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Green innovation, environmental dynamics and organizational resilience: Basis for enhanced green competitive advantage framework in manufacturing enterprises in China

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Abstract

As the world's largest manufacturing country, the green transformation of China's manufacturing industry is of crucial significance to global environmental protection and economic development. With the Chinese government vigorously promoting green development and advancing the goals of carbon peaking and carbon neutrality, enhancing the green competitive advantage of manufacturing enterprises has become an urgent practical need. This study aimed to explore green innovation, environmental dynamics, and organizational resilience among manufacturing enterprises in China, to put forward a framework for enhancing green competitive advantage. It assessed green innovation in terms of product, process, and management innovation; described environmental dynamics through market, technology, and policy and regulation factors; determined organizational resilience via adaptability, recovery capability, and situation awareness; tested the significant relationships among the three; and developed a framework to improve enterprises' green competitive advantage. Using questionnaires, data were gathered from 400 employees of five manufacturing enterprises in Fujian Province to examine the synergistic role of these factors in advancing green transformation and sustainable development. The study analyzed the internal relationships between green innovation, environmental dynamics, organizational resilience, and green competitive advantage, providing a theoretical basis for constructing a framework to enhance the latter. Results show respondents positively recognized green innovation implementation effects, moderately agreed on environmental dynamics and resilience performance, and confirmed a highly significant relationship among all three. Finally, a framework to improve manufacturing enterprises' green competitive advantage was developed, contributing to their green transformation and sustainable development.

Keywords: green innovation, environmental dynamics, organizational resilience, green competitive advantage

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1. Introduction

Against the backdrop of intensified climate change, increasing resource constraints, and rising consumer awareness of environmental issues, the global business environment is undergoing profound transformation. Enterprises are compelled to seek a dynamic balance between achieving economic benefits and fulfilling environmental responsibilities. Green and low-carbon practices have become a core aspect of enterprise competitiveness in the new era, rather than a marginal strategy in the traditional sense. At the same time, governments worldwide are increasingly guiding businesses toward sustainable development through environmental policies and carbon regulations. This trend poses higher demands for corporate strategic adjustment and organizational adaptability.

From the perspective of global corporate practices, green transformation has evolved from an optional strategy to a matter of survival. In recent years, Apple has leveraged green product design, Tesla has relied on innovations in battery recycling technology, and Siemens has capitalized on environmental management system certification, each building competitive barriers across the three dimensions of green innovation. These cases affirm the synergistic value of multidimensional green innovation (Khan et al., 2021). To cope with the challenges of green transformation, enterprises urgently need to build a systemic capability framework suited to complex environments. Green innovation, as a key pathway to sustainable development, mainly includes green product innovation, green process innovation, and green management innovation. It helps enterprises achieve differentiated competitive advantages while reducing energy consumption and emissions (Qiu et al., 2020). Meanwhile, the external environment in which firms operate is increasingly uncertain and highly dynamic, characterized by three typical dimensions: rapid changes in market preferences, continuous technological innovation, and frequent policy adjustments.

Facing this complexity and volatility, an enterprise’s ability to promptly perceive external changes and quickly reallocate internal resources hinges on its organizational resilience, which comprises key elements such as adaptability, recovery capability, and situational awareness (Duchek, 2020). Globally, more and more companies are integrating green innovation into their core strategies. However, whether green practices can effectively translate into competitive advantages is often influenced by both environmental dynamism and organizational resilience. In this context, exploring the interaction pathways among the three is of significant theoretical and practical value for understanding how green strategies are implemented within firms.

As a core link in the global industrial chain, China's manufacturing sector plays a decisive role in achieving global sustainability goals. Known as the "world’s factory", Chinese manufacturing contributes over 30% of global industrial output, yet it faces the stringent constraints of the "dual carbon" targets (carbon peaking by 2030 and carbon neutrality by 2060) and increasingly tight environmental regulations (Jin et al., 2022). An empirical study by Lu et al. (2020) on China's manufacturing industry indicates that green product innovation indirectly influences firms’ competitive advantage through green dynamic capabilities. However, this effect is significantly constrained by policy stability, reflecting the practical challenges enterprises face. Specifically, frequent policy changes, such as revisions to environmental regulations and the improvement of carbon trading mechanisms, can trigger compliance risks (Zhang et. al.,2021). Meanwhile, consumers’ reluctance to pay a premium for green products may lead to operational volatility for firms (Qi et. al.,2023). These real-world challenges highlight the urgent need for the manufacturing sector to explore effective pathways to enhance green competitive advantage.

Although existing literature has explored the effects of green innovation, environmental dynamism, or organizational resilience on firm performance from various perspectives, there remains a lack of systematic integration and empirical analysis regarding the synergistic mechanisms and interaction pathways among the three. Most current studies focus on the direct impact of single variables on firm performance, overlooking the moderating role of environmental dynamism on the outcomes of green strategies, and lacking in-depth analysis of the bridging role of organizational resilience in addressing green uncertainty. Therefore, this study constructed a conceptual model linking "Green Innovation—Organizational Resilience—Green Competitive Advantage," with environmental dynamism introduced as a contextual variable, aiming to reveal how the interplay among these dimensions jointly drove the formation of sustainable competitive advantage. Theoretically, this research contributed to the integration of strategic management and organizational theory within the green context; practically, it offered a roadmap for Chinese manufacturing enterprises navigating green transformation amid high uncertainty.

The researcher had long been concerned with China's manufacturing transformation and had witnessed traditional energy-intensive firms fall into business distress due to their failure to adapt to the green transformation trend, and found it necessary to deeply understand the confusion enterprises faced regarding "how green investments can be converted into competitive advantages." This study not only responded to the dual national strategies of "Made in China" and "Beautiful China," but also aimed to provide generalizable insights for green transformation in manufacturing sectors of developing countries (Zhong et al., 2022).

Objectives of the Study - The study aimed to explore green innovation, environmental dynamics, and organizational resilience among manufacturing enterprises in China, in order to put forward a framework for enhancing green competitive advantage. Specifically, the study sought to describe green innovation practices in terms of green product innovation, green process innovation, and green management innovation; assessed environmental dynamics in terms of market environment dynamics, technology environment dynamics, and policy and regulation dynamics; assessed organizational resilience in terms of adaptability, recovery capability, and situation awareness; tested the significant relationships among green innovation, environmental dynamics, and organizational resilience; and developed a framework to improve the green competitive advantage of enterprises.

2. Methods

Research Design - The study will used a descriptive research design for an adequate and precise interpretation of the findings, explored green innovation, environmental dynamics, and organization resilience among manufacturing enterprises in China. This method included all the studies that aimed to present facts concerning the nature and status of anything including survey and correlational.

Participants of the Study - In this study, 400 employees from different levels of enterprises in Fujian Province were selected as samples and conducted a questionnaire survey through random sampling at different levels. Moreover, the final number of samples were determined through testing to ensure that the alpha error is 5% and the confidence level is 95%. The selection of these five listed companies, namely Contemporary Amperex Technology Co., Ltd. (CATL), Zijin Mining Group Co., Ltd., Fuyao Glass Industry Group Co., Ltd., Xiamen Tungsten Co., Ltd., and Fujian Sangang Minguang Co., Ltd., as research samples is based on multiple reasons beyond the researcher's geographical location in Fujian and the availability of data. These enterprises belong to key manufacturing sectors such as new energy batteries, mining, glass manufacturing, non-ferrous metals, and steel manufacturing, with prominent industry representativeness, which can reflect the characteristics of green transformation in different sub-fields. They have rich practices in green innovation, covering various aspects such as technological research and development, process optimization, and resource recycling. They have demonstrated significant organizational resilience in the face of complex environments, providing practical cases for the research. Moreover, as listed companies, their public reports and multi-channel information can ensure the comprehensiveness and accuracy of research data, making them suitable for exploring issues related to green innovation, environmental dynamics, organizational resilience, and the framework of green competitive

advantage in manufacturing enterprises.

Among them, the selection of participants is divided according to their job responsibilities, and a questionnaire survey will be conducted on the post employees involved in green innovation, environmental dynamic and organization resilience. Among the basic profiles of the respondents, the gender distribution is relatively balanced, with males accounting for 51.2%. In terms of age, the 30-39 age group is the largest, making up 38.0%. Regarding educational attainment, those with a college degree dominate, accounting for 41.5%. As for income, the group with a monthly income of 5,001-10,000 yuan has the highest proportion, reaching 60.3%. In terms of job positions, ordinary employees are the majority, accounting for 59.8%.

Data Gathering Instrument - This study adopted the method of questionnaire survey. Discussed the green innovation, environmental dynamics and organizational flexibility of Chinese manufacturing enterprises: basis of enhancing the framework of green competitive advantage of Chinese manufacturing enterprises, the researcher completed the questionnaire through on-site survey and copy of questionnaire star form to provide the respondents with choices. According to the objectives of this study, the researcher conducted predictive analysis on employees in the Chinese manufacturing industry. During the questionnaire development stage, project design was conducted through literature analysis and expert interviews, combined with the questionnaires and research results of Zhang et. al.,(2021), Mohsin (2020), and Mo et. al.,(2023). A pilot test was undertaken to determine the survey questionnaire's efficacy. Fifty samples were subjected to a reliability test using Cronbach's alpha via SPSS 28.

Table 1

Reliability Result of a Pre-Test of the Questionnaire Reliability Summary

Indicators	No of Items	Cronbach Alpha	Remarks
Green Product Innovation	5	0.924	Excellent
Green Process Innovation	5	0.903	Excellent
Green Management Innovation	5	0.920	Excellent
Market Environment Dynamics	5	0.943	Excellent
Technology environment dynamics	5	0.891	Good
Policy and Regulation Dynamics	5	0.937	Excellent
Adaptability	5	0.950	Excellent
Recovery Capability	5	0.925	Excellent
Situation Awareness	5	0.876	Good

George and Mallery (2003) provide the following rules of the thumb: "_> .9 – Excellent, _> .8 – Good, _> .7 – Acceptable, _> .6 – Questionable, _> .5 – Poor, and _< .5 – Unacceptable"

According to the table 1, the Cronbach Alpha coefficients are all above 0.8. Among them, the coefficients of Green Product Innovation, Green Process Innovation, Green Management Innovation, Market Environment Dynamics, Policy and Regulation Dynamics, Adaptability, and Recovery Capability are all greater than 0.9, and the conclusion is "excellent". The coefficients of Technology environment dynamics and Situation Awareness are greater than 0.8, and the conclusion is "good". The maximum coefficient is 0.950 and the minimum coefficient is 0.876. This indicates that the reliability and quality of the study data are high enough to be used in subsequent analyses.

Data Gathering Procedure - This questionnaire was completed online through the Tencent Questionnaire platform, with the data collection period accessible via https://www.wjx.cn/vm/hrDZ9Xd.aspx. Tencent Questionnaire, developed by Tencent Holdings Limited of China, is a user-friendly online survey tool that provides users with a complete solution from questionnaire creation and distribution to data analysis. In this study, data could be efficiently collected, statistically analyzed, and presented through Tencent Questionnaire, helping researchers understand respondents' perspectives and supporting research decision-making and data-driven research processes.

Since the questionnaire content involves issues such as green innovation, environmental dynamics, and the integration of organizational resilience in manufacturing industries, five listed companies in Fujian were selected

as research samples. These enterprises belong to key manufacturing sectors such as new energy batteries, mining, glass manufacturing, non-ferrous metals, and steel manufacturing, with prominent industry representativeness. Researchers contacted the person in charge of the human resource management department in each enterprise, who then distributed the questionnaires to active employees, grass-roots managers, middle managers, and senior managers. Active employees filled out and returned the questionnaires voluntarily. A total of 400 valid questionnaires were collected between March 1, 2025, and May 30, 2025, with an effective rate of 100%.

Data Analysis - To perform data analysis, the following statistical tools were used. Weighted mean and ranking were used to describe green innovation practices in terms of green product innovation, green process innovation and green management innovation; assess environmental dynamics in terms of market environment dynamics · technology environment dynamics, and policy and regulation dynamics; assess organizational resilience in terms of adaptability, recovery capability, and situation awareness. Likewise, Spearman rho was used as part of the non-parametric tests to determine the significant relationship. In addition, post hoc test was also conducted. The following Likert Scale was used in assessing the variables: 3.50-4.00 = Strongly Agree; 2.50-3.49 –Agree; 1.50–2.49 –Disagree; and 1.00–1.49 –Strongly Disagree. All data were treated using a statistical software known as JAMOVI version 2.6 to further interpret the result of the study using an alpha level of 0.05 and 0.01.

Ethical Considerations - Prior to conducting the study, the research design underwent thorough ethical review and approval by the Lyceum of the Philippines University-Batangas Campus Ethics Committee. The study strictly adhered to ethical principles, ensuring participant rights were protected and upholding values of voluntariness, confidentiality, and well-being. Participants were informed about the study's purpose and significance, provided with informed consent forms, and assured of their anonymity and data privacy. They were free to withdraw at any point and offered psychological support if needed. The researchers prioritized the safety and security of all participants throughout the data collection process.

3. Results and discussion

Table 2

Summary Table on Green Innovation

Indicators	Weighted Mean	Verbal Interpretation	Rank
Green Product Innovation	3.20	Agree	1
Green Process Innovation	3.03	Agree	2
Green Management Innovation	3.00	Agree	3
Composite Mean	3.08	Agree	

Legend: 3.50 – 4.00 = Strongly Agree; 2.50 – 3.49 = Agree; 1.50 – 2.49 = Disagree; 1.00 - 1.49 = Strongly Disagree

Based on the results of green innovation practices, the table 5 shows that the three sub-dimensions, Green Product Innovation (WM: 3.20), Green Process Innovation (WM: 3.03), and Green Management Innovation (WM: 3.00),exhibit minimal differences in their scores. The overall composite mean is 3.08, all falling within the "Agree" range (2.50–3.49). This indicates that respondents generally recognize the implementation of green innovation practices in enterprises. It also reflects that green innovation has become a crucial pathway for building green competitive advantages and achieving sustainable development. Chen et. al.,(2025) from the perspective of resources and capabilities, argue that green innovation strategies, by integrating environmental resources and cultivating green capabilities, provide core support for enterprises to build sustainable competitive advantages. The synergy of product, process, and management innovation is a concrete manifestation of such resource integration and capability development.

Among the sub-dimensions, green product innovation received the highest score (ranked first), indicating that innovation practices in this area are more widely recognized. By focusing on green product innovation, enterprises not only improve product quality and environmental performance in market competition but also provide a practical platform for pollution reduction. This, in turn, helps enterprises accumulate reputational

capital and develop unique resources, further consolidating their competitiveness.

Although green process innovation and green management innovation scored slightly lower, they still fall within the "Agree" range. This suggests that enterprises have also achieved tangible results in green innovation practices related to process optimization and management coordination. The research by Wang et. al.,(2020) on ambidextrous green innovation provides theoretical support for this. They pointed out that green process innovation and green product innovation are complementary, while green management innovation serves as the institutional guarantee for their synergy. It establishes standards and coordinates resource allocation to provide stable support for both process and product innovation. This corresponds with the observed practical logic among the three dimensions: Green management innovation lays the foundation by improving institutional mechanisms and coordinating cross-departmental resources; Green process innovation then optimizes energy consumption and emission control in production, ensuring environmental attributes at the source; Ultimately, these efforts form a synergistic innovation chain of "product – process –management."

Table 3

Summary Table on Environmental Dynamics

Indicators	Weighted Mean	Verbal Interpretation	Rank
Market Environment Dynamics	3.18	Agree	1
Technology environment Dynamics	3.14	Agree	2
Policy and Regulation Dynamics	2.91	Agree	3
Composite Mean	3.08	Agree	

Legend: 3.50 – 4.00 = Strongly Agree; 2.50 – 3.49 = Agree; 1.50 – 2.49 = Disagree; 1.00 - 1.49 = Strongly Disagree

Table 3 presents an integrated view of enterprises' perceptions of environmental dynamism across three dimensions: market, technology, and policy/regulatory environments. The composite mean score is 3.08, falling within the "Agree" range, indicating that surveyed firms generally acknowledge the profound impact of environmental dynamism on their operations and strategic decisions. Specifically, market environmental dynamism scored the highest (3.18), ranking first; technological dynamism followed closely (3.14), ranking second; and policy and regulatory dynamism scored relatively lower (2.91), ranking third. This result revealed a clear hierarchy, reflecting the varying degrees to which enterprises perceive dynamism in different environmental dimensions, with market and technology dimensions posing more significant shocks, while policy/regulatory changes, though less intense, still act as important external forces driving strategic adjustments.

In terms of market environmental dynamism, the highest score reflected that enterprises are widely experiencing ongoing pressures from changing market demands and competitive structures, requiring them to respond through innovation and dynamic capabilities. Le et. al.,(2024)noted that growing consumer preferences for environmentally friendly products and corporate social responsibility are pushing companies to strengthen green training and innovative responses in order to gain competitive advantages. This aligns closely with the logic in the table that "market dynamism drives strategic adjustment." Barlette et. al.,(2022) further emphasized that in today's fast-changing markets, enterprises must build dynamic capability systems centered on big data analytics and rapid response mechanisms to achieve flexible resource allocation and timely strategic alignment. These studies collectively support the view that market dynamism plays a vital role in fostering firms' dynamic capability development and enhancing their market adaptability, confirming the high perception and responsiveness reflected in the market dimension of the table.

Regarding technological environmental dynamism, which ranked second with a score of 3.14, enterprises show high sensitivity to rapid technological iteration and the urgency of green technology adoption. Qiu et al. (2020), based on a study of Chinese manufacturing firms, found that green technological innovation must be integrated with dynamic capabilities, as the uncertainty and pace of technological change compel firms to enhance green dynamic capabilities, promote product innovation, and gain an early advantage in the green transformation. This finding is fully aligned with the table's logic that "technological dynamism drives technological innovation." Enterprises must engage in green energy innovation to adapt to technological shifts,

balancing economic benefits with environmental sustainability. This further validates the shaping role of technological dynamism in directing innovation and underscores the increasing demand it places on sustainable strategy formulation.

As for policy and regulatory environmental dynamism, it scored 2.91, the lowest among the three dimensions but still within the "Agree" range, indicating that companies widely recognize the changing nature of regulations and the strategic pressure these changes generate. Maghyereh et al. (2025) examined the impact of policy dynamism on corporate ecological footprints in the European context and pointed out that shifts in trade policies and energy regulations can constrain energy use and production behaviors, guiding companies toward green transformation. This demonstrates the external guiding force of policy and regulatory dynamism on corporate behavior. Furthermore, Qiu et al. (2020) noted that dynamic adjustments in green regulations directly influence firms' decisions regarding green innovation strategies. Companies must leverage green dynamic capabilities to respond quickly to policy changes, transforming compliance pressures into innovation opportunities and maintaining competitiveness in a constantly evolving regulatory landscape. This supported the conclusion in the table that policy/regulatory dynamism, although perceived less strongly, remains a crucial external driver of green transformation.

Table 4

Summary Table on Organizational Resilience

Indicators	Weighted Mean	Verbal Interpretation	Rank
Adaptability	3.08	Agree	2
Recovery Capability	2.98	Agree	3
Situation Awareness	3.12	Agree	1
Composite Mean	3.06	Agree	

Legend: 3.50 – 4.00 = Strongly Agree; 2.50 – 3.49 = Agree; 1.50 – 2.49 = Disagree; 1.00 - 1.49 = Strongly Disagree

Table 4 presents a comprehensive evaluation of the three dimensions of organizational resilience. With a composite mean score of 3.06 (within the "Agree" range), the results indicate that manufacturing enterprises possess a certain level of resilience in the context of green competition. However, the uneven development across dimensions suggests a need to optimize the resilience system by leveraging green competitive advantages such as green innovation and low-carbon operations. In the landscape of green competition, the three dimensions of organizational resilience form an organically integrated system characterized by progressive layering and mutual support: Situational Awareness acts as the "outpost," playing a crucial role in identifying green policies and market demands. It provides accurate information anchors that help enterprises capture green opportunities and avoid policy risks, thus serving as the foundation and directional guide for green competition. Adaptability, as the "engine," builds upon the output of situational awareness. It enables rapid adjustments in production processes and agile responses to green market changes, transforming perceived opportunities into actionable strategies. This dimension empowers enterprises to remain flexible and competitive during green transitions. Recovery Capability serves as the "moat," supporting enterprises in resuming operations after green-related crises while simultaneously strengthening green practices. It ensures the sustainability of green competition and reinforces the advantages established through prior situational awareness and adaptability. Together, these dimensions form a closed loop of green competitiveness, perception, action, and consolidation. In the manufacturing sector, situational awareness aids in identifying green transformation opportunities, recovery capability reduces trial-and-error costs during transitions, and adaptability ensures pace and resource alignment with green transformation efforts.

Among the three dimensions, situational awareness scored the highest at 3.12, ranking first. This suggests that manufacturing enterprises are relatively strong in perceiving green policies and market demands, such as identifying carbon tariff policies or consumer preferences for low-carbon products. Zhang et al. (2023) highlight that under environmental uncertainty, situational awareness must focus on green risks and opportunities. By monitoring policy shifts and fluctuations in green demand, enterprises can inform strategies such as low-carbon technology R&D and circular supply chain deployment, aligning with the logic of "precise identification of

green value" within green competitive advantage. Adaptability scored 3.08, ranking second, indicating a moderate level of capability. It reflects room for improvement in how enterprises adjust during green transitions, such as modifying production lines for low-carbon output or restructuring supply chains toward green suppliers. One major challenge in green competition is that green transformation requires significant resources, such as purchasing eco-friendly equipment or training employees in green skills. Some enterprises may suffer from path dependency or resource constraints, leading to adaptability lagging behind green market demands. Wang et al. (2022) also found that manufacturing firms focusing solely on low-carbon production processes while neglecting green culture development weaken adaptability's contribution to green competitive advantage. Finally, recovery capability received the lowest score of 2.98, ranking third. This exposes a vulnerability in how manufacturing enterprises recover from green-related crises. For example, after experiencing environmental incidents or green supply chain disruptions, firms may struggle to resume production efficiently or improve their green practices. When penalized for exceeding carbon emission limits, some enterprises show slow recovery in both resuming operations and implementing green improvements.

Table 5

Relationship Between Green Innovation and Environmental Dynamics

Green Product Innovation	r-value	p-value	Interpretation
Market Environment Dynamics	0.515***	<.001	Highly Significant
Technology environment dynamics	0.607***	<.001	Highly Significant
Policy and Regulation Dynamics	0.696***	<.001	Highly Significant
Green Process Innovation			
Market Environment Dynamics	0.533***	<.001	Highly Significant
Technology environment dynamics	0.597***	<.001	Highly Significant
Policy and Regulation Dynamics	0.630***	<.001	Highly Significant
Green Management Innovation			
Market Environment Dynamics	0.502***	<.001	Highly Significant
Technology environment dynamics	0.566***	<.001	Highly Significant
Policy and Regulation Dynamics	0.587***	<.001	Highly Significant

Table 5 presents the relationships between various dimensions of green innovation, including green product innovation, green process innovation, and green management innovation, and aspects of environmental dynamism, including market dynamism, technological dynamism, and policy and regulatory dynamism. These relationships are interpreted through correlation coefficients (r-values) and corresponding p-values. The correlation coefficients range from 0.502 to 0.696, all of which are statistically significant at the 0.001 level, as indicated by ***.

These findings demonstrate strong positive correlations between the dimensions of green innovation and environmental dynamism: the positive and relatively high correlation values suggest that as environmental dynamism increases, firms tend to engage more actively in green innovation across product, process, and managerial aspects. Conversely, proactively engaging in green innovation also helps enterprises better perceive and adapt to environmental changes, forming a virtuous cycle in which "environmental change drives innovation, and innovation enhances environmental adaptability." The fact that all p-values are below 0.001 indicates an extremely high level of confidence in the observed correlations, suggesting these associations are not random but rather reflect stable and intrinsic relationships. Thus, the positive links between environmental dynamism and various dimensions of green innovation are reliable and replicable, providing robust statistical and theoretical support for enterprises to advance green innovation amid environmental uncertainty.

This comprehensive analysis underscores the critical role of green innovation practices in enabling manufacturing firms to adapt to and thrive in dynamic environments. The positive correlation coefficients imply that implementing green innovation allows manufacturing firms to carve out a path toward enhanced green competitiveness. Through green innovation, enterprises can better respond to environmental dynamism, establish a proactive green image, enhance brand value, and achieve sustainable development. Moreover, strengthening

green innovation helps firms better fulfill their "green responsibilities," including environmental responsibility , social responsibility, and economic responsibility. Green innovation also guides the internal reallocation of resources and adjustment of operations, thereby improving overall efficiency.

Furthermore, as the importance of green innovation for the sustainable development of manufacturing enterprises becomes increasingly apparent, firms that actively participate in green innovation tend to be more proactive in adapting to environmental changes, thereby achieving stronger and more lasting green competitiveness. The high significance of these correlations highlights the robustness and reliability of the relationship between green innovation and environmental dynamism. This has profound implications for Chinese manufacturing enterprises, emphasizing the necessity of enhancing environmental responsiveness and investing in green innovation initiatives, such as green product development, process optimization, and management upgrades to strengthen enterprise resilience under environmental uncertainty. Active green innovation can guide business activities, optimize products to meet green market demands, improve economic performance, and foster an internal organizational climate that supports innovation and sustainability.

In conclusion, recognizing the correlation between green innovation and environmental dynamism is essential for Chinese manufacturing firms aiming to achieve efficient and sustainable development in a competitive and dynamic market. Firms that invest in green innovation are generally more capable of coping with environmental changes and will gain greater reputation, brand value, and overall performance in the evolving green economy.

Table 6

Relationship Between Green Innovation and Organizational Resilience

Green Product Innovation	r-value	p-value	Interpretation
Adaptability	0.313***	<.001	Highly Significant
Recovery Capability	0.622***	<.001	Highly Significant
Situation Awareness	0.402***	<.001	Highly Significant
Green Process Innovation			
Adaptability	0.340***	<.001	Highly Significant
Recovery Capability	0.640***	<.001	Highly Significant
Situation Awareness	0.425***	<.001	Highly Significant
Green Management Innovation			
Adaptability	0.342***	<.001	Highly Significant
Recovery Capability	0.591***	<.001	Highly Significant
Situation Awareness	0.425***	<.001	Highly Significant

Table 6 presents the correlations between the dimensions of green innovation and organizational resilience, interpreted through correlation coefficients (r-values) and p-values. The correlation coefficients range from 0.313 to 0.640, and all values are statistically significant at the 0.001 level, denoted by ***. These findings indicate a strong positive correlation between green innovation and organizational resilience: as green innovation advances across its various dimensions, corresponding dimensions of resilience are also enhanced. Conversely, enterprises with high levels of resilience are better equipped to implement green innovation, forming a positive feedback loop where "green innovation empowers resilience enhancement, and strengthened resilience, in turn, supports innovation practice."

The p-values below 0.001 suggest that these correlations are not coincidental but rather stable and reliable, providing solid empirical support for simultaneously strengthening innovation and resilience during green transformation in manufacturing enterprises. This conclusion is also supported by relevant studies. Gao et. al.,(2024), from a network relationship perspective, confirmed that enterprises implementing green innovation exhibit greater resilience when facing uncertainty, and that "relational ties" further reinforce this effect. This finding underscores the critical role of green innovation practices in enhancing organizational resilience among manufacturing firms, across adaptability, recovery capability, and situational awareness. Manufacturing

enterprises that implement green innovation are better positioned to detect environmental and market dynamics related to green development and adopt innovative resilience-building strategies. For instance: Green product innovation enhances adaptability to meet green market demands; Green process innovation strengthens recovery capability to address environmental crises; Green management innovation improves situational awareness to accurately capture green development opportunities.

Moreover, this correlation highlights the strategic value of promoting green innovation in support of resilience building. By improving green innovation capabilities, advancing green technologies, and strengthening green organizational awareness, manufacturing enterprises can optimize their resilience, better respond to dynamic green market environments, coordinate risk management and innovation, and enhance their sustainable development capacity. In conclusion, recognizing the link between green innovation and organizational resilience is crucial for Chinese manufacturing firms seeking sustainable development in a dynamic and competitive green market. Through the implementation of green innovation practices, enterprises can strengthen their ability to manage risks, improve environmental performance, and lay a solid foundation for long-term, stable growth. This, in turn, contributes to building and reinforcing a green competitive advantage framework, enabling steady progress amid the green economic wave.

Table 7

Relationship Between Environmental Dynamics and Organizational Resilience

Market Environment Dynamics	r-value	p-value	Interpretation
Adaptability	0.315***	<.001	Highly Significant
Recovery Capability	0.539***	<.001	Highly Significant
Situation Awareness	0.448***	<.001	Highly Significant
Technology Environment Dynamics			
Adaptability	0.299***	<.001	Highly Significant
Recovery Capability	0.631***	<.001	Highly Significant
Situation Awareness	0.420***	<.001	Highly Significant
Policy and Regulation Dynamics			
Adaptability	0.325***	<.001	Highly Significant
Recovery Capability	0.684***	<.001	Highly Significant
Situation Awareness	0.404***	<.001	Highly Significant

Table 7 focuses on the relationship between environmental dynamism including market, technological, and policy/regulatory dynamism and organizational resilience, which encompasses adaptability, recovery ability, and situational awareness. Statistical analysis was conducted using correlation coefficients (r-values) and corresponding p-values. The results show that the correlation coefficients range from 0.299 to 0.684, and all are statistically significant at the 0.001 level (marked ***), indicating a generally significant positive correlation between the dimensions of environmental dynamism and organizational resilience.

This suggests that as external environments such as markets, technologies, and policies continue to change, enterprises' adaptability, recovery capacity, and situational awareness will also improve accordingly. Conversely, organizations with higher levels of resilience are better able to respond calmly to environmental fluctuations, proactively identify and seize opportunities, and thereby form a virtuous cycle of "environmental dynamism driving resilience enhancement, and resilience facilitating environmental adaptation." The fact that all p-values are below 0.001 further strengthens confidence in this relationship, indicating that it is not a result of chance but is stable and replicable, providing solid empirical support for manufacturing firms seeking to simultaneously strengthen their adaptability and resilience in complex environments.

This finding highlights the critical role of environmental dynamism in shaping organizational resilience among manufacturing enterprises, affecting multiple dimensions such as adaptability, recovery, and situational awareness. In response to market dynamism, enterprises must keenly observe shifts in consumer green preferences and restructuring of competitive landscapes. They can enhance adaptability by optimizing products

and services, adjust marketing strategies to align with market needs, strengthen recovery to withstand market shocks, and refine situational awareness to grasp market trends accurately. In the face of technological dynamism, breakthroughs in green manufacturing and waves of digital transformation demand that firms quickly absorb new technologies and eliminate outdated processes to improve technical adaptability and recovery capacity, while also anticipating technological trajectories to strategically position innovation resources. Regarding policy and regulatory dynamism, enterprises must pay close attention to changes in carbon emission standards and environmental subsidies, ensure timely compliance and capitalize on policy incentives, build institutional competitive advantages, and ultimately enhance policy adaptability and organizational stability. Clearly, environmental dynamism serves as an external driving force that pushes enterprises to continuously evolve, thus improving organizational resilience and systemic adaptability.

Existing research provides strong theoretical support. Ortiz-Avram et. al.,(2024) argue that dynamic capabilities are the core mechanism through which firms build resilience in turbulent environments. Enterprises that continuously identify external changes, reconfigure internal resources, and quickly adjust strategies can significantly enhance adaptability and recovery, thereby strengthening overall organizational resilience. They emphasize that dynamic capabilities are not just tools for crisis response, but are the internal logic underpinning the generation of resilience. Moreover, this analysis also underscores the strategic importance of enhancing organizational resilience for manufacturing firms coping with environmental dynamism. Highly resilient firms can improve their environmental awareness, optimize adaptation strategies, and strengthen recovery mechanisms, thereby achieving better survival and development in rapidly changing green markets. For example, when market demand shifts abruptly, firms with high resilience can quickly adjust production capacity and product lines to maintain operations. When faced with technological change, they can swiftly adopt new technologies and restructure production processes. In response to policy shifts, they can ensure rapid compliance and leverage policy incentives. This type of coordinated capability helps firms integrate risk management with green innovation, thereby providing a strong foundation for sustainable development.

In summary, clarifying the intrinsic relationship between environmental dynamism and organizational resilience is of great significance for Chinese manufacturing enterprises seeking efficient and steady growth amid green transformation. Only by actively adapting to environmental changes and proactively building and enhancing organizational resilience can firms effectively cope with external uncertainty, improve environmental responsiveness and operational stability, and lay a solid foundation for long-term development. Ultimately, this will help shape and strengthen their green competitive advantage and enable them to move steadily forward in the era of the green economy, contributing to the high-quality, low-carbon transformation of the manufacturing sector under the “dual carbon” strategy.

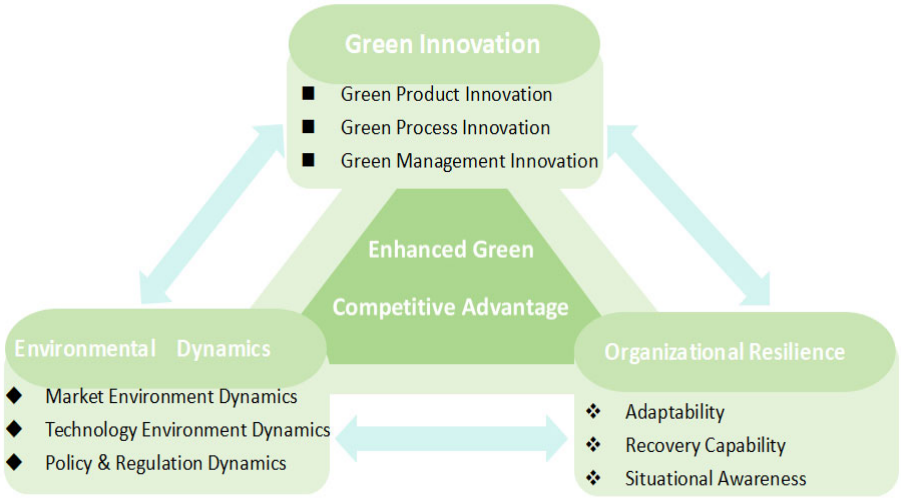

Figure1. Enhance Green Competitive Advantage Framework

Green innovation, environmental dynamics, and organizational resilience form the core foundation of China's manufacturing enterprises' framework for enhancing green competitive advantages, with their synergistic efforts creating a closed - loop logic. Green innovation serves as the driving force, empowering through product, process, and management innovations across multiple dimensions: As Wang et. al.,(2024) indicated, it cuts down resource and environmental costs and aligns with green consumption trends, thereby expanding market share; Zhao et al. (2024) emphasized its role in comprehensively improving sustainable development capabilities in economic, environmental, and social aspects; and Liu et. al.,(2020) confirmed the chain - mediated effect that transforms green organizational identity into sustainable competitive advantage.

Organizational resilience provides the safeguard, as Zhang et. al.,(2024) stressed, enabling flexible adaptation of green innovation strategies, recovery capacity to restart after setbacks, situational awareness to capture policy and technological trends, ensuring continuous implementation of green innovation in dynamic environments. These three elements reinforce each other: environmental dynamics stimulate organizational resilience, which guarantees efficient execution of green innovation, while green innovation transforms into competitive advantages in dynamic environments, collectively establishing a robust foundation for manufacturing enterprises' green competitive advantage framework.

4. Conclusions and recommendations

The implementation effects of green innovation in terms of green product innovation, green process innovation and green management innovation were positively agreed upon by the respondents. The perceived intensity of environmental dynamics in terms of market environmental dynamics, technological environmental dynamics and regulatory policy dynamics was moderately agreed by the respondents.The respondents moderately agreed on the performance of organizational resilience in terms of adaptability, recovery capacity and situational awareness. There is a highly significant relationship between green innovation, environmental dynamics and organizational resilience. A framework to improve the green competitive advantage of manufacturing enterprises was developed. Green innovation may be holistically strengthened by embedding energy-saving design and eco-friendly materials into products, advancing cleaner production and waste recycling systems, and institutionalizing green management through specialized departments, responsive policies, and performance-linked sustainability goals. Firms should dynamically align green innovation strategies by monitoring consumer environmental preferences, tracking clean technology development for capability reserves, and translating regulatory changes into actionable innovation targets. Enhancing organizational resilience requires establishing a prevention–response–recovery framework, improving recovery capacity, integrating information flows for situational awareness, and streamlining decision-making to boost adaptability. A synergistic system emerges when environmental dynamism sets innovation priorities, organizational resilience mitigates risk, and green innovation converts external changes into competitive outcomes. Future research should examine how green innovation, environmental dynamism, and organizational resilience differentially influence green competitive advantage across sectors and firm sizes in China's manufacturing industry.

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