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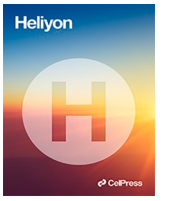

The impact of environmental regulation, Environment, Social and Government Performance, and technological innovation on enterprise resilience under a green recovery

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ABSTRACT

In recent years, the world has witnessed an alarming rise in extreme events, posing significant challenges to the survival and growth of enterprises. In response, adopting a green development strategy has emerged as an imperative for businesses to bolster their resilience. It is crucial to recognize that not all enterprises possess the same level of resilience, thereby highlighting the disparities in their ability to withstand adversity. Consequently, scholars have been fervently engaging in discussions and research to identify the most effective paths of green development, enabling enterprises to enhance their resilience and adeptly navigate through crises. This study employs questionnaires to scrutinize the influence of environmental regulation, environment social and government performance, and technological innovation on enterprise resilience by constructing structural equations that encompass both external constraints and internal corporate management. The findings demonstrate that environmental regulations can stimulate technological innovation for the purpose of promoting sustainable development, thereby bolstering enterprise resilience; By incorporating environment social and government principles into their operations, enterprises can instil a culture of environmental consciousness and proactively incentivize innovative solutions, ultimately enhancing their capacity to adapt swiftly and recover from crises; The practice of environmental regulation and the incorporation of environment social and government concepts serve as a catalyst for enterprises to engage in technological innovation, thereby promoting technological advancement and enhancing corporate resilience.

1. Introduction

The survival and growth of businesses have been severely tested by the impact of extreme events such as pandemics and financial crises. Since the global financial crisis in 2009, countries worldwide have pursued new avenues for economic growth. However, due to the persistent effects of the COVID-19 pandemic, the S&P 500 Index experienced a significant decline of 19.33% in 2022. Although many countries declared an end to the pandemic in 2023 and witnessed a global economic rebound, it will take considerable time for businesses to recover. For instance, China experienced a rapid economic resurgence following the end of the pandemic; nevertheless, during the first two months of 2023, profits among Chinese industrial enterprises above the national scale declined by 22.9%, with a

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notable drop of 32.6% recorded within the manufacturing sector alone. These statistics place corporate resilience under unprecedented scrutiny within society.

The term resilience was initially introduced by Holling [1] to characterize the capacity of ecosystems to adapt to changes in their external environment and quantitatively assess their velocity and efficacy in returning to their initial state. Presently, it is extensively employed across various fields and disciplines [2]. Especially in the aftermath of the global financial crisis, resilience has emerged as a crucial strategic approach in business and management for organizations to thrive amidst turbulent business environments [3]. Enterprise resilience encompasses the capacity of a firm to sustain robust operations, adaptability, and resilience when confronted with external shocks, challenges, or unfavourable circumstances [4]. It is a comprehensive concept influenced by three key factors: individuals, firms, and the environment [5]. Individual factors of influence pertain to the cognitive level of top management and their teams [6]; enterprise factors of influence relate to the crisis-stricken enterprises' capacity for learning and innovation [7]; while environmental factors encompass external dynamics [8]. These determinants shape a company's flexibility, adaptability, innovative prowess, and resource management efficacy, constituting pivotal elements in bolstering enterprise resilience [9]. The speed at which enterprises recover from disruptive events exhibits significant variation, reflecting the heterogeneity in enterprise resilience.

In response to disruptive events, enterprises often prioritize enhancing the flexibility and adaptability of their operations to bolster their responsiveness to external risks by leveraging their own learning capabilities. This process of organizational response to environmental changes through flexibility and adaptability typically serves as a catalyst for innovation [10]. The concept of green development represents a paradigm shift from traditional approaches, embodying a novel model that acknowledges the limitations imposed by ecological and environmental capacity as well as resource-carrying capacity. By prioritizing environmental protection as a fundamental pillar, it strives to achieve sustainable development. Consequently, this approach has garnered increasing recognition worldwide [11]. Enterprises that embrace green development and seize the new international trend can gain a relative competitive advantage, breakthrough resource and environmental bottlenecks, lead the concept of green consumption, enhance their market position and social influence, and broaden their resilience. Technological innovation capability is crucial for enterprises to pursue green development and improve resilience. It also plays a positive role in driving sustainable growth [12,13]. In an era where the green concept has become deeply ingrained in the public consciousness, there is a heightened stimulation of consumers' demand for environmentally friendly products [14]. Consequently, corporate management has increasingly recognized the significance of green competitive advantage and actively invested in technological innovation for sustainable development [15]. However, divergent opinions exist within academia. Some argue that the positive impact of technological innovation on firms' environmental progress is primarily observed in affluent nations, with limited or no significant effects found in middle-income and low-income countries [16].

The cognitive abilities of top management and their teams provide intellectual support for the organization's responsiveness and strategic decision-making in times of crisis. The composition and processes of the top management team play a crucial role in determining the strategic direction of corporate development [17]. In recent years, corporate management models based on environmental, social, and governance (ESG) principles have gained widespread recognition. The concept of sustainable development rooted in ESG principles has become a global consensus for corporate advancement [18]. Corporate top management is dedicated to promoting green development and inevitably places greater emphasis on ESG implementation performance while driving economic growth. Furthermore, ESG metrics can serve as indicators of enterprise resilience during periods of corporate crisis [19].

The strategic choices made by an enterprise are contingent upon the external environment in which it operates [20]. Corporate top management's concern for environmental protection and social responsibility is not only influenced by market demand for green products and the proliferation of ESG concepts but also shaped by external environmental regulations. In the absence of mandatory environmental regulations, various voluntary CSR initiatives may not come into existence [21]. Appropriate environmental regulation can foster technological innovation within firms [22]. However, the impact of environmental regulation on technological innovation may vary across different industrial structures, stages of economic development, and types of regulatory instruments employed [23].

According to the aforementioned research, it is evident that environmental regulation, technological innovation, and ESG performance are all pivotal factors influencing enterprise resilience. Considering that enhancing enterprise resilience through green transformation aligns with the contemporary social environment's development trend, this study adopts environmental regulation, technological innovation, and ESG performance as focal points to investigate the mechanisms underlying intrinsic influencing factors of enterprise resilience. The objective is to explore sustainable development pathways for improving enterprise resilience and effectively managing crises in emerging markets [24].

2. Literature review and hypotheses

From an economic perspective, numerous social predicaments arise due to the negative externalities engendered by economic activities. Corporate social responsibility serves as a driving force that leverages economic growth and quality of life to mitigate externalities and bolster enterprise sustainability [25]. According to stakeholder theory, enterprises have a responsibility to fulfil their social obligations and must take into account the interests of stakeholders or accept their limitations when making business decisions. The implementation of environmental, social, and governance (ESG) by enterprises precisely reflects the consideration of stakeholders' interests and the assumption of corporate social responsibility. At a time when environmental pollution and climate change, a by-product of rapid economic development, threaten people's survival and quality of life, the application of ESG concepts in enterprises can urge them to pay attention to social responsibility, increase investment in research and development of emission reduction technologies, improve corporate governance mechanisms, and guide people to advocate green consumption concepts [26], which can ultimately make use of the capital market to correct negative externalities and stimulate positive ones. According to the resource allocation theory, the flow of social resources from one party to another is contingent upon the mechanism of competition. Due to the

lack of constraints from external environmental regulations, the implementation of green management concepts cannot be well promoted by the conscious awareness of top management alone. Therefore, a conceptual framework (Fig. 1) is proposed to explore the interplay between environmental regulation, ESG performance, technological innovation and enterprise resilience, providing novel insights for expediting industrial recovery towards corporate green development.

2.1. Environmental regulation and technological innovation

In the delicate balance between safeguarding the environment and promoting economic growth, what measures can governments take to steer enterprises towards sustainable development? This represents the "Hamlet" level of economic and social discourse regarding the interplay between environmental regulation and technological innovation, a question of economics that has been subject to constant debate since the 1820s up until the present times. There exist two overarching schools of thought regarding environmental regulation and technological innovation. The first, referred to as the restrictive hypothesis, is rooted in neoclassical economics and posits that such regulations impose a heavy burden on enterprises while impeding their progress. For instance, Blackman et al. [27] discovered a negative correlation between environmental regulation and technological innovation, while Brulhart et al. [28] contend that such regulations impede enterprises' green technological innovation behaviour. The latter perspective is commonly referred to as the Porter hypothesis.

Porter & Linde [29] expound on the correlation between environmental regulation and technological innovation within a dynamic analytical framework, suggesting that reasonable environmental regulation provides incentives for regulated enterprises to engage in technological innovation. Jaffe & Palmer [30] developed the Porter hypothesis. They expanded the Porter hypothesis into "weak Porter hypothesis", "strong Porter hypothesis" and "narrow Porter hypothesis ". "The weak Porter hypothesis suggests that environmental regulation stimulates technological innovation; The "strong Porter hypothesis" argues that the benefits of technological innovation induced by environmental regulation exceed the costs and therefore help to promote enterprise exports; The "narrow Porter hypothesis" argues that only appropriate environmental regulation can stimulate enterprises to engage in technological innovation [30]. The formulation of these hypotheses has led to numerous scholars explore the relationship between environmental regulation and technological innovation, and many empirical studies and tests have emerged. Chen et al. [31] verify that there is a significant positive relationship between environmental regulation and investment in green technology innovation (the weak Porter hypothesis). Tang et al. [32] found that environmental regulations in the eleventh Five-Year Plan had a negative impact on small firms, state-owned enterprises, and firms in western and eastern China (the narrow Porter hypothesis). Rubashkina et al. [33] argue that moderate environmental regulations can facilitate the expansion of a country's trade (the strong Porter hypothesis). Nevertheless, divergent opinions exist among scholars regarding the correlation between environmental regulation and technological innovation. Langpap & Shimshack [34] contend that the implementation of environmental regulations escalates firms' expenses, particularly in industries with high ecological costs, which amplifies R&D expenditures and exerts an adverse influence on technological innovation. Xia et al. [35] propose that the relationship between the intensity of environmental regulation and enterprise resilience follows an inverted U-shaped curve. Lin & Chen [36] find a non-linear relationship between environmental regulation and technological innovation. Generally, the prevailing view supports Porter's hypothesis that under environmental regulation stimulation, enterprises will concentrate on differentiated competitive strategies, overcome environmental barriers through technological innovation, disseminate green product concepts, guide green consumption concepts and stimulate demand for green markets. The current debate centres on what type of environmental regulation can better promote technological innovation and whether the existence of such regulations can help companies break into international markets and develop new tracks for international competition [37]. Therefore, we propose the following hypothesis:

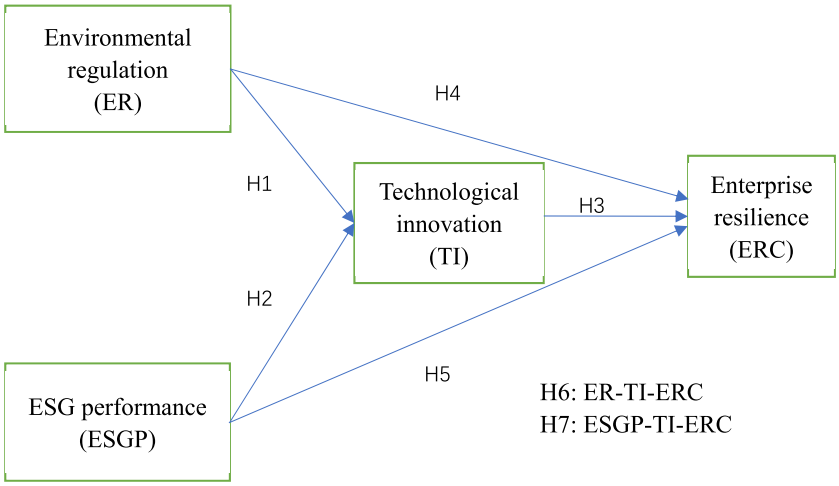

Fig. 1. Conceptual framework.

H 1. Environmental regulation is positively related to technological innovation.

2.2. ESG performance and technological innovation

In 2004, the United Nations Global Compact and 20 financial institutions jointly published the report "Who cares wins". The concept of ESG was first introduced in the report, which called on enterprises to take environmental responsibility, social responsibility and corporate governance into account in their development process.

ESG incorporates existing theories of corporate social responsibility and enriches them with other derived concepts [12]. Since its development, ESG performance has become a key indicator of corporate green development [38]. Technological innovation has an outstanding contribution to addressing environmental pollution and improving ecological quality. Therefore, implementing the ESG concept and promoting green technological innovation to create green products are key steps for enterprises to achieve sustainable development strategies [39].

China's economic development has gradually made the transition from a stage of high growth at the expense of the environment to a stage of high-quality development. People are constantly exploring ways to resolve the contradiction between the people's growing need for a better life and unbalanced and insufficient development. Environmental governance is currently a very prominent contradiction [18].

The green preferences of investors and consumers have increased significantly [40]. Based on stakeholder theory, technological innovation is necessary to meet the social interests of the enterprise's stakeholders. An enterprise's commitment to technological innovation depends on the support of significant social resources. Enterprises that receive resources will further increase their R&D investment and green innovation activities. According to resource allocation theory, the flow of social resources from one side to the other relies on competitive mechanisms. Good ESG performance increases investors' confidence and willingness to invest [41]. Therefore, the indicator for judging the green competitiveness of an enterprise is its ESG performance, and enterprises with good ESG performance place more emphasis on green technological innovation [42]. Therefore, we propose the following hypothesis:

H 2. ESG performance is positively related to technological innovation.

2.3. Technological innovation and enterprise resilience

Resilient organizations are able to maintain positive adjustment in challenging conditions in the context of environmental change or the threat of disaster. Among other things, innovation is key to enabling businesses to recover from a recession [43]. In 2014 the European Commission suggested that innovation is essential to increase resilience to economic crises [44]. Madrid-Guijarro et al. [45] suggest that enterprises that invest more in R&D tend to perform better in crises and have higher long-term survival rates than their non-innovative counterparts. Innovation is one of the most important and sustainable sources of competitive advantage for enterprises.

Technological innovation can help enterprises reach new levels of performance. Enterprises resilience is typically manifested through crisis perception, which refers to their ability to discern changes in the marketplace, and crisis adaptation, which pertains to their capacity for swift transformation, development of novel products, and iterative updates to the executive team [46]. Crisis perception serves as a metric for assessing the proactive crisis management approach adopted by companies. Technological innovation plays a pivotal role in effective crisis management [47]. Coccia [48] contends that crises often give rise to intricate challenges, and technological innovations emerge as solutions to address these specific problems. The assimilation of novel technologies and experiential learning can bolster an enterprise's resilience against crises [49]. The emergence of novel technologies and the introduction of innovative products are commonplace during this stage. Technological advancements play a crucial role in enterprise development and crisis management, exhibiting a strong correlation with the enhancement of enterprise resilience [46]. Augmenting enterprise resilience can pave the way for enterprises to embark on a trajectory towards innovation and growth. The higher an enterprise's capacity for complex technological innovation, the more resilient it is [50]. Therefore, we propose the following hypothesis:

H 3. Technological innovation is positively related to enterprise resilience

2.4. Environmental regulation and enterprise resilience

The resilience of an enterprise is an important part of its survival and development, as are environmental factors. Some manufacturing industries are not only high-emission and high-energy consumption industries but also pillar industries of the national economy. At present, the model of exchanging the cost of the environment for economic development is no longer in keeping with the times. The development of green energy, the innovation of green products and the promotion of green technology are the directions of strategic development of enterprises. The current level of development of the manufacturing industry makes it difficult to achieve this goal and therefore requires the restraint of environmental regulation. Environmental regulation is an effective way to solve environmental problems, improve industrial structure and enhance the resilience of enterprises [51,52]. Numerous scholars have conducted systematic research on achieving environmental sustainability amidst national economic crises, focusing on attaining high energy efficiency and implementing energy-saving measures. They emphasize the necessity of addressing social and environmental concerns within the framework of crisis management principles [53,54]. Environmental regulation serves as a stimulus for enterprises' crisis perception in the external environment. The ability to perceive environmental crises is indicative of enterprises' risk perception and their level of support for policies on environmental regulation [55]. Additionally, amplifying the salience of future repercussions resulting from environmentally detrimental behaviours (i.e., environmental regulation) can effectively convey the gravity and

immediacy of environmental crises, thereby bolstering enterprises' crisis perceptions [56], and facilitating the implementation of efficacious measures to enhance enterprise resilience. Therefore, we propose the following hypothesis:

H 4. Environmental regulation is positively related to enterprise resilience

2.5. ESG performance and enterprise resilience

An organization's ESG factors can serve as indicators of its resilience and sustainability. There is a causal relationship between ESG investments and growth in organizational revenue, profitability and investor value [57]. Enterprise development requires external support to remain resilient and competitive in a changing global environment [58]. Finance is a scarce resource. Implementing ESG and disclosing ESG reports to the public can help establish a corporate image, enhance enterprise reputation and improve the ability of enterprises to raise external finance. At the same time, after implementing ESG, an enterprise will pay more attention to the interests of stakeholders, pay more attention to green protection, and be able to compete on the green track earlier in the market, which is conducive to developing new green products, expanding new businesses and carrying out green the transformation, thus enhancing the resilience of the enterprise. Broadstock et al. [59] discovered that ESG performance is inversely correlated with financial risk for corporations. Gregory [60] confirms that enterprises boasting high ESG scores are less susceptible to negative fiscal policies during the Covid-19 pandemic. Zhou [61] discovers that superior ESG performance not only mitigates the volatility of enterprise share prices caused by the Covid-19 crisis, but also enhances enterprise resilience. However, some scholars have presented divergent perspectives. Gianfrate et al. [62] observe that outside of the US, there is no evidence to suggest a correlation between enterprise ESG performance and crisis resistance during the Covid-19 pandemic. Beloskar et al. [63] found limited evidence on the role of ESG performance during a crisis, with little support in the literature from emerging markets. However, their examination of the Indian stock market suggests that in such markets, good ESG performance contributes positively to returns during a crisis. The incorporation of ESG principles by companies to enhance their governance framework reflects their crisis perception capabilities. Moreover, the elevated status of ESG performance indicators can gauge an enterprise's resilience in times of crisis. Therefore, maintaining and enhancing corporate resilience can be achieved through good ESG performance. Consequently, we propose the following hypothesis:

H 5. ESG performance is positively related to enterprise resilience

2.6. Environmental regulation, technological innovation and enterprise resilience

Environmental regulations provide incentives for enterprises to engage in technological innovation, which in turn positively impacts the enhancement of enterprise resilience [13]. Gunasekaran et al. [58] propose, based on a nationwide survey, that streamlining legislation and environmental regulations, alongside technological advancements, have the potential to enhance enterprise resilience. To ascertain whether and how governmental implementation of environmental regulations incentivizes enterprises to embrace technological innovations for crisis resilience improvement, Zhang et al. [64] conducted a "quasi-natural experiment" utilizing data from publicly listed companies in China. The implementation of environmental regulations can ultimately facilitate manufacturing enterprises in making technological innovations and adjustments, thereby enhancing their performance, improving industrial structure, and bolstering enterprise resilience [65]. According to Porter's hypothesis, governmental implementation of environmental regulations serves as a catalyst for technological innovation within enterprises in response to perceived crises. Consequently, these technological advancements enhance the adaptive behavior of enterprises when faced with crises [29]. This hypothesis has undergone extensive examination in both developed and emerging economies [66–68]. According to scholars, it can be found that environmental regulation can promote enterprises to open new development paths through technological innovation and take them to new development areas, thus increasing their resilience. Therefore, we propose the following hypothesis:

H 6. Technological innovation has a mediating effect between Environmental regulation and enterprise resilience

2.7. ESG performance, technological innovation and enterprise resilience

The strength of enterprise resilience is related to the level of technological innovation and management of the enterprise [69]. Management innovation and technological innovation have a significant positive impact on sustainability and organizational performance [70,71]. Promoting green business development through high-quality innovation is a crucial strategy [72]. ESG is an advanced concept to improve the management capacity of companies and stimulate green management innovation. It focuses on the interests of stakeholders and innovation in corporate governance. Good ESG performance of enterprises can help enterprises to obtain scarce financial and human resources, resist the risk of technological innovation and increase enterprise resilience. The development of new green technologies, products and skills facilitates the practice of ESG concepts in enterprises, further increasing their innovation capacity and resilience [73]. It has also been suggested that maintaining a high level of technological innovation by enterprises will result in a large investment of resources that many enterprises may not be able to support in the long term [74]. Very low levels of technological innovation will not be sufficient to prepare for new market requirements and competitive conditions [75]. There is an inverted U-shaped relationship between enterprise technological innovation and enterprise resilience [76]. The intensity of enterprises' investment in technological innovation depends on the performance of ESG concepts on corporate governance [77]. Enterprises value financial and sustainability information, and good ESG performance tends to lead to better financial performance [78]. Therefore, we propose the following hypothesis:

H 7. Technological innovation has a mediating effect between ESG performance and enterprise resilience

3. Methodology

This study uses a questionnaire to measure all variables. Ethical approval for this questionnaire was obtained from the MSU University Ethics Committee. All participants provided informed consent before participating in the survey, and the consent process was approved by the MSU University Ethics Committee.

3.1. Survey instruments

The questionnaire consists of two main parts. The first part is the basic information about the respondents. This part is the demographic variables of the respondents, mainly including age range, education level, gender, geographical location of the respondent enterprise and ownership of the enterprise. The second part is a specific questionnaire scale. The questionnaire consists of four dimensions: environmental regulation, ESG performance, technological innovation and enterprise resilience. The questionnaire is based on a seven-point Likert scale, ranging from "strongly disagree" to "strongly agree" on a scale of 1–7. The questionnaire is based on a seven-point Likert scale, ranging from "strongly disagree" to "strongly agree" on a scale of 1–7. To ensure the reliability and validity of the questionnaire, the scale measures were taken from established scales in the literature and modified to take into account the characteristics of the Chinese manufacturing industry.

3.1.1. Environmental regulation

The measurement of environmental regulation is defined in terms of its classification as an indicator. The degree of constraint of environmental regulation in manufacturing enterprises is measured by the scores assigned to the observed indicators. In general, environmental regulation is divided into three categories: command-and-control regulation, market-based regulation and voluntary regulation [79]. Previous studies in the literature have measured command-and-control regulation in terms of the stringency of environmental standards, the environmental expectations of environmental regulators (including environmental requirements for the enterprises' products and processes), and the severity of penalties for violating environmental regulations [80,81]. Market-based environmental regulation is measured in terms of whether enterprises have the freedom to choose to take environmental action, government incentives for green development (including government subsidies, tax benefits, and payment of emissions deposits), and the promotion of green credit [82]. Voluntary environmental regulation is measured in terms of whether companies voluntarily participate in environmental initiatives; Whether they publish information in a timely and accurate manner; And whether they listen to environmental impact assessment reports issued by experts or relevant institutions and adapt their business management model [83].

3.1.2. ESG performance

The ESG performance of enterprises is based on ESG scores, which measure three aspects of environmental, social and corporate governance respectively. The measurement indicators refer to the ESG evaluation indicators published by Thomson Reuters' China Capital Markets Institute and the China ESG Development Overview 2022. Specific indicators measured include the extent to which the company places a high priority on environmental performance; the integration of environmental protection concepts into the corporate culture; a high level of CSR compliance; the effectiveness of CSR compliance supported by stakeholders; the existence of an excellent corporate management team; and the existence of a sound corporate governance mechanism to address the challenges posed by ESG [84].

3.1.3. Technological innovation

The process of technological innovation is the process of knowledge integration and knowledge creation. Technological knowledge acquisition has an important impact on the innovation capability of enterprises. We adopt the measurement scale proposed by Xiong and Sun [85] to measure technological innovation by dividing it into explicit knowledge acquisition and tacit knowledge acquisition. The acquisition of explicit technological knowledge can directly contribute to the enhancement of an enterprise's technological innovation capability. Tacit knowledge is often latent in complex organizational processes and practices and is often difficult to imitate. Competitors need to have similar experiences to acquire similar knowledge. It's often the source of an organization's differentiated competitive advantage. Therefore, the acquisition of tacit technical knowledge is essential for activities that reflect an enterprise's technological innovation capabilities, such as patenting and developing new products. Indicators include: companies have obtained many patent transfers and patent descriptions from research institutions; Enterprises have gained an understanding of technological trends from many research institutions; Employees have improved their technological innovation capabilities; Employees have acquired many new scientific research and technological development concepts; Employees have improved their understanding of technological trends; And employees have mastered the means and methods of technological development [85].

3.1.4. Enterprise resilience

This paper examines enterprise resilience along two dimensions: crisis perception and crisis adaptation [86]. Crisis perception measures the extent to which enterprises are proactive and able to prepare for crises in advance. Crisis adaptation measures the responses, options and resources available to the enterprise in the event of a crisis. Indicators include: the enterprise has an organizational culture that learns from crises; The enterprise clearly priorities what is important during and after a crisis; the enterprise actively monitors the external environment; The enterprise is prepared for potential problems in advance; Top management is actively

concerned about possible problems in the enterprise; The enterprise is able to collaborate with peers to deal with crises; The enterprise is able to switch quickly from day-to-day mode to crisis response mode; If key people are not available, there are always others who can take their place; When a crisis arises, professional help is easily available [86].

3.2. Sampling and data collection

3.2.1. Sampling

This study focuses on manufacturing companies listed on the main board of Shanghai and Shenzhen A-shares in 2022. Firstly, China, as an emerging market, is still in the early stages of promoting and developing ESG concepts. While the idea of green development was introduced in 2015, explosive growth in ESG practices has only been witnessed in 2021. State-owned enterprises listed on the stock exchange have played a pioneering and leading role in ESG disclosure. Currently, it is primarily listed companies and large enterprises that actively disclose their ESG reports, while small and medium-sized enterprises (SMEs), despite their significant volume and wide range of activities, have not yet fully participated [87]. Moreover, ESG widely spreads in Chinese listed companies in 2021, and the effect of its implementation can only be reflected in 2022. Therefore, the listed companies in 2022 are selected. Secondly, the stock exchanges in mainland China include Shanghai Exchange, Shenzhen Exchange and Beijing Exchange. The Beijing Exchange was only established in November 2021, which is a short period of time. Therefore, choosing companies listed in Shanghai and Shenzhen better reflects the current economic and political situation in China. Thirdly, the manufacturing industries were selected due to their significant representation and the urgent need for technological innovation to address high energy consumption and pollution. Listed companies in this sector face external constraints when implementing ESG practices, requiring substantial investment that may also pose risks of value reduction. Furthermore, as a pillar industry of the national economy and people's livelihoods, the manufacturing sector can strongly influence public perception during ESG implementation.

According to the National Bureau of Statistics of China, the Chinese mainland region as a whole can be divided into three major economic regions. Enterprises are divided into eastern, central, and western regions according to their location. Stratified sampling is used in this study to achieve a balanced representation of enterprises in the three regions. Each region is randomly sampled using stock codes. Listed companies were located according to their stock codes and a top management of the company was randomly identified and invited to participate in the survey. This is because top managements are more knowledgeable than employees about the current state of the enterprise in terms of environmental regulation, ESG implementation and corporate innovation. Only one top management from each listed company is randomly selected to complete the questionnaire. This is because top management of the same company tends to holds similar views [88]. To prevent response bias in the sampling process and to limit the generalizability of the findings [89], the respondents were voluntary and anonymous during the research process.

3.2.2. Data collection

The China Listed Companies Association released a report showing that the number of manufacturing enterprises listed in China's A-shares reached 3313 by the end of 2022, accounting for 65.5% of all A-shares [90]. Therefore, the overall number for this study is 3313. Drawing on the Morgan scale designed by Krejcie & Morgan (1970), the sample size is measured according to the confidence level, confidence interval and overall number. The sample size for this study is 346. Therefore, we define the size of the sample firms as 346. As the questionnaire return rate is less than 100%. And not all the questionnaires received are valid. According to the American

Table 1
Respondent profile.

Demographic Category	Sample Size (n = 312)	%
Gender		
Male	186	59.62%
Female	126	40.38%
Age		
25 and below	0	0
26–35	60	19.23%
36–45	125	40.06%
46–55	93	29.81%
56 than above	34	10.90%
Education		
Diploma/certificate	12	3.85%
Undergraduate degree	244	78.21%
Postgraduate degree	56	17.95%
Ownership		
state-owned enterprise	61	19.55%
private enterprise	212	67.95%
foreign-invested enterprises	39	12.50%
Location		
eastern areas	97	31.10%
the central region	115	36.86%
the west area	100	32.05%

sociologist Babi, there is a simple hierarchy: for analysis and report writing, a minimum return rate of 50% is sufficient, a return rate of at least 60% is good, and a return rate of 70% is very good. However, he also makes it clear that the above figures are only approximate and not statistically based [91]. Based on the 70% return rate, 500 questionnaires were distributed to the public. The questionnaires were distributed through field visits and electronic questionnaires distributed by email.

The period of this research is from 5 November 2022 to 15 March 2023. The total number of questionnaires returned is 330. The response rate is 66%. After conducting data cleansing, any missing, unreasonable, inconsistent or incompatible data is identified and addressed. This may involve removing samples with short answer times, duplicates or logical inconsistencies. Finally, 312 completed questionnaires are retained and used for subsequent data analysis.

Table 2
Sample mean and standard deviation.

	Code	Item	Mean	Standard Deviation	Population mean	Cronbach's α
Environmental regulation (ER)	ER1	Environmental regulations introduced by the government are becoming increasingly stringent	4.91	1.438	4.933	0.923
	ER2	Increasing government expectations for environmental protection of enterprise products and processes etc.	4.54	1.579		
	ER3	Significant penalties for companies breaching environmental protection regulations	5.06	1.502		
	ER4	Businesses have some freedom of choice when faced with multiple environmental regulations	5.07	1.506		
	ER5	Companies receive increasing environmental subsidies and environmental tax incentives	5.12	1.555		
	ER6	Enterprises have had an increasing amount of green credit in recent years	4.74	1.592		
	ER7	Enterprises voluntarily adopt environmental protection measures	5.06	1.579		
	ER8	Enterprises can release timely and accurate information on the environment to the public	4.79	1.479		
	ER9	The enterprise can accept the recommendations of the environmental impact assessment report issued by experts or relevant institutions and adjust its business management model	5.12	1.652		
ESG performance (ESGP)	ESGP1	The company attaches great importance to environmental protection, and environmental performance can better meet national requirements.	5.29	1.427	5.458	0.860
	ESGP2	The company incorporates the concept of environmental protection into its corporate culture.	5.2	1.295		
	ESGP3	The company has a high degree of corporate social responsibility fulfillment.	5.35	1.177		
	ESGP4	The effectiveness of corporate social responsibility performance is supported by stakeholders.	5.41	1.228		
	ESGP5	The enterprise has an excellent corporate management team, which can safeguard all stakeholders' interests.	5.44	1.171		
	ESGP6	Companies have well-developed corporate governance mechanisms to meet the challenges posed by ESG.	6.06	0.931		
Technological innovation (TI)	TI1	The enterprise has access to patent assignments and patent descriptions from many research institutions	5.09	1.304	5.064	0.888
	TI2	The enterprise has gained an understanding of technological trends from many research institutions	4.72	1.518		
	TI3	Employees of the enterprise have an increasing capacity for technological innovation	5.04	1.385		
	TI4	The enterprise's employees have acquired many new ideas for scientific research and technological development	5.11	1.491		
	TI5	Employees' understanding of technology trends continues to improve	5.21	1.431		
	TI6	Employees are equipped with the tools and methods of technology development	5.21	1.465		
Enterprise resilience (ERC)	ERC1	Enterprises have an organizational culture that learns from crises	5.11	1.295	4.947	0.897
	ERC2	The top management of the enterprise takes an active interest in the possible problems of the enterprise	4.91	1.447		
	ERC3	Enterprises define clearly the priorities of important issues during and after a crisis	4.95	1.415		
	ERC4	Enterprises actively monitor the external environment and prepare for potential problems in advance	4.63	1.518		
	ERC5	Enterprises can work together with peers to tackle the crisis	4.9	1.393		
	ERC6	Enterprises can quickly switch from day-to-day mode to crisis response mode	5.04	1.460		
	ERC7	When a crisis arises, enterprises have easy access to professional help	5.09	1.516		

3.3. Data analysis

SPSS 26.0 and AMOS 24.0 are used for the statistical analysis of this study. Firstly, reliability and validity tests and common method bias tests of the scales were conducted. Secondly, a structural equation modelling approach (SEM) was used to construct a conceptual model and to conduct a path analysis of the seven hypotheses. Finally, a Bootstrap approach is used to test for mediating effects.

4. Results

4.1. Sample profile

As shown in Table 1, the 312 respondents in this study show a similar number of males 186 (59.62%) to females 126 (40.38%), which is approximately balanced. The age group of respondents is mainly middle-aged (40.06%) between 36 and 45 years old. The majority of the respondents hold a Bachelor's degree (78.21%). The ownership of the enterprises in which the respondents work is 19.55% state-owned, 67.95% private and 12.5% foreign-invested. The region of all respondents' enterprises is 32.05% in the western region, 36.86% in the central region and 31.10% in the eastern region.

4.2. Descriptive statistics

According to the 7-point Likert scale, a mean value of 4.9–7 is considered to be a high level of agreement [92]. The mean and variance of the questionnaire items (Table 2) show that the respondents' enterprises have a high level of agreement with external environmental regulation (mean 4.933); They believe that their ESG performance is good (mean 5.458); They are doing well in technological innovation (mean 5.064); And they have a high level of agreement with enterprise resilience (mean 4.947). This further suggests that the sample selected is appropriate for this study.

According to Anderson and Gerbing [93], the reliability of the scale is very good for Cronbach's α greater than 0.8 and acceptable for Cronbach's α greater than 0.7. The Cronbach's α for all variables in this study ranged from 0.86 to 0.923. Therefore, the internal consistency of the questionnaire is good. The KMO value for the survey scale in this study is 0.946, which is greater than the standard value of 0.7. A factor analysis can be done. A p-value of less than 0.05 indicates that the data reached a significant level. The reliability of the scale is good. As the measures for each variable are formed by adapting existing, literature-validated scales. Therefore, confirmatory factor analysis (CFA) is conducted in this study without an exploratory factor score (EFA).

Table 3
The measurement model.

Latent variables	Code	std. Factor loading	S.E.	C.R.	*P*-value	CR	AVE
Environmental regulation (ER)	ER1	0.78	–	–	–	0.923	0.571
	ER2	0.724	0.075	13.52	***		
	ER3	0.754	0.071	14.203	***		
	ER4	0.746	0.071	14.028	***		
	ER5	0.766	0.073	14.478	***		
	ER6	0.757	0.075	14.286	***		
	ER7	0.784	0.074	14.899	***		
	ER8	0.737	0.07	13.822	***		
	ER9	0.751	0.078	14.133	***		
ESG performance (ESGP)	ESGP1	0.508	–	–	–	0.861	0.517
	ESGP2	0.75	0.136	11.471	***		
	ESGP3	0.779	0.124	11.839	***		
	ESGP4	0.828	0.132	12.408	***		
	ESGP5	0.831	0.126	12.449	***		
	ESGP6	0.546	–	–	–		
Technological innovation (TI)	TI1	0.775	–	–	–	0.886	0.564
	TI2	0.749	0.068	15.432	***		
	TI3	0.737	0.063	15.022	***		
	TI4	0.694	0.07	13.722	***		
	TI5	0.769	0.064	16.065	***		
	TI6	0.777	–	–	–		
Enterprise resilience (ERC)	ERC1	0.735	0.07	12.508	***	0.898	0.558
	ERC2	0.771	0.078	13.119	***		
	ERC3	0.774	0.076	13.167	***		
	ERC4	0.709	0.082	12.062	***		
	ERC5	0.776	0.075	13.199	***		
	ERC6	0.741	0.079	12.602	***		
	ERC7	0.721	–	–	–		

4.3. Common method bias test

Environmental regulation, ESG performance, technological innovation and enterprise resilience are measured simultaneously in one questionnaire. Due to the respondents' reflective bias, social expectations, emotional state, understanding of the questionnaire, etc., there may be a common response bias when answering the questionnaire, allowing the error variance to be shared between the measured variables, causing bias between the data results and the true results, thus affecting the accuracy of the study results. For this reason, this study used the Harman one-way method to conduct exploratory factor analysis on the variables involved.

Podsakoff & Organ [94] concluded that the common method bias is not significant if the variance explained by the unrotated single factor from the exploratory factor analysis (EFA) does not exceed 50%. The results show that a total of four common factors with eigenvalues above 1 are extracted, with the first common factor accounting for 41.915% of the total variance explained, which is below the critical threshold of 50%, and there is no significant common method bias in the study data.

4.4. Measurement model

Before conducting hypothesis testing, the paper performs a Confirmatory Factor Analysis (CFA) on the measurement models to determine the reliability and validity of the constructs in this study. As shown in Table 3, the composite reliability of all the constructs is greater than 0.8, which exceeds the recommended standard value of 0.7 [95]. It can therefore be concluded that the internal consistency of the measures is good. To assess the explanatory power of measured variables on latent variables, standardized factor loadings and the average variance extracted (AVE) are used. A standardized factor loading greater than 0.5 is considered acceptable, and greater than 0.7 is ideal [96]. All standardized factor loadings in this study are greater than 0.5, with C.R. values greater than 3.29, and $P < 0.001$. Therefore, all factor loadings are significant. The average variance extracted (AVE) is used to assess the explanatory power of measured variables on latent variables by measuring the similarity of results when different methods are used to measure the same construct. An AVE greater than 0.5 is considered strong evidence for the ability of measured variables to explain latent variables [97]. In this study, all AVE values are greater than 0.5, indicating that each measured variable effectively explained its corresponding latent variable. To confirm that measured variables do not belong to the same latent variable and are indeed measuring different constructs, discriminant validity is assessed. Discriminant validity is measured by comparing the square root of the AVE of a latent variable with its correlation with other latent variables. If the square root of the AVE is greater than its correlation with other variables, then discriminant validity is established [97,98]. In this study, the square roots of the AVEs for each latent variable are greater than their correlations with other latent variables (Table 4). Therefore, the discriminant validity of the measurement model is established.

Model fit is the degree of consistency between the theoretical model and the actual data. The following indicators are usually used to determine model fit: $\chi 2/df$ is used as an indicator of model fit, with values between 1 and 3 indicating good model fit; SRMR and RMSEA have values between 0 and 1. The values of SRMR and RMSEA are between 0 and 1. When they are less than 0.05, the model fits well, and less than 0.08, the model fits acceptably; the fit criteria of GFI, AGFI, IFI, CFI and TLI are higher than 0.9, the model fits well; GFI and AGFI are higher than 0.8, the model fits acceptably [97,99]. According to Table 5, $\chi 2/df = 1.620$, between 1 and 3; SRMR < 0.080, RMSEA < 0.080, indicating that the measurement model has a good fit; GFI and AGFI are greater than 0.8, IFI, CFI and TLI are all above 0.9, indicating that the data have a good fit.

4.5. Structural model

The research hypothesis describing the relationship between latent variables is tested by means of a structural model. This study began with a model fit test of the theoretical model. As shown in Tables 5 and in this study, $\chi 2/df = 1.248$, which is between 1 and 3; SRMR <0.050 and RMSEA <0.050, indicating a good model fit; GFI, AGFI, IFI, CFI and TLI are all above 0.9, indicating a good fit between the data and the model. GFI and AGFI above 0.8 indicate that the data and the model are acceptable. According to Table 5, all indicators meet the criteria of the ideal requirement of the fit, and the path analysis can be continued.

Hypothesis testing of direct effects through path analysis can be judged by standardized path coefficients, p-values and z-values. Chin (1998) suggests that standardized path coefficients should be at least 0.20 and preferably 0.30 or greater. Z-values greater than 1.96 and p-values less than 0.05 are considered to be valid for direct effects. As shown in Table 6 and Fig. 2, the standardized path coefficients for H1, H2, H3, H4 and H5 are 0.450, 0.359, 0.312, 0.339 and 0.294 respectively. All standardized path coefficients are greater than 0.2. *P*-values are less than 0.001 and Z-values are greater than 1.96. Therefore, the hypothesis of the direct effects of H1, H2, H3, H4 and H5 holds. In other words, environmental regulation is positively related to technological innovation; ESG performance is positively related to technological innovation; technological innovation is positively related to enterprise resilience; environmental regulation is positively related to enterprise resilience; ESG performance is positively related to enterprise resilience. In the following,

Table 4
Correlations and average variance extracted.

	ERC	TI	ESGP	ER
ER	0.664	0.628	0.479	0.756
ESGP	0.644	0.576	0.719	
TI	0.701	0.751		
ERC	0.747			

Table 5
Goodness of fit index of measurement model and structural model.

Fitting Metrics	χ2/df	GFI	AGFI	TLI	CFI	RMSEA	SRMR
Reference Value	<3	>0.800	>0.800	>0.900	>0.900	<0.08	<0.08
Measurement Model Fit Value	1.822	0.882	0.861	0,938	0.944	0.051	0.0696
Structural Model Fit Value	1.248	0.917	0.901	0.981	0.983	0.028	0.0355

Table 6
Test results of path relationship.

Hypothesis	path	Unstd. path coefficient	S.E.	Z-value	*P*-value	Std. path coefficient	Test result
H1	ER→TI	0.398	0.041	9.707	***	0.450	support
H2	ESGP→TI	0.415	0.053	7.830	***	0.359	support
H3	TI→ERC	0.304	0.049	6.204	***	0.312	support
H4	ER→ERC	0.292	0.041	7.122	***	0.339	support
H5	ESGP→ERC	0.33	0.051	6.471	***	0.294	support

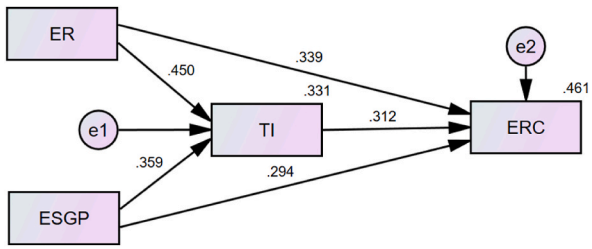

Fig. 2. Path analysis.

we continue to discuss the mediating effect of Technological innovation and its related hypotheses.

4.6. Mediated effect

As the Bootstrap method has the best bias correction among the methods for mediated effects testing [100]. Therefore, in the paper, Bootstrap is used to test the sample for mediated utility. A 95% confidence interval is set for this test, with 1000 draws from the sample. In this study, judgements are based on the confidence intervals of Bias-corrected and Percentile. If the confidence interval does not contain 0, the mediating effect holds. According to Table 7, the confidence intervals for all the variable relationships do not contain 0. Therefore, the mediating effect holds. Based on the path coefficients in Fig. 3, it is possible to calculate both direct and indirect effects between all variables. The results are corroborated by the data presented in Table 7, which confirms that both direct and mediating effects hold. The relationship between environmental regulation, technological innovation and enterprise resilience holds. Hypothesis

Table 7
Bootstrap mediation effect.

Path Relationship	Point Estimate	Coefficient Derivative Values		Bootstrapping Test				Result
				Bias-corrected 95%		Percentile 95%		
		SE	Z	Lower	Upper	Lower	Upper	
Indirect Effect								
ER→TI→ERC	0.120	0.039	3.077	0.051	0.209	0.050	0.208	approval
ESGP→TI→ERC	0.523	0.375	1.395	0.235	1.555	0.224	1.442	approval
Total Indirect Effect	0.643	0.377	1.706	0.334	1.679	0.32	1.56	approval
Direct Effect								
ER→ERC	0.259	0.036	7.194	0.192	0.334	0.19	0.332	approval
ESGP→ERC	1.174	0.789	1.488	0.628	3.432	0.627	3.383	approval
Total Direct Effect	1.432	0.79	1.813	0.896	3.615	0.884	3.609	approval
Total Effect								
Total Effect	2.075	1.108	1.873	1.361	5.127	1.361	5.112	approval
Percentage								
P1	0.187	0.082	2.280	0.065	0.391	0.06	0.378	approval
P2	0.813	0.082	9.915	0.609	0.935	0.622	0.94	approval
P3	0.310	0.063	4.921	0.191	0.443	0.189	0.435	approval

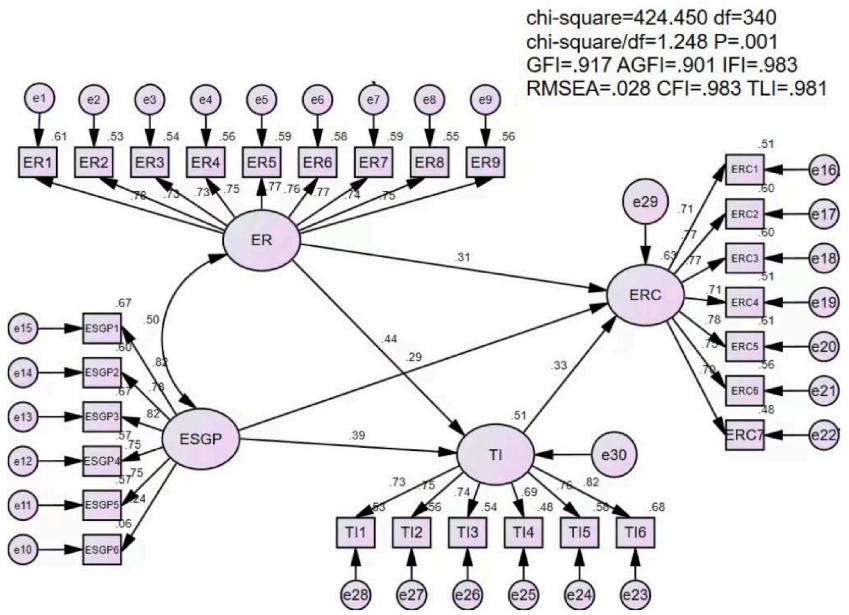

Fig. 3. The standardized path coefficient for bootstrapping mediating.

H6 holds. The relationship between ESG performance, technological innovation and enterprise resilience holds. Hypothesis H7 holds. The indirect effect of environmental regulations→technological innovation→enterprise resilience (P1) accounts for 18.7% of the total indirect effect. The indirect effect of ESG performance→technological innovation→enterprise resilience (P2) accounts for 81.3% of the total indirect effect. The indirect effect (P3) accounts for 31% of the total effect. Thus, it can be concluded that the implementation of ESG performance and technological innovation by enterprises plays a more important role in enhancing corporate resilience.

4.7. Robustness test

In order to assess the model's robustness, this study employs a method of varying sample sizes and selecting a representative subsample dataset for validation purposes. Based on the demographic characteristics of the questionnaire respondents, state-owned enterprises account for 19.55%, private enterprises account for 67.95%, and foreign-invested enterprises account for 12.5% in terms of company ownership. Notably, there is a relatively high proportion of private enterprises. As Chinese state-owned enterprises have greater access to state resources during their transformation and development, private enterprises tend to be policy followers and receive less government support in comparison. Therefore, the questionnaire results of respondents from private enterprises were analyzed without altering the model or research methodology to verify its robustness. The sample size consisted of 212 respondents from private enterprises, on which hypothesis testing and mediating effect testing were conducted.

Based on the path analysis, it is assumed that the standardized path coefficients of H1, H2, H3, H4, and H5 are 0.507, 0.291, 0.377, 0.323, and 0.276, respectively. All standardized path coefficients are greater than 0.2. The p-values are less than 0.001, and the z-values are all greater than 1.96. Thus, the hypothesis of a direct effect of H1, H2, H3, H4, and H5 is valid.

The bootstrap method is used in this study for mediating effect test. This study is based on the confidence intervals of Bias-corrected and Percentile. The confidence intervals for all variable relationships did not contain 0. Therefore, the mediation effects of H6 and H7 were established.

The research hypotheses proposed in this study are found to remain valid when tested using the reduced sample size approach, thus further confirming the robustness of the empirical findings.

5. Discussion

The aim of this study is to demonstrate the impact of advanced green management concepts (ESG) on technological innovation within enterprises, as well as the influence of external environmental constraints (environmental regulation) on technological innovation and ultimately enterprise resilience viability through research. Throughout the study, stakeholder theory and resource allocation theory are utilized to examine how the integration of green business concepts and green innovation can create new avenues for competitive advantage among enterprises. The research model posits that enterprises when motivated and pressured to adopt environmentally sustainable practices, will exhibit proactive behaviour in implementing green business management concepts and increasing their level of green innovation. The results provide evidence for the positive influence of the ESG concept and environmental regulations on technological innovation and enterprise resilience, as hypothesized by H1 to H7. This can be largely attributed to the significant role played by the Chinese government and industry associations in promoting sustainable development among

enterprises. In response to the policy incentives for green transformation, such as green credit and tax breaks, as well as the pressures of environmental regulations and social advocacy for sustainable consumption, local entrepreneurs' federations have proactively established various communication platforms to facilitate knowledge sharing and promote innovation among their members.

The standardized path coefficient for H1 is 0.450, which exceeds the threshold of 0.2. Additionally, it exhibits a significant p-value of less than 0.001 and a z-value exceeding 1.96. Consequently, we can conclude that H1 holds true. It is in line with the findings of Chen et al. [31]. Despite the fact that environmental regulations impose additional burdens on enterprises [27], they tend to comply with environmental constraints. This behaviour may be attributed to enterprises' aspirations for expanding into new competitive arenas and meet evolving consumer demands [101]. The effectiveness of environmental regulation on green technological innovation hinges upon the adequacy of "innovation compensation" generated by such innovations to offset the costs incurred by enterprises [102]. Environmental regulation can be classified into market-based incentives, command-and-control measures, and voluntary participation approaches. These mechanisms collectively foster green economic development by stimulating technological innovation and securing adequate compensation for innovation. Consequently, the government's judicious selection of policy tools is pivotal in ensuring an effective policy mix [103].

The standardized path coefficient for H2 is 0.359, which exceeds the threshold of 0.2. Additionally, it exhibits a significant p-value of less than 0.001 and a z-value exceeding 1.96. Consequently, we can conclude that H2 holds true. This finding aligns with Tan et al.'s [42] research, which suggests that the environmental quality of a region is related to both ESG concepts and technological innovation. The more severe the environmental degradation, the more stringent the environmental regulations in the region, and the higher the expectations of enterprises seeking to overcome economic development challenges, the more favourable green ideas and technological innovations become. Li and Li [86] also found that enterprises with greater sensitivity to local environmental conditions exhibit a more positive attitude towards green transformation benefits. Enterprises that embrace the ESG concept prioritize the interests of their stakeholders, demonstrating a heightened concern for their well-being and satisfaction. The efficacy of this concept in fostering technological innovation hinges upon the establishment of a value compensation path by the enterprise. This compensation path not only caters to consumers' green demands for products and services but also facilitates the company's green development through technological innovation, thereby enabling it to capture a larger market share [104]. Intellectual capital plays a pivotal role in forging this value compensation path [105]. Executives' perceptions determine the extent of technogenic support for implementing ESG practices and corporate value compensation. Selecting an executive team characterized by environmentally conscious thinking serves as an intellectual safeguard for driving corporate technological innovation.

The standardized path coefficient for H3 is 0.312, which exceeds the threshold of 0.2. Additionally, it exhibits a significant p-value of less than 0.001 and a z-value exceeding 1.96. Consequently, we can conclude that H3 holds true. The assertion of H3 regarding the positive correlation between technological innovation and enterprise resilience is substantiated, as enterprises that are impacted by extreme events and economic uncertainties recognize the significance of augmenting their R&D efforts and engaging in technological innovation as a crucial business activity. As a result, enterprises are likely to prioritize the positive economic impacts of technological innovation over the negative ones. This contradicts Omri's [16] study. However, China's success in capturing market share through green strategies after gaining competitive advantage via technological innovation has inspired many other enterprises to follow suit, as evidenced by Panjaitan et al.'s [50] findings.

The standardized path coefficients for H4 and H5 are 0.339 and 0.294, respectively, both exceeding the threshold of 0.2. These coefficients exhibit significant p-values below 0.001 and z-values surpassing the critical value of 1.96. The validation of both H4 and H5 confirms the positive impact of enterprises' transformation under environmental regulation constraints and implementation of green management concepts on their enhanced resilience. Furthermore, there exists an inherent correlation between environmental regulations and ESG performance, with the combined effect positively reinforcing enterprise resilience. These findings align with those of Zameer et al. [15]. The integration of government policy tools and the implementation of corporate green development concepts necessitate the incentivizing role of policies, the demonstrative role of central enterprises, and the guiding role of national strategies. The Chinese government has taken a leading position in promoting ESG implementation and disclosure within central enterprises, alongside introducing legislation and regulations on corporate environmental protection. Furthermore, strategic objectives have been set to achieve carbon peaking by 2030 and carbon neutrality by 2060. However, there is a lack of awareness regarding ESG among most market players. Many companies disclose information through annual reports, social responsibility reports, and other public documents; however, the quality of disclosure varies significantly. Therefore, optimizing ESG management becomes imperative.

As the confidence intervals for Bias-corrected and Percentile do not encompass 0, it can be concluded that the mediating effects of H6 and H7 are significant. The economic benefits derived from technological innovation have become a crucial factor influencing enterprises' active implementation of ESG and adaptation to environmental regulation constraints (H6 and H7). The study revealed that economic benefits exert the most significant direct and indirect influence on enterprises' adoption of ESG practices and compliance with environmental regulations, serving as a crucial indicator of the effectiveness of their technological innovation. Enterprises tend to prioritize positive impacts over negative ones [106], reflecting their heightened concern for favourable outcomes.

6. Conclusions

6.1. Policy implications

The government has acknowledged that economic growth cannot replace sustainable social development. China's economy has entered a phase of high-quality development, with the current policy emphasizing equity as much as efficiency. Enterprises have an unshirkable responsibility to focus on social values. However, extreme events often impede both the country and businesses in their

pursuit of economic and sustainable development. Improved ability and speed in recovering from extreme events is an unavoidable issue for the development of Chinese enterprises today. The Chinese government has proposed a target of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060. For the manufacturing industry, enhancing resilience while reducing energy consumption and emissions is currently a formidable challenge. This study investigates the influence of environmental regulations, ESG performance, and technological innovation on enterprise resilience. It also examines how Chinese enterprises have responded to environmental economic policies, potentially providing a solution to this issue.

We have drawn three conclusions from our research. Firstly, environmental regulations can compel enterprises to engage in technological innovation and achieve green development in manufacturing, thereby enhancing their resilience. Furthermore, the integration of ESG concepts into enterprise operations can instill environmental consciousness within the organizational culture, prompting the proactive pursuit of technological innovation and bolstering agility and resilience in times of crisis. Thirdly, the combination of external environmental regulations and internal ESG management practices serves as a driving force for technological innovation, ultimately enhancing corporate resilience.

The implementation of China's environmental regulatory policies and ESG concepts will not only facilitate enterprises in pursuing a low-carbon development path, but also promote their relative leadership in the field of green products through the guidance of a new business philosophy, thereby significantly enhancing their international status and influence [107]. The key management recommendations derived from this study are summarized below.

Firstly, to drive green technological innovation, the role of various environmental regulations must be leveraged. In order to accelerate enterprise's green transformation and promote sustainable economic development, governments should adopt a range of environmental regulatory policy tools and adjust them accordingly based on regional economic conditions. Given China's current economic context, it is imperative for the government to strengthen market-based environmental regulatory policies through mechanisms such as environmental taxes and emissions trading licenses in order to enhance enterprise resilience by fully utilizing their externalities. In order to achieve the desired outcomes, the government should undertake rational planning, establish regulations, and promote effective implementation of command-and-control environmental regulatory policies. This approach aims to optimize resource allocation among enterprises by restraining the entry of low-productivity entities and facilitating the exit of such entities. Ultimately, a combination of voluntary and mandatory disclosure mechanisms will be employed as incentive-based environmental policy tools to gradually foster green economic development.

Secondly, establishing a robust green safeguard system is crucial to ensure the effective implementation of existing environmental regulations. This requires the development of a corresponding support system and acceleration in training sustainable talents that meet market demands. The objectives of talent development must be effectively aligned and integrated with industry employment standards to ensure that the green-skilled personnel trained can meet the demands of the job market. This necessitates incorporating green skills into both academic and non-academic training programs.

The government should accelerate the development of sustainable talent that meets market demands. The objectives for talent training must be effectively aligned and synergized with industry hiring standards to cultivate skilled personnel who meet green employment conditions. This requires incorporating green skills into both academic and non-academic training programs.

Creating a top management team with shared green perceptions. The implementation of corporate social responsibility can effectively amplify the influence of age and educational diversity within the top management team on organizational resilience [108]. When selecting top management members, enterprises should consider the mutual coordination and balance of individuals with diverse academic qualifications and age structures. Establishing a communication platform that fosters relaxed and harmonious interactions within the top management team can encourage innovation and creativity, thereby enhancing the organization's adaptability in crisis situations. Simultaneously, employing various methods to recruit exceptional creative talents into the top management team is crucial. Additionally, it is imperative to integrate social responsibility into the corporate culture and conduct corresponding activities to strengthen all company members' awareness of the repercussions associated with neglecting social responsibilities.

An improved environmental liability insurance system is necessary for the government. The government should legally promote the implementation of a mandatory liability insurance system for environmental pollution in high-risk areas. Environmental liability insurance can provide compensation for losses caused by environmental pollution, while also serving as a protective measure and warning for enterprises. Additionally, it can encourage enterprises to disclose their environmental information in accordance with legal requirements.

Thirdly, it is necessary to improve government regulations for the implementation of enterprise ESG. Compared to developed countries, China's implementation and regulation of ESG are still in their infancy. Enterprises' focus on implementing ESG mainly centres around social responsibility and environmental protection. As the implementation of ESG is still in its exploratory stage, the monitoring system remains imperfect. Achieving carbon peaking and neutrality goals necessitates significant investment in R&D and green upgrading across the entire industrial chain. This is a systematic process, and the pursuit of economic interests is inherent in capital. Some enterprises have capitalized on green concepts by engaging in "greenwashing" tactics to gain market share. Without government intervention, this will drive out legitimate businesses. Enterprise greenwashing poses significant risks to businesses. It is imperative for the government to develop policies and for corporate governance to establish robust institutional constraints that regulate inappropriate enterprise behaviour. Otherwise, the adoption of ESG as a green philosophy will not only fail to enhance the enterprise's brand reputation as expected but also lead to squandered investments and compromised business interests. Although ESG is not yet widely mandated by law, greenwashing can result in serious legal consequences for the enterprise involved. Therefore, there is a need to further enhance institutional constraints on executives and state penalties for corporate non-compliance.

6.2. Limitations and future research

The research limitations of the thesis are mainly in the following three areas:

First, there are theoretical limitations in this study. The thesis explores the interplay among environmental regulations, technological innovations, ESG performance, and enterprise resilience. The theoretical analysis of this study has certain limitations. The level of environmental pollution varies across different subsectors within the manufacturing industry, and there may also be variations in the combination and intensity of environmental regulatory measures employed. Specifically, the impact of these relationships in relation to the degree of economic development of the region where the enterprise is located and the division of environmental regulation dimensions is inadequately addressed, which may somewhat diminish the explanatory power of the paper's findings. Secondly, there are limitations in the model construction of this study. There are various pathways through which ESG can enhance enterprise resilience. However, this paper solely examines the impact of technological innovation on enterprise resilience without delving into other potential routes, thereby somewhat diminishing the influence of multiple mediating factors on enterprise resilience. Thirdly, the findings of this study have limitations in terms of generalization. This study is based on Chinese manufacturing enterprises, whose environmental regulatory policies and corporate management models have distinctly Chinese characteristics. The applicability of the study findings to other countries requires further verification.

Due to spatial limitations, the mechanisms underlying environmental regulation and ESG concepts for enhancing enterprise resilience have not been fully developed, which would provide more comprehensive research materials for future studies. Specifically, by refining environmental regulations from multiple dimensions, we will analyze the impact of different types of environmental regulations on enterprise resilience to determine their extent. Secondly, we will conduct further analysis to examine whether the chain of "environmental regulation - ESG performance - technological innovation - enterprise resilience" is influenced by external regulations and economic conditions, and provide constructive recommendations accordingly. Thirdly, we will explore multiple pathways from different perspectives through which ESG implementation impacts enterprise resilience and offer practical suggestions.

Ethics declarations

This study was reviewed and approved by Management and Science University Ethics Committee, with the approval number: EA-L1-01-PGC-2023-05-0001.

All participants provided informed consent to participate in the study.

Author contribution statement

Yujuan Wu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Jacquline Tham: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e20278.

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