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Human Capital Investment, Technological Innovation, and Resilience of Chinese High-End Manufacturing Enterprises

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Abstract: In the era of VUCA, cultivating and enhancing the resilience of high-end manufacturing enterprises is critical. Based on existing research, this paper defines enterprise resilience at the beginning and constructs an enterprise resilience evaluation index system that includes three segmented capabilities: recognition and resistance, adaptation and adjustment, and recovery and rebound. Finally, the relationship between human capital investment, technological innovation, and high-end enterprise resilience is empirically studied. The research results show that human capital investment positively affects the resilience of high-end manufacturing enterprises, with breakthrough innovation and progressive innovation playing a mediating role. Digital transformation positively moderates the impact of human capital investment on the resilience of high-end manufacturing enterprises. Further, there is a higher threshold between human capital investment and technological innovation in improving the resilience of high-end manufacturing enterprises. Human capital investment has a significantly positive effect on high-end manufacturing enterprises' ability to resist risks and adapt to adjustments but has no significant impact on recovery and rebound ability. Breakthrough and progressive innovation partially mediate the impact of human capital investment on the ability to resist risks and adapt to adjustments, while breakthrough innovation has no significant impact on the recovery of the rebound ability; however, progressive innovation completely mediates the relationship between human capital investment and the recovery of rebound ability. Compared with Chinese non-state-owned enterprises, state-owned enterprises' efforts to increase investment in human capital only positively impact their ability to resist risks. Compared with large-scale enterprises, the increase in human capital investment in small-scale enterprises only has a significant positive impact on the ability to resist risks. Based on the above, this paper suggests that high-end manufacturing enterprises should enhance their strategic focus and constantly strengthen their investment in human capital and technological innovation; at the same time, they should further optimize the structure of human capital investment and introduce and cultivate cutting-edge talents.

Keywords: human capital investment; technological innovation; high-end manufacturing enterprises; enterprise resilience

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1. Introduction

As the foundation for establishing a country and the basis to be powerful, the manufacturing industry is the national economy's lifeline. With China's industrial upgrading development, high-end manufacturing enterprises with significant capital investments, high technological content, and high added value have maintained rapid growth in recent

years. Data from the National Bureau of Statistics of China show that in the first half of 2024, the profit of the equipment manufacturing industry increased by 6.6% year-on-year, contributing more than 60% to the profit growth of industrial enterprises above the designated size. The output of 3D printing equipment, new energy vehicles, and integrated circuit products increased by 51.6%, 34.3%, and 28.9% year-on-year, respectively, driving double-digit profit growth in the electronics and automotive industries. It can be seen that the development of high-end manufacturing industries can not only enhance the international competitiveness of China's industry but also effectively strengthen the internal impetus for economic growth.

Although the development of high-end manufacturing enterprises has made some achievements, they still face severe challenges. The international situation is treacherous, the neighboring environment is complex and volatile, market competition is becoming increasingly fierce, and technology is updating at a progressively rapid pace. Enterprises must nurture and continuously improve their resilience in such environments to achieve smooth and healthy business growth. As the core link in the industrial chain, their resilience is not only related to their own survival and development but also has an important impact on the stability of the whole chain and national economic security.

The term "resilience" was initially applied to fields such as physics and engineering, but now it has been an interdisciplinary vocabulary. Subsequently, the concept of resilience was introduced in the field of organizational management. Barghouti et al. [1] considered enterprise resilience a situational variable, while Duchek [2] and Zhang et al. [3] regarded it as a multinational capability formed during the enterprises' development process. To date, scholars have not reached a clear consensus on the meaning of enterprise resilience. Existing studies have been conducted to explore factors that influence enterprise resilience from both internal and external aspects. Internal influences are both at the individual level, such as the traits, perceptions, and behaviors of business leaders [4,5], and at the organizational level, such as company size [6], organizational learning [7], and corporate resources [8]. Studies on external influencing factors focus on the policy environment [9–11], digital transformation [12,13], social capital [14], and social responsibility [15].

Established research suggests that various aspects influence the cultivation and enhancement of enterprise resilience. In addition, Zhang et al. [16] pointed out that the core of China's manufacturing industry development is innovation, which means mastering critical core technology. Therefore, the key to fostering and promoting resilience in high-end manufacturing enterprises lies in comprehensively stimulating vitality and strengthening technological innovation. Studies have explored the relationship between technological innovation and corporate resilience from a resource perspective. Li et al. [17] argued that technological innovation can enhance resilience by accelerating digital transformation. Ramdani et al. [18] and Heredia et al. [19] believed that technological innovation can enhance resilience by optimizing business models. Ma et al. [20] considered that technological innovation can enhance resilience by promoting industrial upgrading. According to the Innovation Theory of Joseph Alois Schumpeter, we can learn that innovation is a knowledge-based process whose basis is the ability to create, manage, and maintain the knowledge that humans create. Hence, human capital is usually viewed as an essential input for corporate technology innovation. At the same time, humans are the most active and decisive dynamic subjects in the development process of enterprises. This is crucial to their development. At present, most scholars have realized the importance of technological innovation in enhancing enterprise resilience. However, few scholars have considered human capital when exploring the impact of human capital investment and technological innovation on enterprise resilience.

Based on the above, this paper will define enterprise resilience at the beginning and, on this basis, construct a resilience evaluation index system for high-end manufacturing enterprises. It will then explore the functioning mechanism of human capital investment and technological innovation. This paper selects 682 high-end manufacturing enterprises in China from 2018 to 2022 as research samples to conduct an empirical study on the relationship between human capital investment, technological innovation, and high-end manufacturing enterprises.

The contributions of this paper are as follows. Firstly, high-end manufacturing enterprises are the main forces driving China's economic growth. In recent years, some Western countries have implemented restrictive measures against Chinese high-end manufacturing enterprises, such as controlling core technologies and stopping the supply of core equipment and components. This paper focuses on cultivating and enhancing high-end manufacturing enterprises' resilience, explores the functioning mechanism of human capital investment and technological innovation on enterprise resilience, and puts forward corresponding management suggestions. Hence, the research results have some strategic value and practical significance. Second, drawing from previous studies, this paper focuses on the role of human capital investment, systematically investigates how technological innovation and human capital investment affect the resilience of high-end manufacturing enterprises, and broadens the enterprise resilience research framework. At the same time, the resilience evaluation index system established in this paper will provide necessary support for subsequent research. Finally, strong enterprise resilience can enable enterprises to maintain a stable business state in the face of uncertainties, such as natural disasters, market fluctuations, and economic cycle changes. They can flexibly adjust their business strategies, optimize resource utilization, reduce pollution emissions, and actively respond to environmental challenges. Therefore, improving resilience helps enterprises achieve a win-win situation of economic efficiency and environmental protection and promotes the overall sustainable development of society.

2. Definition of Enterprise Resilience and Measurement of High-End Manufacturing Enterprise Resilience

2.1. Definition of Enterprise Resilience

Based on the dynamic capability theory, most existing studies on the definition of enterprise resilience have led to two perspectives: "reactive" and "proactive". Barghouti et al. [1] regarded resilience as a situational variable in a complex and changing environment. Companies will respond to every crisis and build their resilience in this process. Duchek [2] and Zhang et al. [21] believed that enterprise resilience is not only a passive response of an enterprise in a changing environment but also a comprehensive ability formed in their development process, including three dimensions: pre-crisis prevention, adaptation during the crisis, and post-crisis recovery and growth. Up to now, scholars have not reached a clear consensus on the meaning of enterprise resilience. The practice has shown that highly resilient enterprises tend to be keenly aware of changes in internal and external environments and effectively respond to them. They have both preparedness to prevent risks and strategies to cope with challenges, as well as the ability to take the strategic initiative to turn dangers into opportunities. It can be seen that the essence of enterprise resilience is a kind of sustainable development ability [22]. This paper believes that enterprise resilience is a multi-dimensional ability that gradually forms in the development process of enterprises, a synthesis of three kinds of subdivision capabilities: recognition and resistance, adaptation and adjustment, and recovery and rebound.

2.2. Construction of Resilience Evaluation Index System for High-End Manufacturing Enterprises

Enterprise resilience is characterized by diversification and multi-dimension. To date, scholars have not reached a consensus on how to measure enterprise resilience. Currently, the measurement methods for enterprise resilience can be roughly divided into direct [23] and indirect [24] measurements. The direct measurement method sets corresponding test items according to the concept and connotation of enterprise resilience and performs statistical measurements by issuing questionnaires [23]. The indirect method measures enterprise resilience from the results' perspective using relevant data publicly disclosed by listed companies or financial institutions [24]. For example, DesJardine et al. [25] measured enterprise resilience from two dimensions: severity of loss and time to recovery. Lv et al. [26] measured enterprise resilience from two dimensions: long-term growth and financial volatility. Since scholars are yet to reach a consensus on the concept and connotation of corporate resilience, there is a big difference in the quantitative content when using the direct measurement method to measure enterprise resilience. The comprehensiveness of the selected financial indicators is insufficient when using the indirect measurement method. Therefore, based on the definition of enterprise resilience, this paper divides it into three sub-capabilities: recognition and resistance, adaptation and adjustment, and recovery and rebound. Combining the typical embodiment of each sub-capability, we determine the appropriate measurement indexes to construct a high-end manufacturing enterprises' resilience evaluation index system.

When faced with a potential crisis, resilient companies can often quickly sense environmental changes, predict their impact in advance, and make plans to respond. The capability to recognize and resist risks is mainly reflected in business scale [27], human resources [28], and cash flow sufficiency [29]. Existing studies have shown that larger enterprises can better support longer innovation revenue chains and innovation closed loops, providing enterprises with sustained innovation power and effectively dispersing R&D risks. The enterprise operating scale usually manifests as the scale of enterprise profits and operating revenues. Therefore, this paper reflects the scale of enterprise operations in terms of total profits and operating revenues. Talent is the most crucial resource for an enterprise. Owning rich talent resources can help enterprises promptly identify and actively resist risks. For high-end manufacturing enterprises, establishing their own technological innovation advantages through effective R&D activities is an important basis for resisting risks. R&D personnel are the backbone of cultivating and enhancing resilience [28]. Therefore, this paper uses the number of R&D personnel to reflect the talent resources of high-end manufacturing enterprises. Daily cash held by companies has both transactional and preventive value. Cash mainly plays a transactional role when no risks are identified. Once risks appear, the preventive value of cash comes to the fore, and it is as important to companies as blood is to the body [29,30]. The adequacy of cash flow is affected by the enterprise's own "hematopoietic" ability and external "transfusion" ability, which are reflected by net cash flow from operating activities and net cash flow from financing activities, respectively.

Resilient firms will adapt actively and adjust flexibly in times of crisis. This ability to adapt and adjust is closely related to their operational efficiency, degree of flexibility in resource allocation, and government support. First of all, operational efficiency reflects the enterprise's output capacity and response speed to changes in market demand [31]. Higher operational efficiency usually means that the enterprise can recover funds more quickly, reduce the cost of capital occupancy, and then improve overall profitability. This paper uses the current and fixed asset turnover to reflect the enterprise's operational efficiency. Secondly, different resource allocation schemes will lead to different flexibilities in responding to the crisis [32]. Enterprises' resource allocation needs to consider the expenditure structure of capital, R&D, and selling expenses, so this paper uses the proportion of these

three to reflect the degree of flexibility in corporate resource allocation. Finally, due to the role and contribution of high-end manufacturing enterprises, the government often provides substantial support [33,34], such as government subsidies, when they are in a crisis. Hence, this paper uses government subsidies to reflect government support.

Opportunities often hide in crises. Resilient enterprises can not only promptly recover under pressure, but also seize the opportunity to learn, improve, and rebound. This recovery and rebound ability intuitively manifests as their profitability, innovation capacity, and growth capacity [35]. Profitability is the outstanding performance of an enterprise's recovery and rebound ability. Good profitability means that enterprises can better adapt to the changing environment and ensure the continuity of business activities. This helps them recover and rebound promptly in an uncertain environment. Hence, this paper chooses the net profit margin of total assets to reflect the profitability of high-end manufacturing enterprises [36]. Innovation and growth ability are critical forces that support manufacturing enterprises in maintaining continuous high-end development. They help break inertia dependence in uncertain situations, constantly innovate, make breakthroughs, and better adapt to complex and changing environments. Therefore, they are also key to improving their recovery and rebound ability [2]. Enterprise innovation capability, usually denoted by the number of patent applications, reflects an enterprise's ability to create and apply new knowledge. Hence, this paper uses the number of patent applications to measure the innovation capability of high-end manufacturing enterprises [37]. Enterprise growth capacity is the ability to continue to grow, so this paper uses the operating income growth rate and total assets growth rate to reflect it. In conclusion, the resilience evaluation index system for high-end manufacturing enterprises constructed in this paper is shown in Table 1.

Table 1. Resilience evaluation index system for high-end manufacturing enterprises.

First-Grade Index	Second-Grade Index	Third-Grade Index
Recognition and Resistance Ability	Corporate Operating Scale [27]	Total Profit [27]
		Operating Revenue [27]
	Corporate Talent Resource [28]	Number of R&D Personnel [28]
	Enterprise "Hematopoietic" Ability [29]	Net Cash Flow from Operating Activities [29]
	Enterprise "Transfusion" Ability [30]	Net Cash Flow from Financing Activities [30]
Adaptation and Adjustment Ability	Corporate Operating Efficiency [31]	Current Asset Turnover [31]
		Fixed Asset Turnover [31]
	Resource Allocation Flexibility [32]	The Proportion of Expenditure on Capital, R&D, and Advertising in Sample Enterprises [32]
	Government Support [34]	Government Subsidies [33]
Recovery and Rebound Ability	Corporate Profitability [35]	Rate of Return on Total Asset [36]
	Corporate Innovation Ability [35]	Number of Patent Applications [37]
	Corporate Growth Ability [35]	Growth Rate of Total Asset [35]
		Growth Rate of Operating Revenue [35]

2.3. Resilience Evaluation Methods for High-End Manufacturing Enterprises

Many commonly used multi-index comprehensive evaluation methods exist, such as the analytic hierarchy process, fuzzy comprehensive evaluation, gray clustering method, TOPSIS model method, and entropy evaluation method [38]. In these methods, the analytic hierarchy process is highly subjective, while the fuzzy comprehensive evaluation, gray clustering method, and TOPSIS model method need to determine the weight indirectly. The entropy evaluation method can effectively eliminate the interference of subjective

factors, directly determine the weight, and objectively reflect the information of the evaluation object. Therefore, this paper selects the entropy evaluation method to calculate the resilience index of high-end manufacturing enterprises based on a constructed evaluation index system.

3. Internal Mechanism Analysis

Culturing and enhancing high-end manufacturing companies' resilience is a dynamic process whose external manifestation is the capacity to consistently overcome the constraints of critical core technologies and create their own technological advantages. Therefore, technological innovation plays an essential role. As a vital component of the real economy, high-end manufacturing companies must uphold the principle that talent is the primary resource and innovation is the primary power to strengthen and improve their sinews. History has fully proven that human capital is a vital force standing at the forefront of technology, leading technological innovation and supporting the high-quality development of enterprises. Human resources are the most positive factor in innovation activities. A large-scale, reasonably structured, and well-qualified talent team can promote innovation development in enterprises [39]. According to the resource-based view, human capital is a crucial resource that is scarce, valuable, inimitable, and irreplaceable. This is also the initial point for cultivating and enhancing enterprise resilience [40]. Meanwhile, human capital is regarded as an important input for R&D innovation [41], which is conducive to enhancing technological innovation in enterprises. Based on the above, this paper argues that there are two paths for the impact of human capital on the resilience of high-end manufacturing enterprises. On the one hand, human capital will directly affect the enhancement of enterprise resilience. On the other hand, human capital indirectly affects it through technological innovation.

From the perspective of the direct path, enterprises can affect their employees' abilities, attitudes, and psychological states through continuous human capital investment and then improve high-end manufacturing enterprises' resilience. Firstly, by selecting and deploying enterprise staff, human capital investment can build a workforce team with appropriate competencies [42]. Secondly, investing in human capital can also be used to continuously enhance workers' skills through systematic training and development to adapt to changing task requirements in the development process [41]. At the same time, it also helps improve their sense of responsibility, loyalty, and sense of belonging and enhances their centripetal force toward the enterprise. In addition, human capital investment can further optimize the psychological state of employees through effective employee motivation and enhance employees' adversity quotient level and self-efficacy. When an enterprise faces a potential crisis, enterprise managers with a strong sense of mission and keen insight can identify the crisis in time. Meanwhile, they will play leadership behavioral qualities through the integration of the internal and external resources of the enterprise to make full preparations to respond to the crisis. When a crisis occurs, managers are able to maintain a relatively stable and healthy psychological state, quickly adjust corporate strategies, optimize resource allocation, and flexibly respond to market changes. Employees can complete their tasks on time based on their professional competence. Meanwhile, a strong sense of responsibility and mission helps them unite under pressure to actively seek solutions to various problems. After a crisis, a strong sense of belonging and self-efficacy can help stimulate managers' and employees' learning motivation under pressure. In this way, they aim to constantly make breakthroughs to find new growth points and maintain continuous innovation and stable operations. Therefore, human capital investment is crucial for improving the resilience of high-end manufacturing enterprises. Based on the above, this paper proposes the first hypothesis.

H1: *Human capital investment enhances the resilience of high-end manufacturing enterprises.*

At the same time, the prosperous development of digital transformation has penetrated various aspects of high-end manufacturing enterprises, accelerating the enhancement of their resilience [3,43]. First, when facing a potential crisis, employees can utilize digital technology to search for, integrate, and analyze scattered data and information from internal and external environments in a high-level digital situation. It is beneficial for enterprises to predict and recognize potential external risks. Secondly, when a crisis occurs, enterprise employees can enhance the intelligence of the enterprise's production and operation process by learning digital technology to improve production efficiency. This allows companies to quickly allocate existing resources and engage in new production activities in the face of unexpected crises. Meanwhile, external impacts may destroy the original communication channels of an enterprise organization, fragmenting the connections between employees in the enterprise. Digital technology, however, can change the original cross-departmental and cross-level interaction patterns, effectively connecting separated business modules and uniting them into a whole. This greatly improves communication efficiency within the enterprise organization, thus optimizing the business and decision-making processes in a crisis event and enhancing their ability to deal with emergencies. Finally, enterprises with higher digital levels will replace much of their simple, programmed manual work with digital equipment and technology after the crisis. This will lead to an increase in the specialization of employees, who will be more proactive in learning new knowledge and technologies in order to prevent themselves from being replaced by digital equipment. This will also help high-end manufacturing enterprises improve their ability to recover and rebound, thus contributing to resilience formation. Based on the analysis above, this paper puts forward the second hypothesis.

H2: *A high degree of digital transformation positively moderates the enhancing effect of human capital investment on the resilience of high-end manufacturing enterprises.*

From the perspective of the indirect path, human capital investment can enhance the resilience of high-end manufacturing enterprises through technological innovation. Human capital is a collection of employees' knowledge, professional ability, experience level, and labor force. According to the knowledge-based view, the knowledge and capabilities embedded in human capital are fundamental forces driving innovation and development [44]. As a complex activity, technological innovation is characterized by breakthrough and progressive attributes. A single mode of technological innovation can no longer satisfy the development of enterprises. They must pursue both breakthrough and progressive innovation to be compatible with their short-term development needs and long-term competitive advantages. Breakthrough innovation is a higher degree of innovation, which refers to engaging in activities related to developing new products, technologies, and processes. Progressive innovation is a relatively low degree of innovation that refers to engaging in activities related to improving current products, technologies, and processes.

Continuous investment in human capital can not only enrich knowledge and enhance the ability of employees, but also promote knowledge sharing and reorganization among the team through training and development and stimulate employees' innovative motivation through effective incentives. This helps increase the enterprise's knowledge reserve, promoting breakthrough innovation and fundamental transformation. High-end manufacturing enterprises can also enhance their resilience through breakthrough innovation. Firstly, human capital can be invested by selecting and hiring a group of corporate employees with a broad knowledge base and high-level cognitive thinking to form an R&D

team, which is crucial for identifying and utilizing breakthrough innovation opportunities. Secondly, human capital investment can be made through systematic training and development, as well as by deeply communicating and learning with experts from specific industries and technological fields. This can help enterprises better understand the potential barriers to achieving breakthrough innovations and provide technical capabilities and theoretical support for breakthrough innovation practices. Finally, according to the cognitive behavior theory, whether enterprise employees show innovative behavior depends not only on the employees' innovating ability but also on their innovating willingness. Through effective incentives, human capital investment can stimulate employees to innovate and enhance their willingness to innovate, thus promoting enterprise breakthrough innovation.

At the same time, breakthrough innovation creates possibilities for high-end manufacturing enterprises. When enterprises face a potential crisis, breakthrough innovation enables the company to identify possible future challenges earlier and make timely adjustments. This ability to identify and proactively respond to future challenges in advance enables enterprises to cope better with uncertainty and change, thus promoting their resilience. When a crisis occurs, breakthrough innovation enables enterprises to have a unique competitive advantage in the market, which can help them better keep a foothold in fierce market competition and enhance enterprise resilience. After a crisis, breakthrough innovations may lead to entirely new business models, products, and services, enabling enterprises to explore new markets and seize new business opportunities. In this way, enterprises are able to reduce their dependence on traditional markets, diversify their risks, and improve their ability to recover and rebound, thereby enhancing their resilience. Therefore, this paper proposes the third hypothesis.

H3: *Human capital investment enhances the resilience of high-end manufacturing enterprises through breakthrough innovation.*

In addition, human capital investment can also enhance enterprise resilience by promoting progressive innovation [45]. Firstly, human capital investment helps enterprises attract talented people with higher education and cognition levels who can better understand market needs and adopt and apply new knowledge to improve products and services continuously. Secondly, human capital actively summarizes and accumulates industry-related experience through systematic training and development. This experience can help employees understand industry standards, customer needs, and technological trends so that they can effectively innovate based on existing results and improve existing products and services through progressive innovations. Finally, continuous investment in human capital is also conducive for employees to access diversified information and resources, which are crucial for enterprises to implement progressive innovation.

On this basis, progressive innovation is less risky than breakthrough innovation and significantly enhances enterprise resilience. When facing a potential crisis, the improvement and optimization of progressive innovation are carried out on an existing basis, and it is easier to find problems and adjust them in time through experimentation and verification. This helps reduce failure risk and protect companies from significant losses, thus increasing their resilience. When a crisis occurs, the trial-and-error cost of progressive innovation is relatively low. Enterprises can continue to experiment and learn, accumulating experience in the market and technological development. This continuous learning allows firms to better adapt to market changes and be more flexible in adjusting their strategies, thus enhancing their resilience. After a crisis, enterprises can steadily improve the quality of their products and efficiency of services through sustained progressive innovation, thereby improving economic performance. Stable economic performance can enhance business resilience by

allowing companies to gradually recover and rebound from economic fluctuations and competitive markets. Therefore, this paper puts forward the fourth hypothesis.

H4: *Human capital investment enhances the resilience of high-end manufacturing enterprises through progressive innovation*.

In summary, this paper argues that both human capital investment and technological innovation can contribute to cultivating and enhancing the resilience of high-end manufacturing enterprises. On the one hand, enterprises invest human capital through the recruitment, selection, continuous training, and development of talent, which forms an irreplaceable and important resource for enterprises and directly promotes their resilience. On the other hand, human capital investment will enhance high-end manufacturing enterprises' resilience by driving breakthroughs and progressive innovation. Therefore, this paper formulates the following theoretical model in Figure 1.

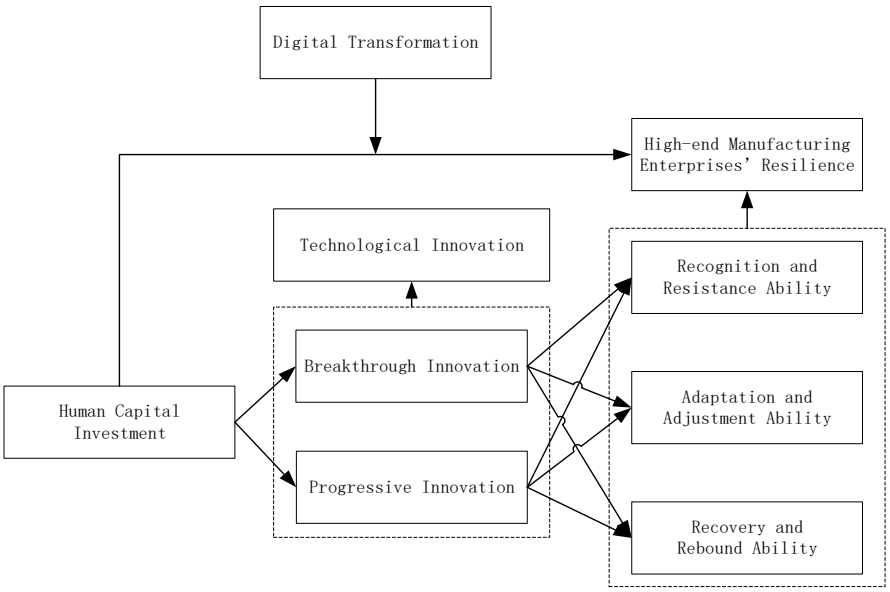

Figure 1. Theoretical model.

4. Research Design

4.1. Sample Selection and Data Sources

According to the industrial classification for national economic activities [46], this study selects listed companies from six industries: pharmaceutical manufacturing; general-purpose equipment manufacturing; special-purpose equipment manufacturing; instrument and meter manufacturing; computer, communications, and other electronic equipment manufacturing; and railroad, ship, aerospace, and other transportation equipment manufacturing, in the A-share of the main board of Shanghai and Shenzhen in 2018–2022. After excluding ST-type companies and companies with missing key data, we obtained 2999 unbalanced panel data samples from 682 companies. Among them, R&D expenditures and the number of enterprise patent applications are from the CNRDS database, and other data are from the CSMAR database.

4.2. Variable Design

4.2.1. Explained Variables

Enterprise resilience (ER). Based on the constructed resilience evaluation index system for high-end manufacturing enterprises in the previous section, we use the entropy value method to calculate their resilience index to reflect their resilience.

4.2.2. Explaining Variables

Human capital investment (HCI). Drawing on the research of Hong et al. [44], this paper agrees that employee compensation can roughly reflect a firm's human capital investment in an efficient market. Therefore, we use the natural logarithm of the total employee compensation of high-end manufacturing enterprises to reflect their human capital investments.

4.2.3. Mediating Variables

Technological innovation (TI). This paper uses the natural logarithm of R&D expenditures of high-end manufacturing enterprises to reflect technological innovation and divides it into breakthrough innovation and progressive innovation according to the intensity of R&D innovation [47]. Among them, the intensity of R&D innovation is measured by the proportion of R&D expenditure to operating income. Considering the difficulty in achieving breakthrough innovation, it is divided into 75 quantiles. If the variable is greater than or equal to 75 quantiles, it is set as breakthrough innovation and vice versa, as progressive innovation.

4.2.4. Control Variables

Based on existing studies [48–50], we control for variables that may have an impact on enterprise resilience, such as firm age (Age), gearing (Lev), nature of property rights (Soe), and size of the firm (Size). Definitions of the specific variables are listed in Table 2.

Table 2. Variables definitions.

Variable	Variable Name	Variable Code	Variable Definition
Explained variable	Enterprise resilience	ER	Comprehensively calculate by entropy value method.
Explaining variable	Human capital investment [51]	HCI	Ln (payroll payable) [43]
Mediating variable	Technological innovation [52]	TI	Ln (R&D expenditure) [47]
	Breakthrough innovation [53]	BI	The proportion of R&D expenditure to operating income is greater than or equal to 75 quantiles.
	Progressive innovation [54]	PI	The proportion of R&D expenditure to operating income is less than 75 quantiles.
Moderating variable	Digital transformation [3]	DT	Use the Python tool to extract the key feature word "digital" in the annual reports of listed companies and take the logarithm of the sum of the feature words' frequency [3].
Control variable	Enterprise age [50]	Age	Take the natural logarithm of the number of that accounting year minus the listing year of the company and add one [50].
	Asset-liability ratio [50]	Lev	Total liabilities/total assets [50]
	Nature of property right [50]	Soe	For state-owned enterprises, the value is 1, otherwise it is 0. State-owned enterprises are those whose capital is owned or controlled by the state [50].
	Enterprise size [49]	Size	Ln (total assets) [49]

4.3. Construction of Models

Based on the above research hypotheses and variables design, this paper constructs the basic regression Model (1) to test the impact of human capital investment on the resilience

of high-end manufacturing enterprises and constructs Model (2) to test the moderating effect of digital transformation. Additionally, Model (3), Model (4), and Model (5) are constructed to examine breakthrough innovation's mediating role in the impact of human capital investment on the resilience of high-end manufacturing enterprises by stepwise regression method. Model (3), Model (6), and Model (7) are constructed to test progressive innovation's mediating role in the impact of human capital investment on the resilience of high-end manufacturing enterprises by stepwise regression method.

$$ER_{i,t} = \beta_0 + \beta_1 HCI_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$ER_{i,t} = \delta_0 + \delta_1 HCI_{i,t} + \delta_2 DT + \delta_3 HCI \times DT + \delta_4 Controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$ER_{i,t} = \eta_0 + \eta_1 HCI_{i,t} + \eta_2\ Controls_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$BI_{i,t} = \alpha_0 + \alpha_1 HCI_{i,t} + \alpha_2 Controls_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$ER_{i,t} = \theta_0 + \theta_1 BI_{i,t} + \theta_2 HCI_{i,t} + \theta_3\ Controls_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$PI_{i,t} = \alpha_0 + \alpha_1 HCI_{i,t} + \alpha_2 Controls_{i,t} + \varepsilon_{i,t} \quad (6)$$

$$ER_{i,t} = \theta_0 + \theta_1 PI_{i,t} + \theta_2 HCI_{i,t} + \theta_3\ Controls_{i,t} + \varepsilon_{i,t} \quad (7)$$

In these models, $ER_{i,t}$ is the total resilience index of high-end manufacturing firm i in year t. $HCI_{i,t}$ is the human capital investment. $BI_{i,t} PI_{i,t}$ represents technological innovation. Controls $_{i,t}$ is the control variable. β, δ, η, α, θ are coefficients of related variables. $\varepsilon_{i,t}$ is the random disturbance term.

5. Empirical Analysis and Results

5.1. Descriptive Statistics and Correlation Analysis

We used Stata17 software to perform descriptive statistics and correlation analysis of the main variables, and the results are shown in Table 3.

Table 3. Descriptive statistics and correlation analysis results.

Variables	ER	HCI	TI	DT	Age	Lev	Soe	Size
ER	1							
HCI	0.471 ***	1						
TI	0.549 ***	0.738 ***	1					
DT	0.125 ***	0.332 ***	0.399 ***	1				
Age	0.180 ***	0.253 ***	0.312 ***	0.224 ***	1			
Lev	0.184 ***	0.331 ***	0.328 ***	0.271 ***	0.255 ***	1		
Soe	−0.133 ***	−0.227 ***	−0.257 ***	−0.160 ***	−0.463 ***	−0.230 ***	1	
Size	0.583 ***	0.743 ***	0.873 ***	0.300 ***	0.430 ***	0.398 ***	−0.335 ***	1
Min	0.003	7.893	13.737	3.127	0.000	0.014	1.000	18.334
Max	0.878	23.305	23.796	4.392	3.497	2.471	2.000	26.832
Mean	0.057	17.712	18.714	3.703	2.229	0.402	1.708	22.328
Std.Dev	0.086	1.465	1.363	0.263	0.862	0.187	0.455	1.189

Note: *** denotes a significance level of 1%.

As can be seen from Table 3, the mean value of high-end manufacturing enterprises' resilience is 0.057, the standard deviation is 0.086, the minimum value is 0.003, and the maximum value is 0.878. These numbers indicate that high-end manufacturing enterprises' resilience levels vary significantly and that the gap between the mean and maximum values is significant. Hence, we can infer that highly resilient enterprises are relatively scarce. The mean value of human capital investment is 17.712, and the standard deviation

is 1.465, indicating that the level of human capital investment varies from enterprise to enterprise. The minimum and maximum values of technological innovation are 13.737 and 23.796, respectively, indicating apparent differences in the level of technological innovation among enterprises.

From the results of the correlation analysis, it can be seen that the correlation coefficient between human capital investment and enterprise resilience is positive, which preliminarily verifies hypothesis H1. Moreover, a significant correlation exists between most control variables and enterprise resilience, indicating that the selection of control variables is relatively reasonable. The variables are then subjected to the VIF test, and the results indicate that there is no significant multicollinearity issue between the variables and that additional regression analyses are feasible because the VIF values range from 1.12 to 2.71, all of which are less than 10.

5.2. Basic Regression Analysis

In this paper, after fixing the individual firm and year effects, we analyze the impact of human capital investment on the resilience of high-end manufacturing enterprises based on the regression of Model (1). The moderating role of digital transformation is tested based on Model (2). Model (3), Model (4), and Model (5) are used to test the mediating role of breakthrough innovation. Model (3), Model (6), and Model (7) are used to test the mediating role of progressive innovation. The results are shown in Table 4. Column (1) lists the regression results of the control variables on high-end manufacturing enterprises' resilience. Column (2) presents the regression results after adding the explaining variables. Column (3) lists the moderating effect test results for digital transformation. Column (2), Colum (4), and Colum (5) list the mediating effect test results of breakthrough innovation. Column (2), Colum (6), and Colum (7) list the mediating effect test results of progressive innovation.

Table 4. Basic regression results.

	(1) ER	(2) ER	(3) ER	(4) BI	(5) ER	(6) PI	(7) ER
HCI		0.004 ***	−0.023 ***	0.123 ***	0.007 ***	0.117 ***	0.002 *
		(4.722)	(−3.016)	(6.178)	(3.711)	(7.549)	(1.758)
DT			−0.142 ***				
			(−3.769)				
HCI × DT			0.008 ***				
			(3.573)				
BI					0.012 ***		
					(3.129)		
PI							0.012 ***
							(6.840)
Age	−0.012 ***	−0.011 ***	−0.010 ***	0.022	−0.013 ***	0.016	−0.010 ***
	(−5.977)	(−5.825)	(−5.276)	(0.430)	(−2.879)	(0.496)	(−4.531)
Lev	−0.008 *	−0.009 **	−0.009 **	−0.182	−0.010	0.007	−0.011 **
	(−1.787)	(−2.190)	(−2.107)	(−1.638)	(−1.006)	(0.102)	(−2.174)
Soe	0.004	0.004	0.004	0.089	−0.007	0.052	0.004
	(1.333)	(1.317)	(1.413)	(0.947)	(−0.864)	(1.035)	(1.258)
Size	0.035 ***	0.032 ***	0.031 ***	0.710 ***	0.020 ***	0.703 ***	0.024 ***
	(21.114)	(18.091)	(18.002)	(17.459)	(4.333)	(23.084)	(9.755)
_cons	−0.693 ***	−0.700 ***	0.000	1.123	−0.696 ***	0.630	−0.705 ***
	(−19.477)	(−19.743)	(0.357)	(1.348)	(−9.419)	(0.997)	(−16.084)
Firm fixed effect	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES
N	2983	2983	2983	698	698	2192	2192
R^2	0.972	0.972	0.972	0.986	0.976	0.978	0.975
F	91.530	80.695	62.891	86.285	19.561	147.390	50.257

Note: ***, **, * denote significance levels of 1%, 5% and 10%, respectively.

Column (2) of Table 4 shows that human capital investment has a significantly positive effect on the resilience of high-end manufacturing firms, which indicates that firms can significantly improve their resilience through human capital investment; thus, H1 is verified. Column (3) of Table 4 shows that the coefficient of interactivity HCI×DT is 0.008, which is significant at the 1% level. Moreover, both the coefficient of interactivity HCI×DT and the coefficient of human capital investment in Column (2) of Table 4 are positive, showing that higher-level digital transformation has a positive moderating effect on the relationship between human capital investment and the resilience of high-end manufacturing enterprises. Therefore, H2 is verified. As can be seen from Column (4) of Table 4, human capital investment has a significant positive impact on breakthrough innovation. Column (5) of Table 4 shows that human capital investment and breakthrough innovation positively impact enterprise resilience. Combined with the results in Column (2), we can see that breakthrough innovation partially mediates between human capital investment and the resilience of high-end manufacturing enterprises; thus, H3 is verified. Column (6) of Table 4 shows that human capital investment has a significantly positive impact on progressive innovation. Column (7) of Table 4 shows that both human capital investment and progressive innovation have a positive impact on the resilience of high-end manufacturing enterprises. Combined with the results in Column (2), progressive innovation partially mediates the relationship between human capital investment and resilience of high-end manufacturing enterprises. H4 is verified.

5.3. Robustness Test

5.3.1. Changing Sample Size

After removing the samples from 2018, we performed the above regression based on the samples from 2019 to 2022, and the results are shown in Table 5.

We can conclude from Table 5 that neither the main effects nor the mediating effects change substantially from the previous regression results, indicating that the regression results in this paper are relatively robust.

Table 5. Regression results after changing the sample size.

	(1) **ER**	**(2)** **ER**	**(3)** **BI**	**(4)** **ER**	**(5)** **PI**	**(6)** **ER**
HCI		0.003 ***	0.148 ***	0.004 *	0.091 ***	0.002 *
		(3.362)	(5.837)	(1.746)	(5.124)	(1.670)
BI				0.013 ***		
				(3.198)		
PI						0.011 ***
						(5.915)
Age	−0.008 ***	−0.008 ***	−0.003	−0.008 *	0.063	−0.006 **
	(−3.777)	(−3.742)	(−0.046)	(−1.659)	(1.612)	(−2.510)
Lev	−0.010 **	−0.011 **	−0.054	−0.006	−0.006	−0.013 ***
	(−2.205)	(−2.494)	(−0.441)	(−0.617)	(−0.079)	(−2.647)
Soe	0.003	0.003	0.088	−0.005	0.047	0.005
	(0.921)	(0.846)	(0.847)	(−0.569)	(0.856)	(1.267)
Size	0.036 ***	0.034 ***	0.708 ***	0.020 ***	0.685 ***	0.027 ***
	(19.586)	(17.521)	(14.889)	(4.252)	(18.494)	(10.035)
_cons	−0.731 ***	−0.739 ***	0.731	−0.666 ***	1.432 *	−0.773 ***
	(−18.143)	(−18.365)	(0.745)	(−8.557)	(1.832)	(−15.278)
Firm fixed effect	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
N	2439	2439	587	587	1759	1759
R^2	0.982	0.982	0.988	0.983	0.982	0.983
F	78.001	67.262	63.565	14.214	87.752	42.630

Note: ***, **, * denote significance levels of 1%, 5% and 10%, respectively.

5.3.2. Robustness Test Based on Bootstrap

The paper further applies the Bootstrap method to test the robustness of the mediating effect, and the results are shown in Table 6.

Table 6. Results of robustness tests for the mediation effect.

		Observed Coefficient	Bootstrap Std. Err.	z	$p > z$	Normal Based [95% Conf. Interval]	
ER	Indirect Eff	0.019	0.002	12.150	0.000	0.016	0.022
	Direct Eff	0.008	0.002	3.850	0.000	0.004	0.013
	Total Eff	0.028	0.002	13.600	0.000	0.024	0.032

As can be seen from Table 6, the confidence intervals for each set of results do not contain 0, indicating a significant mediation effect. The Bootstrap test results are consistent with the stepwise regression results, indicating a robust mediation effect.

5.4. Endogeneity Test

Considering that there may be a causal relationship between human capital investment and the resilience of high-end manufacturing firms, drawing on the method of Hu et al., this paper conducts an endogeneity test by lagging human capital investment by one period and taking the deviation form of human capital investment as the instrumental variable [55]. The regression results of the endogeneity test using human capital investment lagged by one period are shown in Table 7.

Table 7 shows that the regression results do not change substantially from the previous basic regression results, indicating that there is no endogeneity between human capital investment and resilience of high-end manufacturing firms.

Table 7. Regression results for explaining variables lagged by one period.

	(1) ER	(2) ER
L_HCI		0.002 **
		(2.464)
Age	−0.012 ***	−0.013 ***
	(−5.962)	(−4.024)
Lev	−0.008 *	−0.007 *
	(−1.806)	(−1.656)
Soe	0.004	0.002
	(1.311)	(0.551)
Size	0.034 ***	0.035 ***
	(20.998)	(17.697)
_cons	−0.694 ***	−0.743 ***
	(−19.502)	(−17.233)
Firm fixed effect	YES	YES
Year fixed effect	YES	YES
N	2983	2214
R^2	0.972	0.983
F	76.490	51.550

Note: ***, **, * denote significance levels of 1%, 5% and 10%, respectively.

In this paper, the deviation form of human capital investment is selected as an instrumental variable, i.e., according to the six industrial categories of sample firms, the value of the human capital investment of each firm minus the average value of the human capital investment in the corresponding industry is utilized as an instrumental variable for the human capital investment variable of each firm. There are three tests for instrumental variables: under-identification test, weak identification test, and overidentification test.

Since the number of instrumental and endogenous variables in this paper is equal, the results of the overidentification test Sargan statistic can be disregarded. Table 8 presents the results of the under-identification test and weak identification test. The under-identification test of instrumental variables is conducted using the Kleibergen-Paap rk LM Test. The results show that the statistic values obtained by this model are all relatively large, with a *p*-value of less than 0.01. This means that the original hypothesis of under-identification of instrumental variables can be rejected, indicating the validity of the instrumental variables. The weak instrumental variables test results show that the F-statistics of the models are all very large, and the original hypothesis that redundant instrumental variables exist can be strongly rejected. Therefore, we have sufficient reason to believe that there are no weak instrumental variables.

Table 8. Instrumental Variable Test.

Under-Identification Test (Kleibergen-Paap rk LM Statistic)	Weak Identification Test (Cragg-Donald Wald F Statistic)	Weak Identification Test Critical Values (Stock-Yogo Weak ID F Test Critical Values)
202.051 ***	63,000	16.38 (10% maximal IV size)

Note: *** denotes a significance level of 1%.

After passing the test, the instrumental variables are regressed, and the results are shown in Table 9.

As Table 9 shows, the regression results do not change substantially from the basic regression results, indicating that there is no endogeneity between human capital investment and the resilience of high-end manufacturing firms.

Table 9. Instrumental variables regression results.

	Basic Regression ER	2sls-IV ER
HCI	0.004 ***	0.012 ***
	(4.722)	(5.42)
Age	−0.011 ***	−0.003
	(−5.825)	(−1.53)
Lev	−0.009 **	−0.248 ***
	(−2.190)	(−3.20)
Soe	0.004	0.008 **
	(1.317)	(2.21)
Size	0.032 ***	0.035 ***
	(18.091)	(10.17)
_cons	−0.700 ***	−0.948 ***
	(−19.743)	(−16.30)
Firm fixed effect	YES	YES
Year fixed effect	YES	YES
N	2983	2983
R^2	0.972	0.546
F	80.695	63.000

Note: *** and ** denote significance levels of 1% and 5%, respectively.

6. Further Analysis

6.1. Threshold Effect Analysis

With continuous investment in human capital, the overall enterprise staff's inner quality and professional skills will be significantly improved. When faced with a crisis event, the diversification of human capital can produce more effective solutions through reorganizing and integrating knowledge. Continuous investment in technological innovation also helps enterprises break through core technology in critical areas, generating

more innovation and forming a cumulative effect [56]. Based on the sample data, scatter plots of the relationship between human capital investment and the resilience of high-end manufacturing enterprises and the relationship [57] between technological innovation and the resilience of high-end manufacturing enterprises are drawn in Figures 2 and 3, respectively.

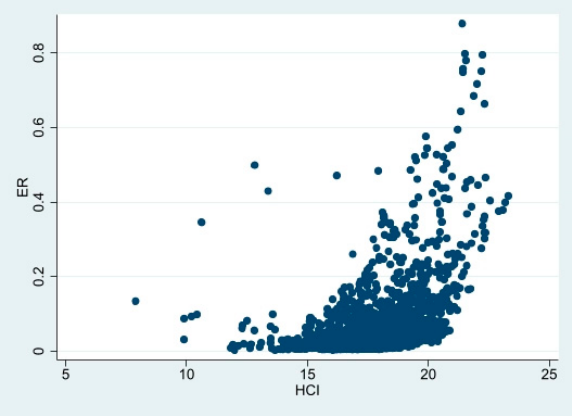

Figure 2. Scatter plot of human capital investment and enterprise resilience.

The scatter plot shows that most high-end manufacturing companies are at a low resilience level, but some have surpassed the threshold and become highly resilient. As a result, this paper argues that there may be a human capital investment threshold and a technological innovation threshold in the influential relationship between human capital investment, technological innovation, and the resilience of high-end manufacturing enterprises.

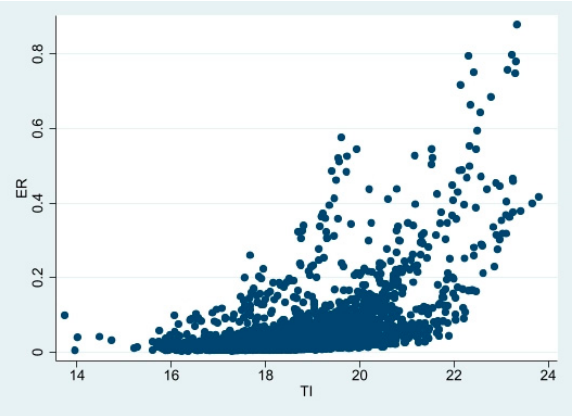

Figure 3. Scatter plot of technological innovation and enterprise resilience.

In order to test the threshold effect between human capital investment, technological innovation, and the resilience of high-end manufacturing enterprises, this paper constructs the following models.

$$ER_{i,t} = \lambda_0 + \lambda_1 HCI \times I(HCI \leqslant \varphi_1) + \lambda_2 HCI \times I(\varphi_1 < HCI \leqslant \varphi_2) + \cdots + \lambda_{n+1} HCI \times I(HCI > \varphi_n) + \lambda_{n+2} Controls + \varepsilon_{i,t} \quad (8)$$

$$ER_{i,t} = \phi_0 + \phi_1 HCI \times I(TI \leqslant v_1) + \phi_2 HCI \times I(v_1 < TI \leqslant v_2) + \cdots + \phi_{n+1} HCI \times I(TI > v_n) + \phi_{n+2} Controls + \varepsilon_{i,t} \quad (9)$$

In both models, $I(\cdot)$ is the characteristic function, which takes 1 if the condition in parentheses can be established and 0 otherwise; φ and v are the threshold coefficients to be

estimated, and the rest of the variables have the same meaning as in the previous models. Based on Model (8) and Model (9), the Bootstrap method is used to sample 300 times autonomously for the threshold effect test, and the results are shown in Table 10.

Table 10. Threshold effect test results.

Threshold Variable	Number of Thresholds	F Value	*p*-Value	Threshold Value		
				1	2	3
Human capital Investment (HCI)	Single threshold	3074.71	0.000	19.8349		
	Double threshold	437.88	0.045	19.8349	20.6095	
	Triple threshold	347.6	0.572	19.8349	20.6095	21.523
Technological Innovation (TI)	Single threshold	2464.48	0.000	21.3422		
	Double threshold	401.5	0.081	21.3422	22.0317	
	Triple threshold	303.17	0.089	21.3422	22.0317	22.5573

As seen from Table 10, the *p*-value of the single and double thresholds of human capital investment is less than 0.1, which passes the significance test. However, the *p*-value of the triple threshold is greater than 0.1, which fails the significance test and indicates the existence of double thresholds for human capital investment. The *p*-value of the triple threshold of technological innovation is less than 0.1 and passed the significance test, indicating that there is a triple threshold of technological innovation.

From Table 10, it can be seen that the two thresholds of human capital investment are 19.8349 and 21.523, respectively. Accordingly, the whole sample is divided into three groups: low human capital investment ($\varphi < 19.8349$), medium human capital investment ($19.8349 < \varphi < 21.523$), and high human capital investment ($\varphi > 21.523$). Based on Model (8), regression was performed for each subgroup sample, and the results are shown in Table 11. From the group regression results, it can be seen that the regression coefficients of human capital investment on the resilience of high-end manufacturing enterprises become larger with the increase in human capital investment, indicating that in the stage of high human capital investment, the marginal contribution of human capital investment to enhance the resilience of high-end manufacturing enterprises is greater. Further analysis of the sample data reveals that the sum of medium human capital investment enterprises and high human capital investment enterprises between 2018 and 2022 is 28, 41, 40, 48, and 53, respectively, which suggests that through sustained human capital investment, some high-end manufacturing enterprises have achieved a qualitative leap through quantitative accumulation and significantly improved their corporate resilience.

Table 11. Threshold effect regression results.

Threshold Variable	Interval	Regression Coefficient	T Value	*p*-Value	Number of Samples
Human capital investment (HCI)	$\varphi < 19.8349$	0.0031	2.29	0.022	2789
	$19.8349 < \varphi < 21.523$	0.0045	3.26	0.001	180
	$\varphi > 21.523$	0.0073	4.02	0.000	30
Technological innovation (TI)	$\phi < 21.3422$	0.0035	2.63	0.009	2879
	$21.3422 < \phi < 22.0317$	0.0048	3.39	0.001	60
	$22.0317 < \phi < 22.5573$	0.0085	4.60	0.000	29
	$\phi > 22.5573$	0.0105	4.87	0.000	31

The three thresholds of technological innovation are 21.3422, 22.0317, and 22.5573, respectively. Accordingly, we divide the entire sample into four groups: low technolog-

ical innovation ($\phi < 21.3422$), medium-low technological innovation ($21.3422 < 22.0317$), medium-high technological innovation ($22.0317 < 22.5573$), and high technological innovation (22.5573). Regression on each grouped sample is performed based on Model (9), and the results are shown in Table 11. It can be seen from the group regression results that with the improvement in technological innovation level, the regression coefficient of human capital investment on the resilience of high-end manufacturing enterprises increases successively. Compared with the results of the full sample regression, the positive impact of human capital investment on the resilience of medium-high technological innovation enterprises and high technological innovation enterprises is significantly increased. In addition, low technological innovation samples accounted for about 95%, indicating that the technical innovation level of the vast majority of high-end manufacturing enterprises needs to be improved.

6.2. Heterogeneity Analysis

6.2.1. Heterogeneity Analysis Based on Segmented Capabilities of Enterprise Resilience

Based on the definition of enterprise resilience and the constructed evaluation index system, significant differences exist between the three segmented capabilities that comprehensively form enterprise resilience. Thus, for high-end manufacturing enterprises, the impact of human capital investment on the three segmented enterprise resilience capabilities may also differ. Given this, this paper regresses the three segmentation capability indices in place of the firm resilience indices in Model (3), Model (5), and Model (7), respectively, and the results are shown in Table 12.

From the regression results in Column (1), Column (2), and Column (3) of Table 12, it can be seen that the sustained investment in human capital by high-end manufacturing firms has a significant positive effect on the ability to resist risks and adapt to adjustments. However, the effect on the ability to recover and rebound is insignificant. From the regression results in Column (4), Column (5), Column (6), and Column (7) of Table 12, breakthrough innovation has a significant positive impact on the ability to resist risks and adapt to adjustments. However, it has no significant impact on the recovery and rebound ability. Human capital investment has a significantly positive impact on the ability to resist risk and adapt to adjustments. However, it also hurts the ability to recover and rebound. This indicates that breakthrough innovation partially mediates the effects of human capital investment on the ability to resist risks and adapt to adjustments, but does not affect the relationship between human capital investment and the ability to recover and rebound. From the regression results in Column (8), Column (9), Column (10), and Column (11) of Table 12, progressive innovation has a significant positive impact on all three kinds of segmented capabilities of enterprise resilience. Human capital investment has a significant positive effect on the ability to resist risks and adapt to adjustments, but does not significantly affect the ability to recover and rebound. This finding indicates that progressive innovation partially mediates the effect of human capital investment on the ability to resist risk and adapt to adjustments. It also mediates the relationship between human capital investment, recovery, and rebound ability. It follows that routine human capital investment helps improve the ability of high-end manufacturing enterprises to resist risks and adapt to adjustments. However, its contribution to their ability to recover and rebound is limited. If high-end manufacturing enterprises want to recover from a crisis and rebound, they inevitably need to break through the constraints of crucial areas and cultivate their core technological advantages. This requires them to update the concept of human capital investment in time and pay attention to introducing and fully using first-class talent. During the recovery period after the crisis, enterprises should pay more attention to progressive innovation and seek development, while maintaining stability. To

recover is the first thing, and then break through the bondage of critical areas through the introduction of first-class talents, so as to rebound.

Table 12. Heterogeneity analysis (segmented capabilities of enterprise resilience).

	(1) ER1	(2) ER2	(3) ER3	(4) BI	(5) ER1	(6) ER2	(7) ER3	(8) PI	(9) ER1	(10) ER2	(11) ER3
HCI	0.006 ***	0.005 ***	−0.003	0.123 ***	0.009 ***	0.009 ***	−0.006 *	0.117 ***	0.004 ***	0.002 *	−0.003
	(5.476)	(4.661)	(−1.456)	(6.178)	(4.033)	(3.969)	(−1.674)	(7.549)	(2.720)	(1.704)	(−1.317)
BI					0.013 ***	0.017 ***	−0.005				
					(2.643)	(3.604)	(−0.605)				
PI									0.013 ***	0.011 ***	0.010 ***
									(5.889)	(5.845)	(2.710)
Age	−0.016 ***	−0.012 ***	−0.001	0.022	−0.016 ***	−0.019 ***	0.016 *	0.016	−0.017 ***	−0.010 ***	0.001
	(−6.219)	(−5.559)	(−0.173)	(0.430)	(−2.827)	(−3.621)	(1.671)	(0.496)	(−5.669)	(−4.026)	(0.116)
Lev	−0.010 *	−0.011 **	−0.004	−0.182	−0.010	−0.006	−0.025	0.007	−0.011 *	−0.011 **	−0.011
	(−1.797)	(−2.137)	(−0.428)	(−1.638)	(−0.769)	(−0.515)	(−1.176)	(0.102)	(−1.684)	(−1.991)	(−0.983)
Soe	0.007	0.006	−0.007	0.089	−0.012	−0.007	0.003	0.052	0.009 *	0.005	−0.005
	(1.611)	(1.623)	(−1.119)	(0.947)	(−1.165)	(−0.743)	(0.171)	(1.035)	(1.902)	(1.181)	(−0.656)
Size	0.039 ***	0.031 ***	0.027 ***	0.710 ***	0.027 ***	0.017 ***	0.018 *	0.703 ***	0.030 ***	0.022 ***	0.024 ***
	(17.053)	(15.107)	(7.563)	(17.459)	(4.707)	(3.151)	(1.889)	(23.084)	(9.212)	(7.943)	(4.604)
_cons	−0.877 ***	−0.697 ***	−0.480 ***	1.123	−0.896 ***	−0.751 ***	−0.168	0.630	−0.886 ***	−0.680 ***	−0.590 ***
	(−19.033)	(−16.904)	(−6.596)	(1.348)	(−9.580)	(−8.521)	(−1.071)	(0.997)	(−15.215)	(−13.468)	(−6.265)
Firm fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	2983	2983	2983	698	698	698	698	2192	2192	2192	2192
R^2	0.972	0.960	0.881	0.986	0.973	0.969	0.878	0.978	0.974	0.962	0.885
F	76.650	59.789	10.459	86.285	19.270	17.572	2.113	147.390	45.879	35.302	8.619

Note: ***, **, * denote significance levels of 1%, 5% and 10%, respectively.

6.2.2. Heterogeneity Analysis Based on the Nature of Property Rights

High-end manufacturing enterprises' own business mechanisms and ability to acquire and integrate various resources are important factors affecting enterprise resilience. In China, compared with state-owned enterprises, non-state-owned enterprises often have greater autonomy and a more prominent advantage in the business mechanism. Compared with non-state-owned enterprises, state-owned enterprises have government credit endorsements, which give them a prominent advantage in acquiring and integrating resources. In order to explore the variability of the impact of human capital investment on the resilience of high-end manufacturing firms with different property rights, this paper conducted a group regression on the research samples based on property rights, and the results are shown in Table 13.

Table 13. Heterogeneity analysis (nature of enterprise property rights).

	Soe = 1				Soe = 0			
	ER	ER1	ER2	ER3	ER	ER1	ER2	ER3
HCI	0.002	0.006 ***	0.002	−0.002	0.006 ***	0.007 ***	0.007 ***	−0.003
	(1.518)	(2.955)	(1.085)	(−0.629)	(4.992)	(4.484)	(5.215)	(−1.170)
Age	−0.006	−0.017	−0.006	0.011	−0.010 ***	−0.013 ***	−0.012 ***	0.000
	(−0.754)	(−1.646)	(−0.687)	(0.700)	(−5.015)	(−4.993)	(−4.850)	(0.013)
Lev	−0.008	−0.015	−0.012	0.019	−0.009 **	−0.009	−0.010 *	−0.010
	(−0.770)	(−1.101)	(−0.980)	(0.874)	(−2.013)	(−1.454)	(−1.784)	(−1.016)
Size	0.042 ***	0.047 ***	0.043 ***	0.033 ***	0.029 ***	0.037 ***	0.027 ***	0.024 ***
	(9.941)	(8.738)	(9.127)	(3.855)	(14.897)	(14.675)	(11.851)	(6.091)
_cons	−0.923 ***	−1.068 ***	−0.950 ***	−0.679 ***	−0.661 ***	−0.844 ***	−0.656 ***	−0.428 ***
	(−9.936)	(−8.917)	(−9.144)	(−3.569)	(−17.497)	(−17.062)	(−14.557)	(−5.480)
Firm fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
N	861	861	861	861	2103	2103	2103	2103
R^2	0.977	0.976	0.969	0.902	0.968	0.968	0.952	0.859
F	21.488	20.253	17.630	3.049	62.942	58.919	45.057	7.130

Note: ***, **, * denote significance levels of 1%, 5% and 10%, respectively.

As can be seen from Table 13, in China's high-end manufacturing industry, from the perspective of whole enterprise resilience, human capital investment has a significant

positive effect on non-state-owned firms' resilience. In contrast, it has no significant effect on state-owned firms' resilience. In terms of the three segmented capabilities of enterprise resilience, human capital investment in non-state-owned enterprises has a significant positive effect on both risk resistance and adjustment adaptation capacity and no significant effect on the recovery and rebound ability; human capital investment in state-owned enterprises has a significant positive effect on risk resistance capacity, and no significant effect on the ability to adapt to adjustments and the ability to recover and rebound. More flexible business mechanisms can help non-state-owned enterprises continuously improve their resilience through human capital investments.

6.2.3. Heterogeneity Analysis Based on the Enterprise Size

The size of high-end manufacturing enterprises is an essential factor affecting their resilience. Compared with large-scale enterprises, small-scale enterprises tend to have a higher sensitivity to the market. At the same time, due to the concise organizational structure, adjusting business direction and technology is relatively easier, and the flexibility of enterprises is improved. Compared with small-scale enterprises, large-scale enterprises have the advantage of economies of scale and find it easier to obtain low-cost external financing. In order to explore the difference in the impact of human capital investment on the resilience of high-end manufacturing enterprises of different sizes, this paper conducted a group regression on research samples based on the enterprise size. Those greater than or equal to the median are labeled large-scale enterprises, while those less than the median are labeled small-scale enterprises. The results are shown in Table 14.

As seen from Table 14, in terms of overall enterprise resilience, the human capital investment of large-scale enterprises has a significant positive impact on enterprise resilience, while that of small-scale enterprises has no significant impact on enterprise resilience. Regarding the three sub-capabilities of enterprise resilience, the human capital investment of large-scale enterprises has a significant positive impact on their ability to resist risks and adapt to adjustments. However, it has no significant impact on the recovery and rebound ability. The human capital investment of small-scale enterprises has a significant positive effect on their ability to resist risks but has no significant effect on their ability to adapt to adjustments, recover, and rebound. We can conclude that large-scale enterprises have a relatively rich variety of resources, forming a scale effect that helps reduce enterprise operating costs, eases external financing, and is more conducive to improving enterprise resilience.

Table 14. Heterogeneity analysis (enterprise size).

	Large-Scale Enterprise				Small-Scale Enterprise			
	ER	**ER1**	**ER2**	**ER3**	**ER**	**ER1**	**ER2**	**ER3**
HCI	0.006 ***	0.008 ***	0.007 ***	−0.005	0.001	0.002 ***	0.001	−0.000
	(3.695)	(4.154)	(3.864)	(−1.450)	(1.541)	(3.368)	(1.008)	(−0.196)
Age	−0.009 *	−0.014 **	−0.009	−0.003	−0.004 ***	0.001	−0.004 ***	−0.010 ***
	(−1.688)	(−1.999)	(−1.448)	(−0.287)	(−3.163)	(0.470)	(−2.810)	(−3.753)
Lev	−0.009	−0.005	−0.014	0.006	−0.001	0.003	0.000	−0.009
	(−0.796)	(−0.367)	(−1.099)	(0.262)	(−0.231)	(1.200)	(0.063)	(−1.497)
Soe	0.004	0.006	0.005	−0.004	0.000	0.002	0.001	−0.005
	(0.810)	(0.889)	(0.867)	(−0.345)	(0.012)	(0.840)	(0.230)	(−0.923)
Size	0.047 ***	0.060 ***	0.047 ***	0.036 ***	0.014 ***	0.011 ***	0.013 ***	0.022 ***
	(13.070)	(12.780)	(11.049)	(4.756)	(9.935)	(8.049)	(8.019)	(6.593)
_cons	−1.099 ***	−1.406 ***	−1.122 ***	−0.645 ***	−0.275 ***	−0.240 ***	−0.264 ***	−0.383 ***
	(−13.867)	(−13.727)	(−12.070)	(−3.927)	(−9.993)	(−8.977)	(−8.094)	(−5.888)
Firm fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
N	1463	1463	1463	1463	1458	1458	1458	1458
R^2	0.974	0.973	0.962	0.880	0.958	0.967	0.934	0.890
F	39.293	38.857	29.956	4.043	21.183	21.824	13.714	8.699

Note: ***, **, * denote significance levels of 1%, 5% and 10%, respectively.

7. Research Conclusions and Limitations

7.1. Conclusions and Implications

Based on the concept definition and mechanism analysis, this paper empirically investigates the impact of human capital investment and technological innovation on the resilience of high-end manufacturing enterprises based on the relevant data of 682 high-end manufacturing enterprises from 2018 to 2022 in China as research samples. The study results show that human capital investment has a significant positive effect on the resilience of high-end manufacturing firms, in which both breakthrough and progressive innovation play a partly mediating role. Further research shows that (1) human capital investment and technological innovation have a threshold effect on high-end manufacturing enterprises' resilience. (2) Regarding the segmented capabilities of enterprise resilience, human capital investment has a significant positive impact on their abilities to resist risks and adapt to adjustments. Meanwhile, there is no significant impact on the ability to recover and rebound. Breakthrough innovation partially mediates the effects of human capital investment on the ability to resist risks and adapt to adjustments, but has no effect on the relationship between human capital investment and the ability to recover and rebound. Progressive innovation partially mediates the influence of human capital investment on the ability to resist risk and adapt to adjustments. It also completely mediates the relationship between human capital investment and the ability to recover and rebound. (3) Human capital investment in Chinese non-state-owned enterprises has a significant positive effect on overall enterprise resilience, while it has no significant effect on state-owned enterprises. Human capital investment in non-state-owned enterprises has a significant positive effect on both risk resistance and adjustment adaptation capacity, but has no significant effect on the ability to recover and rebound; human capital investment in state-owned enterprises has a significant positive effect on their ability to resist risks, but has no significant effect on their ability to adapt to adjustments, as well as their ability to recover and rebound. (4) The human capital investment of large-scale enterprises has a significant positive impact on the overall resilience of enterprises, while that of small-scale enterprises has no significant impact. In terms of the three sub-capacities, human capital investment in large-scale enterprises has a significant positive effect on the ability to resist risks and adapt to adjustments, but has no significant effect on the ability to recover and rebound. The human capital investment of small-scale enterprises has a significant positive effect on the ability to resist risks but has no significant effect on the ability to adapt to adjustments and recover and rebound.

Based on the above results, this paper proposes the following management recommendations:

(1) Adhere to the people-oriented concept and attach importance to human capital investment. Human capital is a critical factor in cultivating and enhancing the resilience of high-end manufacturing enterprises. These enterprises need managers with strategic decision-making abilities and excellent leadership abilities, as well as employees with professional competence, a sense of identity in the corporate culture, and conscientious and responsible qualities. Therefore, they should pay attention to cultivating, uniting, and leading talent and constantly strengthen the construction of the talent team. This requires high-end manufacturing enterprises in the recruitment process to thoughtfully select candidates based on education, experience, ability, and other aspects; at the same time, they should systematically strengthen staff training and development to constantly improve the staff's professional competence and comprehensive quality and enhance the staff's sense of identity to the corporate culture. In addition, it is also necessary to build an effective incentive mechanism to continuously enhance staff's sense of belonging and sense of mission, as well as their sense of responsibility.

(2) Adjust human capital investment strategies and optimize the human capital structure. In the face of a complex and changing living environment, high-end manufacturing enterprises need to update the concept of human capital, adjust the human capital investment strategy, and cultivate many strategic safeguard talents, first-class scientific and technological leaders, and innovation teams in crucial core areas to ensure that the enterprise owns abundant frontrunners in the field of core technology and many pioneers in cutting-edge areas. In addition, enterprises should improve their talent management systems and manage to trust, respect, treat, and tolerate talent to make it talent-oriented. They should give first-class talents greater rights to decide on technical routes, allocate research and development funds, and dispatch resources. They must make efforts to create an open, tolerant, equal, and accessible working environment for all kinds of talent.

(3) Maintain strategic strength and continue to strengthen human capital investments and technological innovation. In the process of cultivating and enhancing high-end manufacturing enterprises' resilience, human capital investment and technological innovation have multiple threshold effects; therefore, these firms need to maintain strategic determination, adhere to long-term, and continue to strengthen human capital investment and technological innovation to promote more high-end manufacturing enterprises to accomplish qualitative leaps through quantitative accumulation and significantly enhance enterprise resilience.

7.2. Limitations and Prospect

The limitations of this study and the outlook for the future are as follows: (1) The sample used in this study contains six industries, that is, pharmaceutical manufacturing, general-purpose equipment manufacturing, special-purpose equipment manufacturing, instrument and meter manufacturing, computer, communications and other electronic equipment manufacturing, and railroad, ship, aerospace, and other transportation equipment manufacturing, whereas each of these has its own characteristics, which can be further studied in the future by subdividing industries; (2) Based on the connotation of enterprise resilience, this study constructs a resilience evaluation index system for high-end manufacturing enterprises, and subsequent studies can verify the effectiveness of this evaluation index system; (3) There is no breakdown of human capital investment in this study. In the future, the influence of human capital structure and the type of human capital on enterprise resilience can be discussed in combination with personnel's educational level and job demand; (4) In future studies, more reasonable instrumental variables can be introduced to strictly test the endogenous relationship between human capital investment and enterprise resilience; (5) This study examines the relationship between human capital investment, technological innovation, and the resilience of high-end manufacturing enterprises through empirical analysis. Future studies may consider adding case studies.

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