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# Research on the impact of hard technology innovation on the high-quality development of SRDI enterprises: based on the moderating role of digital transformation

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**Abstract**

**Purpose** – This paper aims to investigate the relationship linking hard technology innovation with the high-quality development (HDP) of SRDI firms. SRDI firms are typically classified as medium-sized to moderately scaled businesses renowned for their specialized, refinement, differentiation and innovation (SRDI), with a focus on providing exceptional products or services to gain a competitive advantage in specific market segments. These firms are dedicated to expanding market share and enhancing innovation capacities both locally and globally. The research also aims to scrutinize the contextual effects of digital transformation within this framework.

**Design/methodology/approach** – Hard technology innovation consists of three essential components: innovative characteristics, newly developed technology-based intellectual property rights and the volume of R&D initiatives. The evaluation of HDP was performed utilizing the entropy method, with a specific emphasis on assessing value creation and value management capabilities. Subsequently, this study explores the impact of technological innovation on the HDP of firms using a dual-dimension fixed effects model.

**Findings** – Every aspect of hard technology innovation is essential for promoting the HDP of businesses. The digital transformation of businesses exerts a heterogeneous moderating influence in this process. This is evident in the constructive impact on the connection between innovation attributes and the volume of fruitful R&D initiatives, as well as the HDP of firms. Conversely, the moderating effect is deemed insignificant in the association between new technology-based intellectual property and HDP.

**Originality/value** – This research delves deeper into the underlying mechanisms that underlie the promotion of HDP through hard technology innovation, thereby expanding the scope of our exploration on



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the HDP of SRDI firms. It establishes a theoretical framework and practical directives for achieving enhanced development quality amidst the evolving landscape of digital transformation within firms.

**Keywords** Hard technology innovation, High-quality development of enterprises, SRDI enterprises, Digital transformation

**Paper type** Research paper



## 1. Introduction

The transition from rapid economic growth to a focus on enhancing development quality exemplifies the contemporary era of socialism with unique Chinese characteristics, marking a crucial milestone in the economic progression. High-quality development (HDP) is set to serve as the primary strategic trajectory for economic advancements over an extended period, emphasizing notable enhancements in quality, efficiency and dynamism as the focal points of economic evolution, aligning with the principle of "leveraging strengths and addressing weaknesses." This approach to HDP operates across three distinct tiers: the macro-societal tier, meso-industrial tier and micro-enterprise tier, necessitating the establishment of a well-coordinated HDP operational framework overseen by the entire planning bureau (Huang *et al.*, 2018). Firms, serving as the micro-level agents within the macroeconomic landscape and foundational units in meso-industrial progress, assume a pivotal role in propelling the economy toward advanced development. Amidst pressure from the environmental ecosystem and the challenges of the intricate international economic landscape, China urgently requires to enhance the effectiveness of sustainable development and chart a path toward high-quality sustainable development (Wang and Tang, 2024). Particularly, SRDI firms, known for their dynamism as small and medium-sized entities, serve as exemplars and pioneers in this endeavor. SRDI firms actively engage in pivotal but underdeveloped industries and exert a significant impact in promoting the economy's superior advancement and the establishment of an innovation-driven nation.

Enhancing the superior development of SRDI firms has emerged as a focal point of interest for governmental and academic sectors. SMEs, characterized by greater flexibility and growth potential compared to larger corporations, encounter challenges such as funding constraints (Wang *et al.*, 2017), inadequate digital integration (Yoo *et al.*, 2010) and skills mismatches (Liang and Lin, 2015) and other problems. To distinguish themselves, SMEs must pursue differentiation through hard technology product innovation, with core technology breakthroughs and industrial transformation forming the cornerstone of their sustainability (Wu and Shi, 2019). SRDI firms aspire to drive hard technology advancements by amassing technical expertise, progressively mastering cutting-edge technologies, and establishing technical barriers, positioning themselves as pivotal forces in hard technology innovation through a specialized and innovative development trajectory. This approach not only augments independent innovation capabilities and attains self-reliance in core technologies but also addresses deficiencies within the supply chain, thereby bolstering industry competitiveness overall (Yang, 2019).

The current body of literature addressing hard technology innovation has received limited attention, with a predominant emphasis on theoretical analyses concerning policy and economic dimensions. These analyses primarily revolve around the collective state and individual case studies exploring factors influencing hard technology innovation. However, discussions regarding the impact engendered by hard technology innovation primarily center on theoretical perspectives. For instance, scholars like Guan Qingyou and Zhang Aoping have underscored the significance of hard technology innovation in the HDP of firms through their theoretical investigations. While some literature has explored the implications of hard technology innovation on the multi-level progress of SRDI firms (Zhou and Li, 2023), there is still a need to determine the impact of advanced technological innovation on fostering advanced corporate development. Moreover, current research indicates that digital transformation has emerged as a new trajectory for companies striving for high-quality advancements. Zhang *et al.* (2021) delve into the principles, precursors and outcomes of digital transformation, utilizing theoretical frameworks to illustrate the beneficial effects of digital transformation on innovation potential in the physical economy. Despite the recognized substantial influence of digital technology on superior development, clarity is lacking on the distinctive mechanisms whereby hard technology innovation influences enterprise HDP amid digitalization. Consequently, this study incorporates digital transformation as a contextual factor to address this gap.

This paper employs manual data collection to compile a roster of A-share listed companies categorized as SRDI giants, as released by the Ministry of Industry and Information Technology. Utilizing a sample comprising 633 SRDI firms listed on China's A-share market between 2012 and 2020, the study empirically examines the mechanisms underlying the impact of hard technology innovation on firm HDP, while also investigating the moderating influence of digital transformation levels. Against the backdrop of ascending SRDI firms, this research furnishes empirical insights into the pathway to hard technology innovation for SRDI firms seeking enhanced quality development, offering valuable guidance for the prosperous advancement of such firms.

The paper is structured in the following manner: Chapter 2 offers a thorough examination of existing literature, Chapter 3 outlines the proposed hypotheses, Chapter 4 details the empirical data and the approach to analysis, Chapter 5 discusses the findings from the empirical study and Chapter 6 concludes with a recap of the research and suggestions for subsequent scholarly pursuits.

## 2. Literature review

In the realm of economic and social progress, science and technology stand as pivotal drivers of advancement. Evaluating the forefront of scientific and technological breakthroughs necessitates an examination of the laws governing their emergence and evolution. The diffusion of an innovative idea involves a transition from its inception at the frontier to its integration into everyday use, progressing from a niche concept to widespread adoption. Some scholars propose a hierarchy known as the science and technology pyramid, where advancements are classified in a descending order from science fiction, black technology, hard technology, high-tech, and ultimately technology. The term "high-tech" denotes a level of technology that surpasses conventional norms, while hard technology represents advancements that exceed even high-tech standards, such as artificial intelligence. Research on hard technology innovation is nascent, with many scholars remaining in the initial stages; nonetheless, some researchers have demonstrated that metrics such as the allocation of resources for R&D, the participation of individuals in R&D activities, technology-based intangible assets, and technology-based patents positively influence enterprise development. For instance, Wakelin (2001) and Vancauteren (2018) revealed an affirmative correlation between R&D investment and patent output, indicating that increased investment leads to enhanced patent generation and innovation capabilities. Cheng *et al.* (2016) discovered that highly educated professionals in innovative firms, representing high-level talents, exhibit elevated productivity and enhanced innovation prowess due to their vast knowledge base, efficient work ethic and substantial human capital accumulation, thereby driving improved innovation performance. Hence, for innovative firms, prioritizing R&D investments and attracting as well as nurturing highly educated professionals unquestionably constitute pivotal strategies for bolstering innovation capabilities and gaining a competitive edge. In addition, Baldwin *et al.* (2012) utilized hierarchical analysis to categorize the value drivers of intangible corporate assets and gauge enterprise performance through a set of indicators, demonstrating the fundamental role of intangible assets in heightening added value and market performance, ultimately enhancing overall competitiveness. Hunter *et al.* (2012) emphasized the crucial link between intangible assets and innovation capacities, underscoring their significance in bolstering core competitiveness. Andonova and Ruiz-Pava (2016) delved into the profitability of intangible assets in the District of Columbia, highlighting their substantial contribution to corporate performance enhancement, emphasizing the pivotal role of intangible assets in elevating enterprise value creation. In conclusion, intangible assets play a significant role in enhancing the value-added, market performance and overall competitiveness of firms. It is crucial for firms to comprehend fully the significance of intangible assets and leverage them effectively through efficient management and utilization to secure a competitive edge in the fiercely competitive market. Analysis of scholars' research indicates that while direct academic studies on the link between hard technology innovation and high-quality enterprise development are limited, it is evident that scholars have dedicated considerable attention and research efforts to a range of indicators closely associated with hard technology innovation. These indicators include technological innovation investments, R&D efficiency, and the commercialization of technological advancements. They also explore the mechanisms and pathways through which these factors influence the quality of enterprise development.

Upon reviewing the prevailing literature, beginning with (Romer, 1990), who introduced a pioneering theory of economic growth emphasizing the pivotal roles of science, technology, and innovation as catalysts for economic advancement, there has been a considerable amount of scholarly work has concentrated on the HDP of firms from both internal and external perspectives. Internal influences pertain to the intrinsic elements and operational mechanisms within an organization. For example, (Martin, 2010) an empirical study was conducted to explore the link between technological innovation and economic growth, highlighting its substantial impact on economic progress and its capacity for expansion. Xie *et al.* (2022) identified the vital impact of the digital economy in driving high-quality corporate development, serving as a crucial pathway for economic advancement. Their work underscored how digital transformation can enhance corporate development by elevating levels of Corporate Social Responsibility adherence. On the contrary, external influences center on the external environment within which businesses function, mainly emphasizing the policy and market landscape. External factors differ significantly from internal factors as they can offer various favorable signals and backing to an organization. External factors typically encompass a broader array of environments and contexts compared to internal factors. They not only present opportunities and incentives for organizational growth but also serve to alleviate the deficiencies of internal factors to some degree. For example, (Meuleman and Maeseneire, 2008; Kleer, 2010; Feldman and Kelley, 2006) emphasized that securing R&D subsidies acts as a form of endorsement for firms, facilitating access to external funding and providing financial backing to support HDP efforts. Additionally, government subsidies can mitigate the challenges faced by startups regarding innovation resources and capabilities, empowering them to endure and grow by bolstering their innovative capacities in the long term.

The existing literature has generated a strong theoretical foundation in understanding the connection between cutting-edge technological advancements and the enhanced growth trajectory of corporations. However, the specific impact that these advancements have on the high-quality evolution of businesses remains a topic of debate among scholars. This research endeavors to fill a void in existing scholarly work by presenting a novel analytical framework that seamlessly merges state-of-the-art technological progress with the quest for corporate eminence. The study's primary objective is to delve deeply into the positive effects of hard technology innovation on enterprise HDP through empirical research. Through meticulous data analysis, we aim to uncover the significant role of hard technology innovation in enhancing market competitiveness and other aspects, providing robust theoretical backing and practical guidance for firms striving for HDP.

## 3. Hypotheses development

Compared with soft science (Rachinger *et al.*, 2019) and technology innovation, hard technology innovation is directly implemented in the materials, equipment, and processes essential for material production, proving to be instrumental in advancing the productivity of material goods. Furthermore, hard technology serves as a pivotal tool in propelling China's economic progress, aiding in the reduction of the technological disparity between China and leading developed nations globally. This proactive approach alleviates core technology limitations imposed by external factors and fosters the establishment of essential competitiveness for firms, thereby facilitating the attainment of HDP.

Combining Zhou and Li (Zhou and Li, 2023), the assessment of hard technology innovation encompasses three integral dimensions. Firstly, based on the outcomes of extensive research on hard technology trends conducted by SEDI Consultants, China's hard technology sector maintains a steady Innovation Vitality Index rating of 100. However, navigating the high technological thresholds, substantial R&D investments, and the conversion of hard technology breakthroughs is a prolonged and consistent process demanding substantial and stable financial commitments. Against this backdrop, the establishment of the Science and Technology Innovation Board emerges as a crucial avenue for enlarging financing opportunities for innovative firms, instigating a robust financial stimulus for the progress of hard technology ventures and fortifying the groundwork for China's economic revitalization. The scientific and innovative attributes prove pivotal in capturing the interest of market investors toward firms listed on the Science and Innovation Board, with investors showing a particular preference for firms displaying high R&D investment intensity and sizable R&D workforce. Enterprises exhibiting strong science and innovation attributes tend to attract external investments more effectively, substantially boost their market value, and thus significantly propel their journey toward HDP. Secondly, within the realm of technology-based intangible assets, increased contributions of innovation to firm value underscore the rising significance of intangible assets as the bedrock of competitive advantage, surpassing less distinctive tangible assets. Intangible assets play a crucial role in upholding a firm's competitive edge owing to their non-imitative nature and their pivotal role in firm internalization. The intangible resources facilitating access to financial, informational and relational avenues not only foster the cultivation of dynamic capabilities but also play a pivotal role in enhancing export performance. Finally, concerning R&D projects, the proportion of capitalizable corporate R&D expenditures highlights the perceived value of a company within the market, underscoring the link between capitalized R&D outlays and overall firm value. Capitalized R&D spending sends out a clear signal to external stakeholders indicating the potential for enhanced economic returns in the future, enabling listed companies to garner higher valuations in the capital market, attract sustainable economic returns, and secure essential resources vital for HDP.

Amidst the rapid progress of digital technology, digital transformation has emerged as an imperative choice for enterprises and a pivotal driver for fostering breakthrough innovation and ensuring sustainable development. Thus, the adoption of digital transformation by enterprises could serve as a critical factor in catalyzing HDP through the lens of hard technology innovation. Primarily, from the perspective of science and innovation attributes, the substantial demands of hard technology innovation require significant resources, necessitating substantial investments in R&D to overcome high technological barriers and sustain prolonged transformation cycles. By embracing enterprise digital transformation, companies can address capital scarcity through enhanced access to the digital financial market, resolving capital shortage issues (Xu *et al.*, 2023) to attract additional investors and stimulate capital inflow. Hence, this study asserts that enterprise digitization can effectively mitigate fund shortages during the course of hard technology innovation, enabling enterprises to enhance their hard technology innovation outcomes and ultimately drive the HDP of enterprises. Secondly, from the perspective of technology-based intangible assets, enterprise hard technology innovation drives HDP through the enhancement of technology-based intellectual property rights. (Tang *et al.*, 2020) research reveals that the advancement of digital finance equips enterprises with premium technological tools, facilitating sound and efficient decisions in production and technological innovation. Digital transformation serves a crucial function in swiftly and effectively refining enterprise innovation outcomes by continuously evolving their innovation strategies, guiding them toward optimal innovation decisions, and potentially transforming the essence of the innovation process. This strategic approach enables enterprises to secure additional invention patents, enhance innovation efficiency, and bolster technology-based intellectual property rights, thereby further propelling the high-quality advancement of enterprises. Finally, contemplating the capitalization of R&D expenditures, R&D expenditure capitalization serves as a vital conduit for communicating a company's market worth externally. Existing research indicates that SRDI enterprises leverage iterative digital technology to invigorate their dynamic capabilities and enhance their market value through cutting-edge insights, adaptive reconfiguration, and innovative search practices (Zhang and Han, 2023). In culmination, enterprise digitization effectively moderates the link between hard technology innovation and HDP, thus leading to the proposal of the following hypotheses based on the articulated discussion:

*H1*. Hard technology innovation positively influences the HDP of SRDI enterprises

*H1a*. Science and innovation attributes positively contribute to the HDP of SRDI enterprises

*H1b*. New technology-based IPRs positively influences the HDP of SRDI enterprises

*H1c*. The quantity of successful R&D projects positively impacts the HDP of SRDI enterprises

*H2*. Enterprise digitization serves as a positive moderator in the relationship between hard technology innovation and the HDP of SRDI enterprises

*H2a*. Enterprise digitization acts as a positive moderator in the connection between science and innovation attributes and the HDP of SRDI enterprises

*H2b*. Enterprise digitization positively moderates the relationship between new technology-based intellectual property rights (IPRs) and the HDP of SRDI enterprises

*H2c*. Enterprise digitization serves as a positive moderator in the relationship between the quantity of successful R&D projects and the HDP of SRDI enterprises

The research model diagram of this paper is shown in Figure 1.

## 4. Data and method

### *4.1 Sample selection and data sources*

This research initially selects Small and Medium Enterprises (SMEs) categorized as SRDI within A-share listed companies as the sample, encompassing an observation period spanning from the year 2012 to 2022. The certification of SRDI enterprises is sourced from the Ministry of Industry and Information Technology's official website, while data on National Science and Technology Progress and other awards are retrieved from the National Science and Technology Award Office. Information regarding national major scientific and technological projects is gathered from official Ministry of Science and Technology platforms, the National Major Scientific and Technological Special Projects database, the Public Service Platform of the National Scientific and Technological Management Information System, and the listed companies themselves. The sample screening and processing follow the outlined methods:

- Eliminating samples of enterprises with ST, *ST and other abnormal trading status;
- Eliminating samples of enterprises with a large number of missing variable data; and
- Eliminating samples of enterprises with only one to two years of data, and finally obtaining 2335 pieces of unbalanced panel data from 633 listed enterprises.

Other financial data are mainly obtained from the Cathay Pacific database, in which the missing data are supplemented through listed companies' annual reports announcements and the Internet. Stata17.0 software was used to process and analyze the data.

### *4.2 Variable description and measurement*

Explained variable: HDP. Scholars in the field primarily employ measures such as total factor productivity or composite indices for evaluating systems (Xu *et al.*, 2023) to quantify the extent of HDP in enterprises. This paper integrates the High-Quality Development Performance (HDP) definition as outlined in the 19th CPC National Congress Report, incorporating relevant research to evaluate enterprises' HDP based on their value generation and management proficiency. The value generation proficiency of enterprises encompasses operational and innovative proficiency, while value management involves corporate governance, internal control, and sustainable development levels, with detailed indicators provided in Table 1. The entropy value method is employed to quantify the amalgamation of these indicators.

Explanatory variables: hard technology innovation. Drawing on Zhou and Li, (Zhou and Li, 2023) this scholarly study quantifies the concept of hard-tech innovation using three interconnected metrics: scientific and inventive attributes (referred to as HCT), the acquisition of intellectual property rights based on novel technologies (referred to as RDIPR), and successful R&D initiatives (referred to as RDDN). These metrics embody the essential

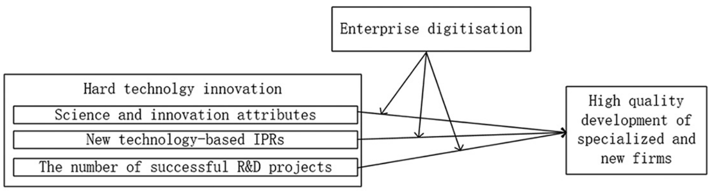


**Figure 1.**
Research framework

**Source:** Figure by authors

| First indicators | Secondary indicators | Variable | Explanation |
|---|---|---|---|
| Value creation proficiency | Enterprise business proficiency | Total assets | Natural logarithm of total assets of listed companies at the end of the period |
| | | Number of employees | Natural logarithm of total number of employees at the end of the period for listed companies |
| | | Return on net assets | Net profit/shareholders' equity balance |
| | | Net profit margin | Net profit/operating income |
| | | Profitability of main business | (Operating revenue - operating costs)/total profit |
| | | Current asset turnover | Operating income/closing balance of current assets |
| | | Total asset turnover | Operating income/total assets closing balance |
| | | Total asset growth rate | (Closing value of assets for the period - Closing value of assets for the same period last year)/closing value of assets for the same period last year |
| | | Net profit margin on total assets | Net profit/total assets balance |
| | | Net profit growth rate | (Amount of net profit for the current year - Amount of net profit for the same period of the previous year) / amount of net profit for the same period of the previous year |
| | Enterprise innovation proficiency | Net intangible assets | Original cost of each of the company's intangible assets, net of amortization and provision for impairment |
| | | Growth rate of intangible assets | Increase in intangible assets during the period/beginning of the period |
| | | R&D investment intensity | R&D investment as a percentage of operating revenue |
| Value management proficiency | Level of sustainable development | Sustainable growth rate | (Net profit/total closing balance of owners' equity) x [1 - dividend per share before tax/ (current value of net profit/closing value of paid-in capital for the period)]/(1 - numerator) |
| | Level of internal control | Internal control index | Adoption of the dibble internal control index |
| | Level of corporate governance | Proportion of independent directors | Number of independent directors/total number of board members |

**Source:** Table courtesy of Xu *et al.* (2023)

**Table 1.** Variable settings of high-quality enterprise development

characteristics of hard-tech innovation, such as significant R&D investment, sophisticated outcomes, valuable intellectual property, and a high success rate in R&D endeavors. HCT is a critical metric for assessing innovation levels in the high-tech sector, capturing a company's R&D investment, achievements in advanced R&D, and patented intellectual property. This metric is guided by the "Guidelines for Assessing High-Tech Attributes" (Provisional) set forth by the Securities and Futures Commission (SFC). HCT is defined as a binary indicator, with a value of 1 designated for SRDI enterprises listed on the STIB or meeting the criteria outlined in the "Provisional Guidelines for Assessing HCT Attributes; otherwise, it is assigned a value of 0. A company fulfills the requirements of the "Provisional Guidelines for Assessing HCT Attributes" if it meets any of the following conditions: R&D expenditure exceeding 60 million RMB in the past three years, an R&D staff ratio of at least 10%, possession of more than five revenue-generating invention patents (except for the software industry, which is exempt if the R&D investment ratio exceeds 10%), a compound annual revenue growth rate of 20% in the last three years, or revenue of 300 million RMB in the most recent fiscal year. Other conditions include the company or its researchers receiving prestigious national scientific and technological honors such as the State Scientific and Technological Progress Award, the State Natural Science Award, or the State Technological Invention Award, with the applied technology being essential to the core operations. Additionally, the company must have led or significantly contributed to key national science and technology projects relevant to its primary business and technological expertise. Finally, the company must possess a portfolio of over 50 invention patents, including defense patents crucial to its core business and technological income.

Considering that High-Tech Certification (HCT) does not encompass all forms of technology-based intellectual property such as proprietary knowledge, non-patented inventions, and formulas, and recognizing that R&D investment is not sufficient evidence of a company's advanced scientific and technological capabilities, the accomplishments of R&D efforts and their impact on maintaining the company's advanced technological standards and in developing high-value products are crucial indicators of significant scientific and technological capabilities. To address the limitations of HCT and better capture the essence of hard-tech companies, characterized by a predominance of intangible assets, substantial technological obstacles, and limited product reproducibility, the concept of RDIPR and the metric RDDN are introduced as supplemental benchmarks for evaluating hard technology. Adding RDDN as an extra measure of hard technology aims to rectify the gaps in HCT and offer a more comprehensive assessment of the unique characteristics of hard-tech companies (Yao *et al.*, 2020). RDIPR is quantified by calculating the natural logarithm of the total value of the company's new technology-based intellectual property rights, inclusive of patents, know-how, formulas, production technology, and in-house developed technologies, incremented by one. RDDN represents the natural logarithm of the count of R&D projects in the company's development phase, increased by one. The data utilized are sourced from the financial statement notes within the CSMAR database.

Moderator variable: digitization transformation (DT). Referring to Wu (Wu *et al.*, 2021), the word frequencies related to digitization are counted in Table 2 in five dimensions: artificial intelligence, big data, cloud computing, blockchain technology and digital transformation. Moreover, due to the positively skewed distribution of the data, the natural logarithm of the data is computed with a 1-unit addition.

Control variables: Considering that larger enterprises have stronger profitability and more resources and capital to engage in production and operations, they are better positioned to promote high-quality. Drawing on existing literature (Wu and Tang, 2016; Xin, 2003), this paper selects the enterprise's size (SIZE), listing timeframe (LA), profitability (ROE), shareholding concentration (TOP1), and whether it is state-owned (SOE) as the control variables. The variables are defined and measured as follows: the listing timeframe is calculated as the natural logarithm of the duration of the enterprise's listing; the enterprise size is represented by the natural logarithm of the total assets; profitability (ROE) is computed as the net profit divided by the average balance of shareholders' equity; and shareholding concentration (TOP1) is determined by the ratio of shares owned by the largest shareholder to the total shareholders' holdings.

### *4.3 Descriptive statistical results*

Polished Paragraph: Table 3 displays the descriptive statistics: the HDP ranges from 0.182 to 0.456, with a mean value of 0.25, reflecting significant variation in HDP levels among Systematically Relevant Digital Institutions (SRDI) small-giant enterprises, emphasizing the

| Variable | Explanation |
|---|---|
| AI technology | Artificial intelligence, business intelligence, image understanding, investment decision support tools, intelligent data analysis, intelligent robotics, machine learning, deep learning, semantic search, biometric recognition, facial recognition, speech recognition, authentication, autonomous driving, and natural language processing |
| Big data | Big data, data mining, text mining, data visualization, heterogeneous data, credit, augmented reality, mixed reality, virtual reality |
| Cloud computing | Cloud computing, streaming computing, graph computing, in-Memory Computing, Multi-Secure Computing, Brain-like Computing, Green Computing, Cognitive Computing, Converged Architecture, Billions of Concurrency, EB Storage, Internet of Things, Information-Physical System |
| Block chain technology | Blockchain, digital currencies, distributed computing, differential privacy techniques, smart financial contracts |
| Digital technology applications | Mobile Internet, Industrial Internet, Internet Healthcare, E-commerce, Mobile Payment, Third-Party Payment, NFC Payment, Smart Energy, B2B, B2C, C2B, C2C, O2O, Streaming Services such as Netflix, Smart Wearable Technology, Smart Agriculture, Intelligent Transportation Systems, Telemedicine, Smart Customer Service, Home Automation Solutions, Intelligent Investment Strategies, Smart Cultural and Tourism Applications, Eco-friendly Intelligent Initiatives, Advancements in Smart Grid Technology, Marketing Technologies, Digital Marketing Practices, Unmanned Retail Concepts, Internet Finance, Digital Banking Systems, Fintech Innovations, Quantitative Finance Models, and Open Banking Platforms |

**Source:** Table courtesy of Wu *et al.* (2021)

**Table 2.** Structured characteristic words for enterprise digital transformation

| | HDP | HCT | RDIPR | RDDN | DT | SIZE | LA | ROE | TOP1 | SOE |
|---|---|---|---|---|---|---|---|---|---|---|
| HDP | 1 | | | | | | | | | |
| HCT | 0.152*** | 1 | | | | | | | | |
| RDIPR | 0.092*** | 0.045** | 1 | | | | | | | |
| RDDN | 0.070*** | −0.005 | 0.250*** | 1 | | | | | | |
| DT | 0.153*** | 0.0220 | 0.069** | 0.0440 | 1 | | | | | |
| SIZE | 0.405*** | 0.113*** | 0.104*** | 0.058** | 0.217*** | 1 | | | | |
| LA | 0.043** | 0.0250 | 0.071*** | 0.076*** | 0.118*** | 0.257*** | 1 | | | |
| ROE | 0.101*** | 0.087*** | 0.0210 | −0.054* | −0.00100 | 0.0090 | −0.198*** | 1 | | |
| TOP1 | 0.027 | −0.127*** | −0.091*** | −0.097*** | −0.072** | 0.119*** | −0.128*** | 0.056* | 1 | |
| SOE | 0.131*** | 0.087*** | 0.064** | 0.070** | 0.0140 | 0.242*** | 0.208*** | −0.112*** | 0.063** | 1 |
| Mean | 0.25 | 0.409 | 2.597 | 0.130 | 3.034 | 6.804 | 1.601 | 0.0844 | 0.323 | 0.0846 |
| SD | 0.0424 | 0.492 | 5.617 | 0.448 | 1.287 | 0.763 | 0.681 | 0.0938 | 0.133 | 0.278 |
| Min | 0.182 | 0 | 0 | 0 | 0 | 4.543 | 0.394 | −1.104 | 0 | 0 |
| Max | 0.456 | 1 | 18.74 | 2.944 | 6.354 | 9.161 | 5.654 | 0.604 | 0.750 | 1 |
| VIF | | 1.06 | 1.08 | 1.07 | 1.07 | 1.22 | 1.21 | 1.07 | 1.11 | 1.12 |

**Notes:** *Indicates $p < 0.1$; **indicates $p < 0.05$; and ***indicates $p < 0.01$
**Source:** Table by authors

**Table 3.** Variable descriptive statistics

need for overall improvement. Moreover, 40.9% of SRDI enterprises exhibit hard technologies. The R&D Intellectual Property Rights (RDIPR) has a mean value of 2.597, equivalent to a company's new technology-based intellectual property rights valued at 190,000 yuan before logarithmic transformation. Additionally, the R&D Diversity Number (RDDN) averages 0.130, representing approximately 1 development-stage R&D project before logarithmic transformation. Furthermore, the Development Time (DT) averages 3.034, reflecting a ratio equivalent to 20.78 before logarithmic transformation. The average company size, Net Asset Value (NAV), and proportion of shares held by the largest shareholder are 6.804, 0.0844, and 0.344, respectively. The average listing duration for the sample firms is approximately 2 years, with 8.46% of the sample firms functioning as State-Owned Enterprises (SOEs). The correlation coefficient value among the main variables is 0.405, indicating a moderate relationship. Additionally, the Pearson correlation coefficient matrix, illustrated in Table 4, reveals that the Variables of Interest Factor (VIF) is below 10, confirming no multicollinearity issues and suggesting potential correlations among the variables as depicted in Table 3.

### *4.4 Model construction*

This paper constructs a panel regression benchmark model to test hypothesis *H1*. Some studies show that from innovation investment to innovation transformation to realizing economic benefits is a long-term process, which requires enterprises to invest continuously in a step-by-step manner. Considering that technological innovation cannot directly promote the HDP of enterprises in the short term due to the need to adapt to the updating of the knowledge system, this paper adopts a two-period lag (Li and Zeng, 2019). Therefore, this paper adopts two-period lagged data, as shown in the following model:

$$\mathrm{Hdp}_{t+2} = \alpha_0 + \sum \alpha_k \mathrm{Control}_{it} + \mu_i + v_t + \varepsilon_{it} \tag{1}$$

$$\mathrm{Hdp}_{t+2} = \alpha_0 + \alpha_1 \mathrm{HCT}_{it} + \sum \alpha_k \mathrm{Control}_{it} + \mu_i + v_t + \varepsilon_{it} \tag{2}$$

$$\mathrm{Hdp}_{t+2} = \alpha_0 + \alpha_1 \mathrm{RDIPR}_{it} + \sum \alpha_k \mathrm{Control}_{it} + \mu_i + v_t + \varepsilon_{it} \tag{3}$$

$$\mathrm{Hdp}_{t+2} = \alpha_0 + \alpha_1 \mathrm{RDDN}_{it} + \sum \alpha_k \mathrm{Control}_{it} + \mu_i + v_t + \varepsilon_{it} \tag{4}$$

In the above model, i is the firm, *t* is the year, $\mathrm{Hdp}_{t+2}$ indicates the HDP of the firm with a two-period lag, $\mathrm{HCT}_{i,\,t}$ signifies whether firm i meets the attributes of science and innovation in year *t*, $\mathrm{RDIPR}_{i,\,t}$ represents the natural logarithm of firm i's new technology intangibles in year t. $\mathrm{RDDN}_{i,\,t}$ reflects the natural logarithm of the number of R&D successes of firm i in year t. $v_t$ is a time fixed effect, $\mu_i$ is an individual fixed effect, $\varepsilon$ represents the random error term, $\beta$ denotes the value of the variable to be estimated and Control is the control variable. $\varepsilon_{i,t}$ is the random error term, $\beta$ denotes the value of the parameter to be estimated for the variable, and Control is the control variable. Equations (1) to (4) examine the impact of control variables, HCT, RDIPR, and RDDN on the HDP of enterprises.

To investigate the moderating influence of digitization on the link between hard technology innovation, and the HDP of enterprises, this study constructs the expanded model as follows:

$$\mathrm{Hdp}_{t+2} = \alpha_0 + \alpha_1 \mathrm{HCT}_{it} + \alpha_2 \mathrm{HCT}_{it} * \mathrm{DT}_{it} + \sum \alpha_k \mathrm{Control}_{it} + \mu_i + v_t + \varepsilon_{it} \tag{5}$$

**Table 4.** Benchmark regression results

| Variables | Model1 Hdp | Model2 Hdp | Model 3 Hdp | Model 4 Hdp | Model 5 Hdp | Model 6 Hdp |
|---|---|---|---|---|---|---|
| HCT | | 0.664*** (0.176) | | 0.613*** (0.177) | | |
| RDDN | | | 0.188** (0.092) | | 0.213** (0.092) | |
| RDIPR | 0.039** (0.019) | | | | | 0.037** (0.019) |
| DT | | | | 0.406*** (0.144) | 0.307** (0.139) | 0.356** (0.181) |
| DT*HCT | | | | 0.613*** (0.177) | | |
| DT*RDDN | | | | | 0.217** (0.088) | |
| DT*RDIPR | | | | | | 0.016 (0.017) |
| LA | −0.401* (0.235) | −0.394* (0.234) | −0.291 (0.222) | −0.382 (0.233) | −0.275 (0.222) | −0.409* (0.234) |
| ROE | 1.322 (1.543) | 0.859 (1.538) | 2.625* (1.502) | 0.910 (1.532) | 2.595* (1.495) | 1.266 (1.540) |
| TOP1 | −0.438 (1.350) | −0.051 (1.347) | −0.401 (1.260) | −0.073 (1.350) | −0.410 (1.260) | −0.337 (1.348) |
| SOE | 0.704 (0.690) | 0.590 (0.685) | 0.419 (0.648) | 0.721 (0.686) | 0.479 (0.646) | 0.799 (0.689) |
| SIZE | 1.735*** (0.232) | 1.814*** (0.227) | 1.591*** (0.217) | 1.716*** (0.229) | 1.513*** (0.218) | 1.629*** (0.233) |
| Constant | 13.648*** (1.576) | 13.153*** (1.553) | 14.434*** (1.489) | 15.056*** (1.499) | 13.923*** (1.570) | 14.498*** (1.590) |
| Observations | 1063 | 1065 | 1048 | 1048 | 1065 | 1063 |
| No. of id | 316 | 316 | 314 | 316 | 314 | 316 |

**Notes:** *Indicates $p < 0.1$; **indicates $p< 0.05$; and ***indicates $p < 0.01$
**Source:** Table by authors

$$Hdp_{t+2} = \alpha_0 + \alpha_1 RDIPR_{it} + \alpha_2 RDIPR_{it} * DT_{it} + \sum \alpha_k Control_{it} + \mu_i + v_t + \varepsilon_{it} \quad (6)$$

$$Hdp_{t+2} = \alpha_0 + \alpha_1 RDDN_{it} + \alpha_2 RDDN_{it} * DT_{it} + \sum \alpha_k Control_{it} + \mu_i + v_t + \varepsilon_{it} \quad (7)$$

Equations (5), (6) and (7) are employed to analyze the intermediary impact of digital transformation on the relationship between hard technology innovation and the high-quality development path (HDP) of firms.

## 5. Empirical results

### *5.1 Fractional-order logit regression results*

The table illustrates six models, with Model 1, Model 2 and Model 3 conducting main effect tests for new technology-based intangible assets, science and innovation attributes, and the number of new R&D projects, respectively. Models 4, 5 and 6 represent moderated effect test models, incorporating the moderating variable of digital transformation and its interaction term with the independent variable in Models 1 to 3, respectively.

Analyses in Models 1, 2, and 3 investigate the influence of attributes related to science and innovation, intellectual property rights stemming from new technologies, and the number of successful R&D endeavors on the high-quality progression of corporations. The results of Model 1 demonstrate a significant and positive coefficient ($\beta = 0.664$, $p < 0.01$) for HCT, indicating that they financially support high-quality growth and alleviate funding scarcity for innovation within enterprises. Model 2 reveals a significant and positive coefficient ($\beta = 0.039$, $p < 0.05$) for RDIPR based on new technologies, highlighting their role in generating additional profits and ensuring competitive advantages for enterprise development. Similarly, Model 3 demonstrates a significant and positive coefficient ($\beta = 0.188$, $p < 0.05$) for RDDN, indicating their positive effect on enterprise market valuation and attracting investor attention for superior development prospects. Overall, the findings from these models provide substantial support for *H1*.

Models 4, 5 and 6 examine the regulatory impact of DT on HCT, RDIPR, and RDDN, respectively. Analysis of Model 4 reveals a strongly significant and positive coefficient ($\beta = 0.613$, $p < 0.01$) for the interaction term between DT and HCT. This suggests that digitalization not only strengthens the financial foundation for HDP but also amplifies the influence of HCT. DT is found to have a positive regulatory effect on the link between these attributes and HDP. Model 5 shows a moderately significant and positive coefficient ($\beta = 0.217$, $p < 0.05$) for the interaction term between DT and RDDN. This indicates that digitalization enhances the external perception of R&D investments, attracting more investor interest and fostering HDP. It confirms the positive regulatory role of digitalization in the connection between successful R&D projects and HDP. However, Model 6 reveals that the coefficient for the interaction between DT and RDIPR, while positive ($\beta = 0.016$), does not reach statistical significance. This indicates that the regulatory effect of DT on the relationship between RDIPR and HDP is inconclusive. In conclusion, *H2* is supported in two of the three proposed pathways, with the relationship between RDIPR and HDP not being supported by the data.

### *5.2 Robustness tests*

Replacement of the dependent variable measurement.

This paper further draws on Xu (Xu *et al.*, 2023) and Zhu (Zhu and Su, 2023; Zhang *et al.*, 2023) study to measure the HDP of enterprises in terms of innovation, coordination, green, openness and sharing. The findings from the robustness evaluation are presented in the subsequent table. Despite minor fluctuations in the level of statistical significance when contrasted with prior research, the results continue to hold significance, surpassing the threshold of a minimum of 10%. This serves to bolster the dependability of the conclusions that were previously established. Table 5 shows the results of the robust test.

Adding control variables.

To ensure the generalizability and stability of the research findings, this paper incorporates Zhang's control variables as a basis (Zhang *et al.*, 2023) and includes the corporate gearing ratio (LEV) to test the robustness of the results. The robustness test confirms the consistency between the findings and the previous regression results, thus providing further support for their reliability. The results of the robust test are depicted in Table 6.

## 6. Discussion

### *6.1 Conclusion*

This study examines a data set of publicly traded "small giant" firms in Science, Research, and Development for Innovation (SRDI) on the A-share market from 2012 to 2022. It

| | (1)<br>Hdp | (2)<br>Hdp | (3)<br>Hdp |
|---|---|---|---|
| RDIPR | 0.127* (0.071) | | |
| HCT | | 0.282** (0.110) | |
| RDDN | | | 0.149* (0.079) |
| LA | 0.242 (0.178) | 0.256 (0.181) | 0.239 (0.185) |
| ROE | −1.229 (1.209) | −1.740 (1.237) | −1.173 (1.278) |
| TOP1 | 0.541 (0.838) | 0.727 (0.885) | 0.579 (0.890) |
| SOE | −0.631 (0.436) | −0.624 (0.459) | −0.648 (0.463) |
| SIZE | 0.648*** (0.158) | 0.650*** (0.164) | 0.634*** (0.168) |
| _cons | −1.292 (1.122) | −1.288 (1.154) | −1.150 (1.188) |
| Observations | 991 | 991 | 974 |

**Notes:** *Indicates $p < 0.1$; **indicates $p < 0.05$; ***indicates $p < 0.01$
**Source:** Table by authors

**Table 5.** Robustness test results

| | (1)<br>Hdp | (2)<br>Hdp | (3)<br>Hdp |
|---|---|---|---|
| RDIPR | 0.040** (0.019) | | |
| HCT | | 0.705*** (0.175) | |
| RDDN | | | 0.188** (0.092) |
| SIZE | 1.489*** (0.249) | 1.548*** (0.243) | 1.373*** (0.232) |
| LA | −0.425* (0.234) | −0.421* (0.233) | −0.311 (0.222) |
| ROE | 2.041 (1.560) | 1.645 (1.552) | 3.249** (1.513) |
| TOP1 | −0.253 (1.345) | 0.181 (1.336) | −0.216 (1.251) |
| SOE | 0.616 (0.688) | 0.476 (0.680) | 0.328 (0.644) |
| LEV | 2.980*** (1.110) | 3.289*** (1.102) | 2.749*** (1.043) |
| _cons | 14.477*** (1.600) | 14.021*** (1.571) | 15.124*** (1.506) |
| Observations | 1065 | 1073 | 1048 |

**Notes:** *Indicates $p < 0.1$; **indicates $p < 0.05$; ***indicates $p < 0.01$
**Source:** Table by authors

**Table 6.** Robustness test results

empirically analyzes the relationship between cutting-edge technological advancements and business growth. Additionally, the study investigates the regulatory effects of digital transformation on both hard tech innovations and the HDP of companies. The research is significant for optimizing corporate resource distribution, identifying growth potential, and yielding key insights. Firstly, the study finds that innovation in hard technology plays a vital role in driving high-quality progression. Subsequently, the digitization of enterprises positively influences the relationship between scientific and technological innovation traits and HDP. Thirdly, digitization does not diminish the link between novel, technology-driven intellectual property rights (IPRs) and HDP. Finally, the digitization of enterprises serves as a positive mediator between the volume of successful R&D initiatives and HDP of businesses.

### *6.2 Implication for practice and policy*

This paper presents theoretical pathways and empirical evidence to support HDP for SRDI enterprises through hard technology innovation. Additionally, it integrates digital transformation into the research framework to expand the understanding of digitalisation's impact, investigates the contextual factors affecting digital transformation in enhancing enterprise development, and highlights how increased utilization of digital technologies in R&D processes enhances hard-technology innovation levels and fosters the HDP of SRDI enterprises. Furthermore, the study categorizes hard technology innovation into three dimensions, enabling a comprehensive exploration of their diverse contributions to the HDP of SRDI enterprises. By focusing on SRDI enterprises as a case study, the research offers valuable insights for guiding innovation initiatives within this emerging segment from a distinct perspective.

The development and growth of SRDI enterprises must be anchored in robust technology. According to the theory of lock-in at the lower end of the value chain, when Chinese enterprises are entrenched at the base of the global value chain, advancing truly becomes a challenge, even with continual increases in R&D investments. Hard technology innovation within SRDI enterprises necessitates R&D funding, technology intangibles, and a high R&D success rate to establish formidable intellectual property barriers, create high-value products, and prioritize breakthroughs in crucial technologies essential for China's economic advancement. This path represents the sole means to genuine prosperity.

Clarifying transformation objectives and expediting digital transformation are crucial for manufacturing enterprises. Advanced digital transformation offers the potential to lower costs, enhance efficiency, optimize resource allocation, and ultimately bolster market competitiveness. The journey of enterprise digital transformation is fundamentally an innovative undertaking, wherein digital technology serves as a tool for enterprises to navigate uncertainties in the external environment, strengthen organizational resilience, enhance manufacturing infrastructure and industrial chains, develop related factor markets, and progressively achieve the digitization of the industrial chain. These efforts position enterprises to assume a pivotal role in the upcoming technological revolution and digital wave.

This research not only offers valuable insights for enterprise operations but also presents profound implications for governmental policy formulation. Integral to the policy framework, the robust and efficient growth of SDRI enterprises bears crucial importance for the stability and advancement of the overall economic system. Through the provision of targeted policy support like tax incentives and financial aid to these enterprises, the government can alleviate operational pressures and foster a more conducive growth environment. Additionally, R&D subsidies can incentivize increased innovation investment, driving technological advancements and industrial upgrades, thereby advancing enterprise development. It is imperative for the government to acknowledge the pivotal role of SDRI enterprises in economic progress and develop precise and effective policies to enhance their development, enabling them to contribute significantly to economic prosperity and stability.

*6.3 Shortcomings and prospects*

The study identifies three principal areas where it falls short in its research scope. Firstly, due to the novelty of the research focus, there is a limited number of samples concerning hard technology innovation and A-share-listed SRDI enterprises. General samples of listed enterprises could potentially replace these limited samples to validate the findings in subsequent research. Secondly, the existing measurement methods for hard technology innovation are limited. This study utilizes common practices for measurement; however, future research could develop evaluation indices from multiple dimensions of hard technology innovation to gain a deeper understanding and enhance measurement accuracy. Finally, this paper exclusively investigates the potential of hard technology innovation in promoting high-quality enterprise development. Future studies could delve into intermediary mechanisms and regulatory factors to provide a more comprehensive analysis.

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