general rather than entrepreneurial innovation spirit, and the two differ considerably in their spiritual elements. By contrast, this paper adopts the perspective of entrepreneurs inside the firm organization, breaks away from the comprehensive measurement of entrepreneurship, and directly focuses on entrepreneurial innovation spirit—namely, examining entrepreneurs headed by the chairman while emphasizing the assessment of the "innovation" spiritual element. To the best of our knowledge, this paper examines the impact of entrepreneurial innovation spirit on corporate digital technology innovation from the perspective of entrepreneurial innovation spirit, addressing the limited evidence on the relationship between entrepreneurial innovation spirit and digital technology innovation. Third, this paper thoroughly analyzes the mechanism through which entrepreneurial innovation spirit affects corporate digital technology innovation and conducts rich heterogeneity analyses, which not only interpret the influence mechanism but also enrich the application scenarios of the impact of entrepreneurial innovation spirit on corporate digital technology innovation, providing feasible suggestions for how to foster entrepreneurial innovation spirit and accelerate corporate digital technology innovation.

Research design

Theoretical analysis and hypothesis development

Entrepreneurial innovation spirit and digital technology innovation

Entrepreneurship plays an important role in the development of enterprises, exerting significant influence on risk control, resource allocation, and innovation and creation (Wennekers and Thurik, 1999). Accordingly, some scholars regard entrepreneurship as entrepreneurs' comprehensive capability in innovation, risk-taking, opportunity recognition and organization (Wang, 2024). Entrepreneurial innovation spirit is an important component of entrepreneurship, with an emphasis on entrepreneurs' comprehensive cognition of and value recognition for innovation (Tripopsakul et al., 2022). Moreover, compared with entrepreneurship in general, the innovation focus of entrepreneurial innovation spirit makes it easier for entrepreneurs' individual innovation consciousness to evolve into the collective innovation consciousness of the management team, and to be internalized into the formulation and implementation of corporate innovation strategies, thereby forming a powerful innovation drive (Yang and Yang, 2023). This is particularly true for corporate digital technology innovation: the prevailing situation of "not daring to innovate" or "being unwilling to innovate" largely reflects the lack of guidance on the direction of digital technology innovation, which intensifies firms' concerns about innovation failure. The formation of entrepreneurial innovation spirit can, however, provide effective

guidance for digital technology innovation, break this impasse, and promote the digital technology innovation of listed companies.

On the one hand, from the perspective of breaking the impasse of "not daring to innovate," the main reason why firms exhibit "not daring to innovate" in digital technology innovation is that the process requires the continuous incorporation of digital technologies such as artificial intelligence and blockchain, and the embedding of digital technologies is highly demanding. Moreover, compared with traditional technological innovation, digital technology innovation mainly focuses on innovation in invention patents and utility model patents and pays less attention to design patents, which further raises the difficulty of innovation in this field. Based on such formidable difficulties, firms' concerns about the failure of digital technology innovation are intensified, and many listed companies therefore dare not venture into digital technology innovation. However, when entrepreneurs headed by the chairman possess a strong innovation spirit, firms' confidence in digital technology innovation increases and their worries about failure are weakened. According to upper echelons theory, entrepreneurs' experience and value orientations exert important influences on corporate innovation strategies and leave corresponding "imprints" (Li et al., 2021). Entrepreneurs with a strong innovation spirit thus have a higher-level cognition and value orientation toward advanced innovation theories such as digital technology innovation (Shane and Venkataraman, 2000), which is internalized into corporate digital technology innovation strategies, clarifies the direction of digital technology innovation, makes it more likely to overcome difficulties such as digital technology embedding, and reduces firms' concerns about innovation failure. In this way, firms break the impasse of "not daring to innovate" in digital technology innovation and ultimately accelerate its development.

On the other hand, from the perspective of breaking the impasse of "being unwilling to innovate," the situation largely arises because digital technology innovation requires more financial and technical support than traditional technological innovation—precisely what firms lack—resulting in the predicament of "being unwilling to innovate." According to signaling theory, a firm's strategic value orientation conveys corresponding information to external stakeholders and forms the basis for stakeholders' investment and financing cooperation with the firm. Therefore, when entrepreneurs headed by the chairman possess a strong innovation spirit, the firm's production, operation and innovation strategies are infused with innovation elements and transmit positive signals about innovative development to external stakeholders, thereby increasing external stakeholders' participation in and support for the firm's investment and financing. This alleviates the difficulty of obtaining financial and technical support for digital technology innovation, raises listed companies' willingness to engage in digital technology innovation, and ultimately accelerates their digital technology innovation development.

In summary, in the process of corporate digital technology innovation, entrepreneurial innovation spirit can exert a powerful innovation-driven effect, breaking the impasse of "not daring to innovate" or "being unwilling to innovate," accelerating the development of corporate

digital technology innovation, and ultimately significantly raising the level of corporate digital technology innovation. Accordingly, this paper proposes the following hypothesis:

H1: Entrepreneurial innovation spirit promotes the improvement of the digital technology innovation level of listed companies.

Entrepreneurial innovation spirit, digital asset allocation and digital technology innovation

Digital asset allocation is a necessary condition for firms to carry out digital technology innovation (Hanelt et al., 2021). Although firms' resources are limited, their resource allocation is influenced by management decisions. When entrepreneurs headed by the chairman possess a strong innovation spirit, it indicates that the entrepreneurs have a higher-level and more scientific cognition of the asset allocation for corporate digital technology innovation strategies, prompting listed companies to increase the proportion of digital assets allocated. As the proportion of digital assets increases, favorable preconditions for digital technology innovation are created. Moreover, such a shift in asset allocation will gradually steer listed companies' innovation strategies toward digital technology innovation, forming effective guidance for digital technology innovation and enhancing the innovation vitality of listed companies, thereby promoting their digital technology innovation development with a higher probability. Accordingly, this paper proposes the following hypothesis:

H2: Entrepreneurial innovation spirit promotes the improvement of the digital technology innovation level of listed companies by increasing digital asset allocation.

Entrepreneurial innovation spirit, digital human resource allocation and digital technology innovation

Digital human resource allocation is also a necessary condition for firms to carry out digital technology innovation (Crook et al., 2011). According to the theory of personnel allocation in human resources (Acemoglu and Restrepo, 2018), a firm's strategic decisions will induce corresponding personnel allocation, producing the effect of concentrating professional personnel or matching personnel to needs. Therefore, when entrepreneurs headed by the chairman possess a strong innovation spirit, it indicates that the entrepreneurs have a deeper cognition of advanced digital technologies and their innovation strategies, and will focus corporate innovation strategies on digital technology innovation, thereby increasing the allocation of human resources for digital technology innovation and pooling the forces of corporate digital technology innovation. Meanwhile, according to personnel allocation theory, implementing a digital technology innovation strategy will prompt listed companies to recruit more digital technology innovation talents or invest more in cultivating such talents, thereby forming a scientific allocation of digital technology innovation talents, safeguarding the knowledge reserves for digital technology innovation, and promoting the improvement of listed companies' digital technology level with a higher probability. Accordingly, this paper proposes the following hypothesis:

H3: Entrepreneurial innovation spirit promotes the improvement of the digital technology innovation level of listed companies by increasing digital human resource allocation.

Entrepreneurial innovation spirit, external R&D knowledge allocation and digital technology innovation

External R&D knowledge allocation provides the knowledge complement needed by firms to carry out digital technology innovation (Cohen and Levinthal, 1990). When entrepreneurs headed by the chairman possess a strong innovation spirit, it indicates that the entrepreneurs have a deeper understanding of advanced digital technologies and their innovation strategies; they will not only focus corporate innovation strategies on digital technology innovation, but also be familiar with the knowledge reserves that the firm lacks in the process of digital technology innovation. This prompts listed companies to acquire the knowledge needed for digital technology innovation through measures such as joining external R&D alliances, thereby making up for the knowledge deficiency in the innovation process, improving the knowledge system for digital technology innovation, raising the probability of innovation success, and ultimately promoting the improvement of listed companies' digital technology level. Accordingly, this paper proposes the following hypothesis:

H4: Entrepreneurial innovation spirit promotes the improvement of the digital technology innovation level of listed companies by increasing the allocation of external R&D knowledge resources.

Data

This paper takes A-share listed companies that disclose chairmen's statements in their annual reports as the initial sample, and uses their sample data from 2016 to 2023 to test the impact of entrepreneurial innovation spirit on digital technology innovation. To improve the scientific rigor of sample selection, firms in the financial and insurance industries, ST firms, and firms with incomplete data are excluded from the initial sample. In addition, all continuous variables are winsorized at the 1st and 99th percentiles. The digital technology innovation data come from the CNRDS database, and the remaining data come from the CSMAR database.

Variable definitions

Dependent variable

Corporate digital technology innovation (DTI). Following Nambisan et al. (2017) and Yang and Lu (2025), the natural logarithm of one plus the number of granted digital technology patents of listed companies is used to measure corporate digital technology innovation (DTI).

Explanatory variable

Entrepreneurial innovation spirit (EIS). Entrepreneurship is entrepreneurs' identification with corporate innovation strategies and the corporate innovation value system, which in turn leads the development of corporate innovation. Meanwhile, the chairman is the strongest representative of the entrepreneurs, and innovation culture is a manifestation of innovation spirit. Although no explicit measurement of entrepreneurial innovation spirit exists in the literature, Lu (2024)'s measurement of corporate innovation culture through text analysis of innovation

keywords provides ideas and reference for this paper's measurement of entrepreneurial innovation spirit. Therefore, this paper focuses the subject of innovation spirit on the chairman as the representative of the entrepreneurs, and measures entrepreneurial innovation spirit (EIS) as the percentage of sentences in the chairman's statement that contain any of 25 innovation keywords (such as "technological innovation," "research" and "development") relative to the total number of sentences in the statement. The higher this proportion is, the stronger the innovation spirit of the entrepreneurs headed by the chairman in the target company, and vice versa.

Mechanism variables

Digital asset allocation (DA). Digital asset allocation refers to the proportion of digital-related assets in a firm's assets. Drawing on Zhang and Chen (2024), this paper measures the digital asset allocation (DA) of listed companies as the proportion of digital-related assets in intangible assets. The higher this proportion is, the more the listed company attaches importance to the allocation of digital-related assets.

Digital human resource allocation (DHR). Digital human resources refer to the allocation of personnel with digital-related expertise in listed companies, covering both ordinary employees and the management team. However, considering that the professional backgrounds of ordinary employees are difficult to obtain, whereas the management team is more representative and important and the relevant résumés are accessible, this paper draws on upper echelons theory (Hambrick and Mason, 1984) and measures the digital human resource allocation (DHR) of listed companies by the number of executives whose personal résumés show digital-related majors or experience. The greater the number of executives with digital backgrounds, the more the listed company attaches importance to the allocation of digital human resources.

External R&D knowledge allocation (RDK). R&D alliances are an important channel for listed companies to acquire external R&D knowledge. Following Zhang (2024) and Du and Xue (2024), this paper defines the external R&D knowledge allocation (RDK) of the target company according to whether it has formed R&D alliances with external enterprises, universities and other related organizations. If the company participates in relevant R&D alliances, RDK is assigned a value of 1; otherwise, RDK is assigned a value of 0.

Control variables

To rigorously test the impact of entrepreneurial innovation spirit on corporate digital technology innovation, and drawing on the practices of existing studies, this paper further controls for firm size (Size), financial leverage (Lev) and other related variables (Li et al., 2024). In addition, given the modest sample size of this paper, OLS regressions are mainly adopted, and industry (Ind) and year (Year) effects are also controlled. The specific variable definitions and descriptions are shown in Table 1.

Table 1 Variables, definitions and descriptions.

Variables	Definition	Symbol	Description

Dependent variable	Corporate digital technology innovation	DTI	Natural logarithm of (1 + number of granted digital technology patents)
Explanatory variable	Entrepreneurial innovation spirit	EIS	Number of innovation-keyword sentences in the chairman's statement / total number of sentences in the chairman's statement
Mechanism variables	Digital asset allocation	DA	Proportion of digital-related assets in intangible assets
	Digital human resource allocation	DHR	Number of executives with digital technology backgrounds
	External R&D knowledge allocation	RDK	1 if the target company participates in R&D alliances, 0 otherwise
Control variables	Firm size	Size	Natural logarithm of (1 + total assets at year-end)
	Financial leverage	Lev	Total liabilities / total assets at year-end
	Return on assets	Roa	Net profit / total assets at year-end
	Growth	Growth	Growth rate of operating revenue
	Operating cash flow	Cfo	Net cash flow from operating activities / operating revenue
	Loss status	Loss	1 if the listed company's net profit is negative, 0 otherwise
	Ownership concentration	Top1	Shareholding ratio of the largest shareholder
	Board independence	Idr	Ratio of the number of independent directors to the total number of directors
	CEO duality	Dual	1 if the chairman also serves as general manager, 0 otherwise
	State ownership	Soe	1 for state-owned enterprises, 0 for private enterprises

Model specification

To test the impact of entrepreneurial innovation spirit on corporate digital technology innovation, this paper constructs the following OLS regression model:

$$DTI_{i,t} = \alpha_0 + \alpha_1 EIS_{i,t} + \gamma Controls_{i,t} + \Sigma Ind + \Sigma Year + \varepsilon_{i,t} \quad (1)$$

where i and t index firms and years, respectively; DTI denotes corporate digital technology innovation; EIS denotes entrepreneurial innovation spirit; Controls denotes the control variables; Ind and Year denote industry and year effects; and ε is the error term.

Empirical analysis

Descriptive statistics

According to the descriptive statistics of the main variables in Table 2, the mean of corporate digital technology innovation (DTI) in the sample is 7.937, with a standard deviation of 5.629, indicating that the average firm obtains approximately 7.937 digital-technology-related patent grants per year and that the patent grants vary considerably across firms. The mean of entrepreneurial innovation spirit (EIS) is 14.060, indicating that 14.060% of the sentences in the chairmen's statements disclosed in the annual reports of listed companies involve innovation-keyword-related expressions. This statistic also reflects that roughly one in every seven sentences of the chairmen's statements concerns innovation-related content, showing that chairmen attach great importance to corporate innovation development—that is, the entrepreneurs headed by the chairman are highly innovation-minded.

Table 2 Descriptive statistics.

Variables	Obs.	Mean	Std. dev.	Min	Median	Max
DTI	688	7.937	5.629	0.000	7.601	19.210
EIS	688	14.060	9.991	0.000	12.000	36.360
Size	688	23.730	1.650	21.330	23.440	26.850
Lev	688	0.472	0.186	0.164	0.460	0.777
Roa	688	0.052	0.050	-0.050	0.045	0.165
Growth	688	0.138	0.223	-0.236	0.101	0.678
Cfo	688	0.067	0.055	-0.024	0.060	0.184
Loss	688	0.086	0.280	0.000	0.000	1.000
Top1	688	0.373	0.147	0.140	0.367	0.624
Idr	688	0.394	0.062	0.333	0.375	0.545
Dual	688	0.221	0.415	0.000	0.000	1.000
Soe	688	0.362	0.481	0.000	0.000	1.000

Baseline regression

Table 3 reports the regression results for the impact of entrepreneurial innovation spirit on corporate digital technology innovation. According to column (1) of Table 3, before adding the relevant control variables, the regression coefficient of entrepreneurial innovation spirit (EIS) on corporate digital technology innovation (DTI) is 0.082 and is significant at the 1% level. According to column (2), after adding the relevant control variables, the regression coefficient of EIS on DTI is 0.090 and is also significant at the 1% level. These empirical results indicate that entrepreneurial innovation spirit exerts a significant positive effect on corporate digital technology innovation, providing support for Hypothesis 1. This also shows that entrepreneurial innovation spirit has a good driving effect in the process of corporate digital technology

innovation: it can give full play to the "innovative" and "destructive" characteristics of entrepreneurial innovation spirit, form innovation leadership and promote the digital technology innovation development of listed companies, ultimately contributing to higher digital technology innovation levels.

Table 3 Baseline regression results.

Variables	(1) DTI	(2) DTI
EIS	0.082***	0.090***
	(3.90)	(4.80)
Size		1.756***
		(9.70)
Lev		-0.844
		(-0.55)
Roa		6.214
		(1.02)
Growth		1.371
		(1.48)
Cfo		-10.024**
		(-2.34)
Loss		-0.837
		(-1.03)
Top1		-6.132***
		(-4.16)
Idr		8.187***
		(2.67)
Dual		0.340
		(0.71)
Soe		0.119
		(0.23)
Constant	-487.648**	-644.130***
	(-2.49)	(-3.61)
Ind	Yes	Yes
Year	Yes	Yes
Observations	688	688
R^2	0.056	0.296

Note: T-statistics are reported in parentheses; ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively. The same applies to the tables below.

Robustness tests

Instrumental variable approach

This paper adopts the instrumental variable approach to mitigate potential endogeneity problems such as omitted variables in the empirical analysis. Because the innovation-keyword-related content in the chairmen's statements of other listed companies in the same province and the same industry is highly likely to induce learning and imitation by the chairman of the target company, yet does not directly affect the target company's digital technology innovation, this paper uses

the mean entrepreneurial innovation spirit (EIS) of other listed companies in the same province and the same industry as an exogenous instrumental variable (IV) and conducts two-stage least squares (2SLS) regressions. The two-stage regression results are reported in columns (1) and (2) of Table 4. The results show that the first-stage F statistic exceeds the critical value of 10, indicating that the selected instrumental variable is not subject to the weak-instrument problem. Moreover, the second-stage regression still shows a significant positive correlation between entrepreneurial innovation spirit (EIS) and corporate digital technology innovation (DTI), which alleviates concerns about endogeneity due to omitted variables and is consistent with the baseline regression results.

Propensity score matching

This paper adopts the propensity score matching (PSM) method to mitigate potential sample self-selection endogeneity. Specifically, this paper first divides the sample into high and low groups according to the industry-year median of entrepreneurial innovation spirit (EIS). Second, all control variables from the preceding analysis are used as covariates for 1:3 nearest-neighbor matching, and the newly screened sample is obtained. Finally, the baseline regression is re-estimated on the new sample, and the results are reported in column (3) of Table 4. The PSM test results are consistent with the preceding baseline regression results, indicating that the baseline regression results are robust.

Fixed effects model

Although this paper mainly adopts OLS regressions given the modest sample size, the empirical results may be affected by heterogeneity across firms and time. Therefore, this paper conducts a robustness test using a fixed effects model; that is, after controlling for firm, industry and year fixed effects, the baseline regression is re-estimated, and the results are reported in column (4) of Table 4. The results again indicate that the preceding baseline regression results are robust.

Alternative dependent variable

Although measuring the dependent variable by the number of granted digital technology patents, as in the preceding analysis, is a commonly used approach, to eliminate potential measurement bias this paper replaces the dependent variable with the natural logarithm of one plus the number of digital technology patent applications (DTI1) and re-estimates the baseline regression model. The results are reported in column (5) of Table 4, and again indicate that the baseline regression results are robust.

Shortened sample period

Since R&D expenses have been reported as a separate line item since 2018, listed companies may have strengthened the disclosure of, and attention to, R&D expense information, which may in turn affect the innovative expressions in chairmen's statements. Therefore, this paper shortens the sample period to 2018–2023 and re-estimates the baseline regression model. The results are reported in column (6) of Table 4, and again indicate that the baseline regression results are robust.

Table 4 Robustness test results.

Variables	(1) First stage	(2) Second stage	(3) PSM	(4) Fixed effects	(5) Alternative DV	(6) Shortened period
IV	0.571***					
	(9.34)					
EIS		0.301***	0.084**	0.028*	0.084***	0.087***
		(5.03)	(4.25)	(1.86)	(4.15)	(4.36)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	659	659	626	688	688	596
First-stage F	87.150					
R^2		0.159	0.305	0.180	0.300	0.288

Mechanism tests

As described in the derivation of the hypotheses, entrepreneurial innovation spirit mainly promotes corporate digital technology innovation by increasing listed companies' digital asset allocation, digital human resource allocation and external R&D knowledge allocation. Therefore, on the basis of defining the mechanism variables, and following Jiang (2022), this paper tests the impact of entrepreneurial innovation spirit on each mechanism variable, with the results reported in columns (1), (2) and (3) of Table 5. Among them, digital asset allocation (DA) and digital human resource allocation (DHR) are continuous variables, so OLS regressions are used to test the impact of entrepreneurial innovation spirit on them; external R&D knowledge allocation (RDK) is a dummy variable, so a Logit regression is used.

Digital asset allocation

In the regression test of the impact of entrepreneurial innovation spirit on digital asset allocation, the results in column (1) of Table 5 show that the regression coefficient of entrepreneurial innovation spirit (EIS) on digital asset allocation (DA) is 0.002 and is significant at the 10% level, indicating a significant positive relationship between entrepreneurial innovation spirit and the proportion of corporate digital assets allocated. These regression results suggest that the stronger the innovation spirit of the entrepreneurs headed by the chairman, the higher the degree to which listed companies allocate digital-related assets. As digital asset allocation increases, the necessary asset preconditions for digital technology innovation are more likely to be met, which is conducive to raising the digital technology innovation level of listed companies. Hypothesis 2 is thus verified.

Digital human resource allocation

In the regression test of the impact of entrepreneurial innovation spirit on digital human resource allocation, the results in column (2) of Table 5 show that the regression coefficient of EIS on digital human resource allocation (DHR) is 0.011 and is significant at the 1% level, indicating a significant positive relationship between entrepreneurial innovation spirit and corporate digital

human resource allocation. These regression results suggest that the stronger the innovation spirit of the entrepreneurs headed by the chairman, the more listed companies emphasize the allocation efficiency of digital technology-related talents and increase the proportion of such talents in the management team. As digital human resource allocation improves, the professional knowledge needed in the process of digital technology innovation is more likely to be satisfied, thereby promoting the digital technology innovation development of listed companies and ultimately contributing to digital technology innovation output. Hypothesis 3 is thus verified.

External R&D knowledge allocation

In the regression test of the impact of entrepreneurial innovation spirit on corporate external R&D knowledge allocation, the results in column (3) of Table 5 show that the regression coefficient of EIS on external R&D knowledge allocation (RDK) is 0.032 and is significant at the 1% level, indicating a significant positive relationship between entrepreneurial innovation spirit and corporate external R&D knowledge allocation. These regression results suggest that the stronger the innovation spirit of the entrepreneurs headed by the chairman, the more listed companies draw on external R&D alliances to acquire knowledge related to digital technology innovation, easing the knowledge bottleneck in the innovation process, potentially raising the success rate of digital technology R&D, and thus significantly improving the digital technology innovation level of listed companies. Hypothesis 4 is thus verified.

Table 5 Mechanism test results.

Variables	(1) DA	(2) DHR	(3) RDK
EIS	0.002*	0.011***	0.032***
	(1.73)	(2.74)	(2.89)
Controls	Yes	Yes	Yes
Ind	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	688	688	688
R^2 / pseudo R^2	0.225	0.041	0.309

Heterogeneity analysis

Heterogeneity in corporate governance quality

First, heterogeneity in agency costs. Information asymmetry exists between shareholders and the management team, giving rise to the Type I principal–agent conflict between them. Agency costs are an important manifestation of this conflict: the larger the agency costs, the more severe the principal–agent conflict between shareholders and the management team, and the greater the information asymmetry between the two (Zhao et al., 2025). Such information asymmetry exerts an important influence on the governance efficiency of the chairman and of the entire management team. When agency costs are small, the degree of information asymmetry between shareholders and the management team is low, and the behavior and decisions of the management team are easier for shareholders to monitor and support. In particular, when

entrepreneurs headed by the chairman possess an innovation spirit, it can be readily internalized into corporate digital technology innovation strategies, promoting the digital technology innovation development of listed companies. Conversely, when agency costs are high, information asymmetry between shareholders and the management team is relatively severe, and the behavior and decisions of the management team are difficult for shareholders to monitor and support. Even if the entrepreneurs headed by the chairman possess an innovation spirit, such spirit may remain superficial and fail to permeate corporate digital technology innovation strategies, so that entrepreneurial innovation spirit can hardly drive corporate digital technology innovation. Accordingly, this paper argues that, compared with firms with higher agency costs, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with lower agency costs.

To test the above analysis and reasoning regarding agency cost heterogeneity, this paper follows Wei et al. (2023) and uses the administrative expense ratio (the ratio of administrative expenses to main business revenue) to measure the agency costs of listed companies, divides the sample into high-agency-cost and low-agency-cost groups according to industry-year medians, and re-estimates the baseline regression model on each group. The results are reported in columns (1) and (2) of Table 6. The results show that the impact of entrepreneurial innovation spirit on corporate digital technology innovation is significantly positive at the 5% level in the high-agency-cost group, and significantly positive at the 1% level in the low-agency-cost group. These empirical results verify that the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with lower agency costs than in those with higher agency costs. This also shows that the shareholder–management information asymmetry highlighted by agency costs exerts an important influence on the conversion efficiency of entrepreneurial innovation spirit: only lower agency costs make it more likely that entrepreneurial innovation spirit will be internalized into corporate digital technology innovation strategies and promote the digital technology innovation development of listed companies.

Second, heterogeneity in internal control deficiencies. Digital technology innovation investment by listed companies is a high-risk project that requires effective internal control governance efficiency for support, with efficient internal control mechanisms reducing the non-financial risks of digital technology innovation (Zheng et al., 2024). In other words, even if a listed company has sufficient funds to support its digital technology innovation activities, effective internal control governance efficiency is needed to ensure that the funds are invested in genuine innovation activities and to improve innovation efficiency. Likewise, in the process whereby entrepreneurial innovation spirit drives the digital technology innovation development of listed companies, effective internal control is also required as a safeguard. Specifically, when the internal control of a listed company is highly effective—that is, when there are no internal control deficiencies—entrepreneurial innovation spirit can be internalized into genuine digital technology innovation strategies and promote the digital technology innovation development of listed companies. Conversely, when internal control is less effective—that is, when internal control deficiencies exist—even if entrepreneurs possess abundant innovation spirit, such spirit

may amount to no more than innovation-tonality manipulation in conforming behavior and can hardly be internalized into corporate digital technology innovation strategies, failing to significantly improve the digital technology innovation level of listed companies. Accordingly, this paper argues that, compared with firms with internal control deficiencies, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms without internal control deficiencies.

To test the above analysis and reasoning regarding internal control deficiency heterogeneity, this paper assigns the internal control deficiency dummy (ICD) a value of 1 if a listed company's internal control evaluation report discloses material, significant or general deficiencies, and 0 otherwise. The sample is then divided into firms with and without internal control deficiencies, and the baseline regression model is re-estimated for each group. The results are reported in columns (3) and (4) of Table 6. The results in column (3) show that, in the firm sample with internal control deficiencies, the impact of entrepreneurial innovation spirit on corporate digital technology innovation is significantly positive only at the 5% level; whereas the results in column (4) show that, in the firm sample without internal control deficiencies, the impact is significantly positive at the 1% level. In summary, compared with firms with internal control deficiencies, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms without such deficiencies. This suggests that effective internal control can improve the governance efficiency of entrepreneurial innovation spirit and promote the digital technology innovation development of listed companies.

Table 6 Heterogeneity test results for corporate governance.

Variables	(1) High agency costs	(2) Low agency costs	(3) IC deficiencies	(4) No IC deficiencies
EIS	0.062**	0.129***	0.082**	0.090***
	(2.51)	(4.46)	(2.30)	(4.24)
Controls	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	371	317	253	435
R^2	0.312	0.310	0.470	0.224

Heterogeneity in chairman compensation and equity incentives

Executive incentives are a means by which listed companies mitigate the principal–agent conflict between shareholders and the management team. Through such incentives, shareholders hope to improve information transparency between the management team and shareholders, align the interests of the management team with those of shareholders, and improve the governance efficiency of the management team. Likewise, as the leader of the management team, the chairman's incentive intensity also exerts an important influence on his or her governance efficiency. When entrepreneurs headed by the chairman receive strong incentives, information transparency between shareholders and the management team improves, and the innovation spirit possessed by the entrepreneurs is more likely to win the support of shareholders (Gao et al.,

2022). Moreover, the entrepreneurs headed by the chairman are more likely, for the sake of common interests, to internalize their innovation spirit into corporate digital technology innovation, forming effective innovation leadership and promoting the digital technology innovation development of listed companies. Conversely, when the management team headed by the chairman receives weak incentives, psychological imbalance may arise, and self-interested behaviors such as perk consumption may be adopted to restore psychological balance, thereby reducing corporate governance efficiency and ultimately resulting in a poor promoting effect of entrepreneurial innovation spirit on digital technology innovation. Accordingly, this paper argues that, compared with firms with weaker chairman incentives, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with stronger chairman incentives. To test the above analysis and reasoning regarding chairman incentives, and considering that chairman incentives comprise compensation incentives and equity incentives, this paper conducts heterogeneity analyses along these two dimensions separately.

First, in the heterogeneity analysis of chairman compensation incentives, this paper divides the sample into high and low chairman compensation incentive groups according to the industry-year median of the total compensation received by the chairman, and estimates the baseline regression model separately for each group. The results are reported in columns (1) and (2) of Table 7. The results in column (1) show that, in the firm sample with high chairman compensation incentives, the impact of entrepreneurial innovation spirit on corporate digital technology innovation is significantly positive at the 1% level; whereas the results in column (2) show that, in the firm sample with low chairman compensation incentives, the impact is significantly positive only at the 5% level. These empirical results also indicate that, compared with firms with low chairman compensation incentives, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with high chairman compensation incentives.

Second, in the heterogeneity analysis of chairman equity incentives, this paper divides the sample into high and low chairman equity incentive groups according to the industry-year median of the chairman's shareholdings, and estimates the baseline regression model separately for each group. The results are reported in columns (3) and (4) of Table 7. The results in column (3) show that, in the firm sample with high chairman equity incentives, the impact of entrepreneurial innovation spirit on corporate digital technology innovation is significantly positive at the 1% level; whereas the results in column (4) show that, in the firm sample with low chairman equity incentives, the impact fails the significance test. These empirical results also indicate that, compared with firms with low chairman equity incentives, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with high chairman equity incentives.

In summary, this paper examines the influence of chairman incentive heterogeneity on the relationship between entrepreneurial innovation spirit and corporate digital technology

innovation along the two dimensions of chairman compensation incentives and equity incentives. The combined results show that, compared with firms with weaker chairman incentives, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with stronger chairman incentives, and the heterogeneity effect formed by equity incentives is particularly prominent. This indicates that strengthening chairman incentives can promote the internalization of entrepreneurial innovation spirit into corporate digital technology innovation strategies and promote the digital technology innovation development of listed companies, and that the effect brought by equity incentives is more pronounced.

Table 7 Heterogeneity test results for chairman compensation and equity incentives.

Variables	(1) High compensation incentive	(2) Low compensation incentive	(3) High equity incentive	(4) Low equity incentive
EIS	0.102***	0.074**	0.084***	0.046
	(4.16)	(2.52)	(3.59)	(1.47)
Controls	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	395	293	435	253
R^2	0.329	0.318	0.255	0.448

Heterogeneity in chairman personal characteristics

First, heterogeneity in chairman age. Chairman age is an important factor affecting the chairman's governance efficiency (Lei and Qiao, 2015) and may also affect the governance effect of the entrepreneurial innovation spirit of entrepreneurs headed by the chairman. Compared with younger chairmen, older chairmen have relatively limited time and energy, which may hinder the internalization of entrepreneurial innovation spirit into corporate digital technology innovation strategies. Moreover, owing to age-related accumulation, a risk-taking innovation spirit is difficult to form, so older chairmen tend to display less innovation spirit, or their innovation spirit can hardly promote corporate digital innovation. By contrast, younger chairmen are relatively active in thinking and more likely to possess a risk-taking innovation spirit; they also have more time and energy to internalize their innovation spirit into corporate digital technology innovation strategies and promote the digital technology innovation development of listed companies. Accordingly, this paper argues that, compared with firms with older chairmen, the impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with younger chairmen.

To test the influence of chairman age heterogeneity on the relationship between entrepreneurial innovation spirit and corporate digital technology innovation, this paper first divides the sample into older-chairman and younger-chairman groups according to whether the chairman's age exceeds the statutory retirement age (60 for men and 55 for women). This grouping is appropriate because the average age of chairmen in this paper's sample is 55.40 years, close to

the statutory retirement age. The grouped samples are then used to re-estimate the baseline regression model, with the results reported in columns (1) and (2) of Table 8. The results in column (1) show that, in the firm sample with older chairmen, the impact of entrepreneurial innovation spirit on corporate digital technology innovation fails the significance test; whereas the results in column (2) show that, in the firm sample with younger chairmen, the impact is significantly positive at the 1% level. These empirical results also indicate that, compared with firms with older chairmen, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with younger chairmen. These results also demonstrate that age is indeed a key factor affecting the corporate governance efficiency of the entrepreneurial innovation spirit of entrepreneurs headed by the chairman: a younger age can enhance the internalization effect of entrepreneurial innovation spirit and better promote the improvement of the digital technology innovation level of listed companies.

Second, heterogeneity in chairman educational attainment. Educational attainment is an important indicator of the chairman's knowledge reserves and may exert an important influence on the governance efficiency of entrepreneurial innovation (Ding and Deng, 2018). Compared with chairmen with lower educational attainment, chairmen with higher educational attainment possess a more complete knowledge system and broader knowledge reserves. In the process of corporate digital technology innovation, extensive knowledge is even more needed as support; likewise, the internalization of entrepreneurial innovation spirit into corporate digital technology innovation strategies also requires higher knowledge to strengthen the conversion efficiency of entrepreneurial innovation spirit. Accordingly, this paper argues that, compared with firms with chairmen of lower educational attainment, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with chairmen of higher educational attainment.

To test the influence of chairman education heterogeneity on the relationship between entrepreneurial innovation spirit and corporate digital technology innovation, this paper first divides the sample into higher-education and lower-education chairman groups according to the chairman's educational attainment, using a bachelor's degree or above as the criterion: chairmen with a bachelor's degree or above are regarded as having relatively higher educational attainment, and otherwise as having relatively lower educational attainment. After distinguishing the samples, the grouped samples are used to re-estimate the baseline regression model, with the results reported in columns (3) and (4) of Table 8. The results in column (3) show that, in the firm sample with chairmen of higher educational attainment, the impact of entrepreneurial innovation spirit on corporate digital technology innovation is significantly positive at the 1% level; whereas the results in column (4) show that, in the firm sample with chairmen of lower educational attainment, the impact fails the significance test. These empirical results also indicate that, compared with firms with chairmen of lower educational attainment, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with chairmen of higher educational attainment. These results also demonstrate that educational attainment is indeed a key factor affecting the corporate governance efficiency of the

entrepreneurial innovation spirit of entrepreneurs headed by the chairman: higher educational attainment can enhance the internalization effect of entrepreneurial innovation spirit and better promote the improvement of the digital technology innovation level of listed companies.

Table 8 Heterogeneity test results for chairman personal characteristics.

Variables	(1) Older chairman	(2) Younger chairman	(3) Higher education	(4) Lower education
EIS	0.054	0.099***	0.081***	0.073
	(1.00)	(4.96)	(4.10)	(1.44)
Controls	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	109	579	543	145
R^2	0.261	0.338	0.348	0.248

Main research conclusions and managerial implications

Research conclusions

Entrepreneurial innovation spirit is an important driving force for corporate innovation development and high-quality development, and fostering entrepreneurial innovation spirit is the theme of innovation-driven development in the new era. Using sample data on A-share listed companies that disclosed chairmen's statements from 2016 to 2023, this paper tests the impact of entrepreneurial innovation spirit on corporate digital technology innovation. The main research conclusions are as follows:

First, entrepreneurial innovation spirit significantly promotes the improvement of the digital technology innovation level of listed companies. Entrepreneurial innovation spirit is the internal driving force of corporate digital technology innovation, and fostering it can infuse listed companies' digital technology innovation strategies with innovation elements and promote their digital technology innovation development. In existing research, entrepreneurial innovation spirit has only been proxied by firm-level R&D investment, which can hardly depict the ideological cultivation of the entrepreneur as the subject of innovation spirit. Therefore, this paper not only enriches the quantitative measurement of entrepreneurial innovation spirit but also broadens the literature on the determinants of corporate digital technology innovation, while providing suggestions for how firms can foster entrepreneurial innovation spirit and improve their digital innovation level.

Second, entrepreneurial innovation spirit mainly promotes the improvement of corporate digital technology innovation by increasing listed companies' digital asset allocation, digital human resource allocation and external R&D knowledge allocation. This shows that entrepreneurial innovation spirit not only generates spiritual value within the management team, but also effectively influences the allocation of digital assets, digital human resources and external R&D knowledge, optimizing corporate digital technology innovation strategies, improving digital

technology innovation efficiency, and ultimately promoting the improvement of the digital technology innovation level of listed companies. This conclusion sheds light on the mechanism through which entrepreneurial innovation spirit affects corporate digital technology innovation and provides a basis for future research on the influence mechanisms of corporate digital technology innovation.

Third, the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation is more significant in firms with lower agency costs, no internal control deficiencies, higher chairman compensation incentives, higher chairman equity incentives, younger chairmen and chairmen with higher educational attainment. This shows that lower agency costs and higher internal control quality can enhance the internalization effect of entrepreneurial innovation spirit in corporate digital innovation strategies and promote the digital technology innovation development of listed companies; stronger chairman compensation incentives and equity incentives can also, by reducing the information asymmetry between shareholders and the management team, align the interests of shareholders and the chairman, improve the chairman's governance efficiency, strengthen the driving effect of entrepreneurial innovation spirit in corporate digital technology innovation, and thus significantly improve the corporate digital technology innovation level; younger chairmen with higher educational attainment can enhance the activeness of their thinking and optimize their innovation knowledge systems, reinforcing the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation. This conclusion expands the application scenarios of the positive impact of entrepreneurial innovation spirit on corporate digital technology innovation, provides practical measures for improving the digital technology innovation level of listed companies, and offers reasonable policy suggestions for how government departments can guide listed companies to accelerate their digital technology innovation development.

Managerial implications

Based on the above research conclusions, this paper offers the following policy implications. (1) Entrepreneurial innovation spirit is indeed the internal driving force promoting the digital technology innovation development of listed companies. At the macro level, the government can therefore intensify the promotion of entrepreneurial innovation spirit, guide firms to form a strong atmosphere and development pattern of digital technology innovation, and continuously improve the degree of integration between the digital economy and the real economy, so as to build more world-class enterprises. (2) Business organizations should also foster entrepreneurial innovation spirit internally and strengthen the leading role of entrepreneurial innovation. In particular, in their daily production, operation and innovation activities, listed companies should intensify the promotion of entrepreneurial innovation spirit among the management team, so that it influences the entire R&D team and employees, exposes all staff to innovative thinking, achieves company-wide participation in innovation, continuously strengthens the innovation cohesion of the management team and employees, and accelerates the digital technology innovation development of listed companies. (3) Lower agency costs and higher internal control

quality can both strengthen the driving effect of entrepreneurial innovation spirit on corporate digital technology innovation. Listed companies should therefore reduce agency costs, improve information transparency, and safeguard a more efficient principal–agent relationship between shareholders and the management team, so that the firms' innovation spirit wins the support and recognition of shareholders and the digital technology innovation development of listed companies is continuously promoted. At the same time, companies should strengthen internal control construction to ensure that entrepreneurial innovation spirit is well internalized in the process of corporate governance, thereby promoting the improvement of corporate digital technology innovation. (4) Companies should optimize their incentive measures and strengthen the cultivation of young, high-caliber corporate executives. Young, high-caliber executives are the core force driving the development of corporate digital technology innovation. Listed companies should therefore strengthen the selection and cultivation of young corporate executives with high degrees and high quality, seize the initiative in digital technology innovation through high-quality human resource advantages, and realize a virtuous cycle between top-notch talent and high-quality corporate development.

Limitations

Several limitations should be acknowledged. First, the measure of entrepreneurial innovation spirit is derived from the language used in chairmen's statements, which may partly reflect rhetorical strategies or impression management rather than the chairman's genuine innovative beliefs; future research could validate this text-based measure against survey or interview data. Second, digital technology innovation is proxied by the number of digital technology patents, which captures quantity but may not fully reflect innovation quality or economic value. Third, the mechanisms examined here focus on resource allocation and on governance and incentive conditions; other possible channels, such as digital organisational capabilities and external institutional pressures, await further investigation.

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Data availability

The dataset generated and analysed during the current study is available in the Supplementary Information files accompanying this article. This dataset contains the cleaned firm-year observations used in the empirical analysis, including the text-based measure of entrepreneurial innovation spirit and the firm-level measures of digital technology innovation. The underlying firm-level data were obtained from the CSMAR database and the digital technology innovation data from the CNRDS database. These source materials are subject to third-party licensing agreements that prohibit redistribution of the raw data; the processed dataset required to reproduce the reported results is therefore provided in the Supplementary Information files. The dataset is provided so that editors and referees can verify and fully scrutinise the methods and findings reported in this article.

Code availability

All code used in the empirical analysis is available in the Supplementary Information files accompanying this article. This includes the code and scripts for data cleaning, the text-based measurement of entrepreneurial innovation spirit, variable construction, and all reported estimations, including the baseline regressions, endogeneity tests, robustness checks and heterogeneity analyses.

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Author contributions

The author: conceptualization, methodology, formal analysis, data curation, writing – original draft, writing – review and editing. The author has read and approved the final manuscript.

Ethics declarations

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Competing interests

The author declares no competing interests.

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