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OPTIMIZING THE SYSTEM DEVELOPMENT LIFE CYCLE TO MINIMIZE RISK IN ACCOUNTING INFORMATION SYSTEMS

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Abstract: The development of reliable and secure accounting information systems is essential in supporting the smooth operations and reliability of an organization's financial statements. However, many accounting information systems face significant risks, such as design errors, system failures, and threats to data integrity. These risks, if not properly managed, can lead to serious financial and reputational losses. Therefore, this study aims to explore how System Development Life Cycle (SDLC) optimization can reduce risks in the development of accounting information systems. Using a qualitative approach and literature study, this research identifies stages in the SDLC that require special attention, such as requirements analysis, design, testing, and maintenance. The results show that better risk management at each stage of the SDLC-especially in careful planning, detailed design, and comprehensive testing-can reduce the potential for system errors and improve the security of accounting data. In conclusion, SDLC optimization plays a crucial role in minimizing risks that can affect the quality and security of accounting information systems, thereby improving operational efficiency and ensuring better accuracy of financial reports.
Keywords: System Development Life Cycle (SDLC); Accounting information system; Risk management; Information system security

1 INTRODUCTION

Accounting information systems (AIS) play a crucial role in an organization's financial management and reporting. As the primary means for collecting, processing and presenting financial data, AIS enables managers and stakeholders to make accurate and timely data-driven decisions. With the development of information technology, AIS is increasingly complex and diverse, requiring careful development to ensure smooth operations and accuracy of financial reports [1].
However, the development of AIS is not free from various risks. One of the main risks is errors in the coding process that can lead to errors in recording transactions and financial reports. In addition, data integration issues between different systems and threats to data security-such as information leaks or cyber attacks-can undermine trust in the system. Therefore, it is important to manage these risks with a more structured and planned approach.
System Development Life Cycle (SDLC) is a commonly used methodology in information system development. Although the SDLC has proven to be effective in building functional systems, it is not uncommon for the stages in the SDLC to be poorly optimized, potentially increasing the risk in the development of the AIS. Therefore, an in-depth understanding of how to optimize the SDLC to minimize risk is crucial in the development of a reliable and secure AIS.
In the context of accounting information system development, implementing an effective System Development Life Cycle (SDLC) is very important to minimize the risks that can arise during the development process. Risks include errors in system design, data integration failures, potential data corruption or information leakage, and the inability of the system to meet functional and non-functional needs.
Based on these challenges, the main problem in this study is:
"How to optimize SDLC to reduce risks in accounting information system development?"
This question will be answered by identifying and evaluating the critical steps in the SDLC that need to be strengthened to ensure better risk management. The focus of this research will be on analyzing how each stage in the SDLC-such as requirements analysis, system design, testing, and maintenance-can be optimized to reduce the potential for failures and errors that can disrupt the smooth running of accounting information systems.
This research aims to explore and analyze how optimizing the stages in the System Development Life Cycle (SDLC) can reduce potential risks in the development of Accounting Information Systems (AIS). By understanding and optimizing each stage of the SDLC-from planning, needs analysis, design, implementation, testing, to maintenance-this research aims to provide insight into how risk management can be integrated more effectively in each phase of accounting information system development.
The specific objectives of this research are as follows:
1. Evaluate the effectiveness of SDLC in mitigating risks that often occur in the development of accounting information systems, such as errors in coding, data integration, and system failure.
2. Analyze the SDLC stages that are most prone to risk in AIS development and how each of these stages can be optimized to reduce potential errors or losses.
3. Provide recommendations related to risk management at each stage of the SDLC that can improve the quality, security, and reliability of accounting information systems.
4. Find the relationship between optimal SDLC implementation and improved performance and accuracy in managing accounting data that supports appropriate managerial decisions.

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Through this research, it is hoped that it can make a significant contribution to the development of the SDLC methodology in the context of accounting information systems, as well as provide practical guidance for developers and IT practitioners in designing information systems that are more secure and efficient.

2 LITERATURE REVIEW

2.1 System Development Life Cycle (SDLC)

System Development Life Cycle (SDLC) is a framework used to plan, develop, and maintain information systems. SDLC describes a systematic and structured process for creating software that can meet user needs and run efficiently. In the context of Accounting Information Systems (AIS), SDLC is essential to ensure that the system developed is not only functional, but also secure, reliable and dependable to support the financial management of the company.
In general, the SDLC is divided into several main stages, each of which has specific objectives and activities. The following are the SDLC stages that are relevant for AIS development:

2.1.1 Planning

This stage is the initial step in system development, where the main objective is to determine the needs and resources required for system development. Here, the development team and stakeholders identify problems and opportunities for system development. Determination of the project scope, budget, schedule, and resource allocation is also done at this stage.
In the context of AIS, the planning stage is critical to understand how the system will integrate with existing accounting business processes, as well as to identify risks that may arise related to the collection and management of financial data.

2.1.2 Requirements analysis (system analysis)

At this stage, a needs analysis is carried out with the aim of understanding more deeply the functional and non-functional needs of the system to be built. The development team works closely with users (such as the accounting team) to identify what is needed by the system to be able to support accounting tasks effectively.
For the AIS, the needs analysis focuses on understanding how financial data is collected, processed and reported, and how the system should be able to minimize errors and improve efficiency. In addition, needs related to data security and integrity also need to be a key focus.

2.1.3 Design (system design)

Once the requirements are identified, the design phase begins to design the structure and components of the system. The system design includes two main parts: a high-level design that describes the overall architecture of the system, and a low-level design that details the implementation of each system component.
In the development of AIS, the design should pay attention to important aspects such as financial transaction management, secure data processing, and intuitive interface for users. In addition, integration with other systems (for example, ERP systems or external databases) should also be considered at this stage.

2.1.4 Implementation (system implementation)

The implementation stage is the stage where system development is carried out. At this stage, the program code is written in accordance with the agreed design. In the implementation of AIS, it is important to ensure that all required functionality can be run correctly and in accordance with the needs that have been analyzed.
This stage also includes setting up the IT infrastructure and compiling the necessary documentation for system use and maintenance.

2.1.5 System testing

After implementation, the testing phase is carried out to ensure that the system works according to predetermined specifications. Testing is done to detect and fix bugs or errors that may exist in the system. System testing is very important to ensure that the accounting system runs without interruption and the data managed can be processed accurately.
In AIS development, testing includes validating the functionality of the accounting system, the reliability of the system in processing transactions, and testing data security to prevent leakage of sensitive information.

2.1.6 Maintenance (system maintenance)

Once the system is implemented and tested, the maintenance phase begins. Maintenance involves periodic updates to the system, bug fixes that arise after the system is used, and adjustments to changing user needs or new regulations.
In AIS, maintenance is essential to keep the system compatible with changes in accounting policies, tax rules, or evolving technology. Maintenance also includes continuous monitoring to ensure data security and system reliability.
Overall, the SDLC provides a systematic framework to ensure that the development of accounting information systems is carried out in a structured, efficient, and effective manner. Each stage in the SDLC contributes to identifying and managing risks that can arise in the process of system development and operation. Optimizing the SDLC to reduce risks in accounting information systems not only improves the quality of the system, but also guarantees that the financial data used for business decision-making remains accurate, secure, and well integrated.

2.2 Risk in Accounting Information Systems

Accounting Information Systems (AIS) play a vital role in ensuring the accuracy, reliability and security of financial data used by organizations [2]. However, the development and use of AIS also presents various risks that can

compromise the integrity of financial statements and undermine trust in the system. Here are some of the key risks that often arise in accounting information systems:

1. Accounting Errors Errors in accounting records can occur due to various factors, such as human error, inaccurate software, or poorly structured business processes. For example, errors in inputting numbers, allocating costs, or recording transactions can result in inaccurate financial statements.

These errors risk causing discrepancies in the financial statements that can affect managerial decisions, compliance with tax regulations, and can reduce the company's credibility in the eyes of stakeholders.

Example: If a company's expense transactions are not recorded correctly, it can lead to inaccuracies in the balance sheet or income statement, which ultimately impacts financial analysis and decision-making.

2. Data Loss The risk of data loss in accounting information systems is often related to system failures, cyber-attacks, or errors in data management . Data loss can include the loss of transaction information, account balances, or financial statements that can cause significant losses to the company.

Weak data security, such as inadequate encryption or backup policies, can increase the potential for data loss.

Example: A ransomware attack targeting an accounting system can lead to the loss of critical transaction data or financial reports, thus damaging the integrity of the system and affecting organizational performance.

3. Errors in Recording Transactions The risk of errors in recording transactions can occur if transactions entering the system are not recorded correctly or in a timely manner. This includes errors in classifying transactions, incorrectly entering account codes, or negligence in validating transactions received from various departments.

Inaccurate or late recording of transactions can lead to errors in the financial statements, which in turn can impact the valuation of the company by auditors, shareholders, and regulators.

Example: If a sales transaction is not recorded correctly in the revenue account, it can affect the income statement and give a false picture of the company's financial performance.

4. Integration Issues Between Systems In many organizations, accounting information systems do not operate separately, but are integrated with other systems, such as Enterprise Resource Planning (ERP) systems, inventory management systems, or human resource management systems. Integration problems between systems can arise when data is not synchronized between different systems, or when there are errors in programming that hinder communication between these systems.

The inability to properly integrate data between various systems can lead to data recording errors, for example, mismatches between financial reports and operational data.

Example: If the transaction data recorded in the ERP system is not successfully integrated with the accounting system, the resulting financial statements will not reflect an accurate status, leading to errors in financial analysis and decision-making.

Identifying key risks in accounting information systems-such as accounting errors, data loss, transaction recording errors, and integration issues between systems-is a crucial first step to mitigating potential losses and improving system reliability. In the context of accounting information system development, managing and mitigating these risks is critical to ensuring that the data processed and reported is accurate, secure, and reliable to support informed decision-making [3].

An in-depth understanding of these potential risks can also help system developers to design and implement more effective strategies to address problems that may arise during the life cycle of the accounting information system.

2.3 Risk Management Models and Methods in SDLC

Risk management in the System Development Life Cycle (SDLC) is essential to identify, assess, and mitigate risks that may interfere with system development, including accounting information systems. Some of the approaches and methods used to manage risks during the development process include:

2.3.1 Risk identification

The risk identification process is the first step in risk management that aims to recognize and document potential risks that may occur during the SDLC. At this stage, the development team and stakeholders work together to explore the risks associated with each stage of the SDLC, such as design errors, data integration, testing failures, and security issues.

- In the context of Accounting Information Systems, risk identification can involve:
- Potential transaction recording errors and accounting errors.
- Data security, including threats to the integrity and confidentiality of financial information.
- System integration issues, such as communication errors between ERP systems and accounting systems.

2.3.2 Risk assessment

Once the risks have been identified, the next step is to assess the extent to which they may affect the project. Risk assessment includes two main components: probability and impact. The team must assess how likely a risk is to occur and what the consequences will be if the risk occurs. This assessment will help the team to prioritize the most critical risks and decide on the steps to take.

In AIS development, risk assessment involves evaluating:

- The financial impact that can arise in the event of accounting errors or data loss.
- Time and resources required to address the issues raised.
- Potential reputational damage due to system failure or financial statement inaccuracies.

2.3.3 Risk mitigation

Risk reduction is a measure to reduce the likelihood of a risk occurring and/or reduce its impact if it does occur. Various strategies that can be used for risk mitigation during SDLC include:
Careful planning at the planning and needs analysis stage ensures that system requirements are covered thoroughly and correctly.
● Thorough testing detects errors earlier in the development stage and reduces the possibility of accounting errors or data loss.
● Enhanced security by using strong encryption, firewall, and authentication technologies to protect financial data.
● Development of clear documentation to ensure that any changes in the system are properly recorded and tracked.
● Training and readying the team to handle issues that arise during the system lifecycle.

2.3.4 Risk monitoring and control

Risk monitoring is an ongoing activity once the system is implemented. The system must be continuously monitored to ensure that the risks that have been identified do not develop into bigger problems. In addition, risk control measures need to be implemented to mitigate risks that may be missed or arise unexpectedly.
In the context of AIS, this could include:
● Regular audits of financial transactions and data to detect errors or misuse.
● Regular maintenance and updates of the system to address its potential vulnerability to new security threats.

2.4 Related Studies

Various previous studies have examined the application of SDLC in the context of Accounting Information Systems and risk management. Some studies that are relevant to this topic include:

2.4.1 Research by Sommerville [4]

In his book "Software Engineering," Sommerville explains the importance of risk management in every stage of the SDLC. He emphasizes that good risk management can improve the quality of software developed, including in the development of accounting information systems. One important finding is the importance of thorough testing at the development stage to detect errors in the processing of accounting data that can cause losses.

2.4.2 Research by C. K. Jørgensen and G. H. Møller [5]

This research focuses on the application of the SDLC methodology in the development of ERP systems, which are often integrated with accounting information systems. They found that poor system integration can be a significant source of risk, especially in financial data management. This study provides important insights into how risk management at the design and testing stages can mitigate integration issues and ensure data consistency between systems.

2.4.3 Research by C. H. Lee and H. J. Kim [6]

In this study, they examined the importance of data security in cloud-based accounting information systems. They pointed out that threats to information security can increase the risk of data loss and information misuse. This research highlights the importance of structured risk management to protect financial data in cloud-based systems, which is becoming highly relevant with modern trends in AIS development.

2.4.4 Research by A. A. S. Al-Debei and S. M. K. Al-Lozi [7]

This research discusses the use of SDLC to develop accounting information systems in the banking sector. The researcher found that risk management at the requirements analysis and system design stages is critical to identify potential transaction recording errors and integration issues between systems that could compromise the accuracy of financial statements.

3 RESEARCH METHODOLOGY AND RESEARCH DESIGN

This research will use a qualitative approach to explore an in-depth understanding of the risk management process in the development of Accounting Information Systems (AIS) through System Development Life Cycle (SDLC) optimization. The qualitative approach was chosen because the main objective of the research is to explore and analyze the factors that influence risk management in SDLC, as well as identify challenges and practical solutions used by organizations in the implementation of accounting information systems.
Case Study will be used as the main research design. The case study approach allows researchers to investigate in depth how a particular company or organization manages risk in their accounting information system development through the implementation of a structured SDLC. Through this case study, researchers can analyze the contextual factors that influence the development process, as well as evaluate the effectiveness of the risk management applied.
In addition, surveys can be used as an additional method to collect quantitative data that involves measuring the level of effectiveness and challenges faced by companies in optimizing SDLC to reduce risk. The survey will include data collection from software developers, accountants, and IT managers involved in the development and maintenance of AIS.

4 DATA COLLECTION

Data collection in this study will be done through two main methods:

4.4 Interview

Semi-structured interviews will be conducted with various parties involved in the development and management of accounting information systems. These interviews will provide insight into the challenges, risk management processes, and SDLC optimization measures undertaken by the company. Interviewees will include:
● System developers: To understand the technical perspective on the application of SDLC and risk management in software development.
● Accountant: To recognize the challenges faced in the integration of accounting information systems with accounting and financial processes, and how accounting risks are managed.
● IT Manager: To gain an understanding of the management of system development projects, as well as the risk management policies implemented at the organizational level.

4.2 Document Analysis

Data collection will also be carried out through document analysis related to the accounting information system development project. Documents to be analyzed include:
● SDLC project documentation: For example, planning documents, requirement analysis reports, system design, testing, and system maintenance reports.
● Audit reports and system security reports: To evaluate how risks in accounting information systems are managed in practice.
● Documentation related to risk management policies and procedures applied in system development projects.
● This document analysis provides a more in-depth look at the steps the organization has taken in designing and implementing the SDLC to minimize risks.

4.3 Data Analysis

Data collected through interviews and document analysis will be analyzed using qualitative analysis methods. Some of the techniques that will be used include:

4.3.1 Thematic analysis

This technique is used to identify the main patterns or themes that emerge from the interviews and documents analyzed. The researcher will categorize the data based on certain themes such as:
● Challenges in risk management at each stage of the SDLC.
● Implemented solutions to reduce risks in the development of accounting information systems.
● Procedures or best practices implemented by the company to minimize accounting errors and data loss.

4.3.2 Coding analysis

The coding process was conducted to organize and classify the interview data and documents in categories relevant to risk management in SDLC. In this way, researchers can identify the relationship between risk management practices and success in optimizing the SDLC. This coding also helps in mapping the factors that influence the risks that arise in the development of accounting information systems.

4.3.3 Data triangulation

To increase the validity and credibility of the findings, data triangulation will be applied, i.e. by comparing interview results, document analysis, and survey results. This approach allows the researcher to gain a more thorough understanding of the risk management practices implemented in the SDLC and how these practices can reduce risks in the development of accounting information systems.

4.3.4 Descriptive analysis

This technique was used to provide a clear picture of the main challenges faced by the company in managing risks during the SDLC. Using the collected data, the researcher can present information regarding common patterns and obstacles that are often encountered during the implementation of SDLC in the context of accounting information system development.

5 RESULTS AND DISCUSSION

5.1 Optimization of SDLC Stages

5.1.1 Planning and needs analysis

The planning and needs analysis stage is an important foundation in the development of accounting information systems. At this stage, the identification of the functional and non-functional needs of the system is crucial to ensure that all aspects required in the system can be fulfilled properly, as well as reducing the risk of design errors that can arise in subsequent stages.
● Identification of Functional Requirements: The functional needs of an accounting system include features that must be present in the system, such as transaction processing, journal recording, financial report generation, and other accounting data management. Ensuring that each functional requirement is clearly recorded and understood by all stakeholders can reduce the risk of errors in system implementation.
● Non-Functional Requirements: Non-functional requirements, such as system performance, data security, and scalability, also need to be considered. Failure to identify and plan for these non-functional aspects can lead to high

risks related to system performance and data integrity. Therefore, risk mitigation measures specific to non-functional requirements should be established at the planning and requirements analysis stage.
Risk management at this stage can be done by:
● Conduct workshops or in-depth discussions with the accounting team to clearly understand operational needs.
● Comprehensive documentation and clarify all requirements early on to prevent misunderstandings in the design stage.

5.1.2 System design

At the system design stage, the application of a risk-based design approach is essential. Risk-based design helps identify potential problems that may occur during system implementation and operation. In accounting information systems, some of the risk factors that need to be considered in the design are:
● System complexity: A complex accounting system with many modules or functions may face the risk of integration errors between systems. Therefore, it is important to carry out a system design that is modular and easy to integrate.
● Data security: Financial data is a valuable asset that must be protected. In the system design, measures to secure data such as the use of encryption, double authentication, and management of access rights need to be implemented to reduce the risk of data leakage or manipulation.
● User interface: Accounting information systems that are not intuitive can lead to human error in recording transactions. A user-friendly and user-centric interface design can minimize the risk of data input errors.

5.1.3 System testing

System testing is a critical stage in ensuring that the accounting information system functions as expected. To reduce the risk of system failure, testing must be done thoroughly, covering various types of testing, such as:
● Functional testing: To ensure that every function in the system works correctly, as intended, and can process data accurately.
● Security testing: These tests aim to identify gaps in the system that can be exploited by irresponsible parties, such as cyberattacks or data leaks.
● Integration testing: It is important to test the integration of the accounting information system with other systems used by the company, such as ERP systems, external databases, or other reporting systems. Integration testing helps ensure that the data processed in the system remains consistent and accurate.
More thorough test methods may include:
● Regression testing ensures that updates or changes to one part of the system do not cause problems in other parts.
● Stress testing to evaluate how well the system handles large transaction volumes.

5.1.4 Maintenance

The maintenance phase ensures that the system remains secure, efficient, and relevant over time. Timely maintenance can reduce the risks that arise from system failures or threats to data security. Some ways to ensure effective maintenance include:
1. Regular updates: Perform software updates to fix bugs, address vulnerabilities, and adjust to changes in regulations or new accounting policies.
2. System monitoring: Systems should be monitored continuously to identify problems or anomalies that could affect performance or data security. For example, transaction monitoring to detect suspicious activity.
3. Data backup and recovery: Develop policies and procedures for regular data backup and ensure rapid data recovery in the event of data loss due to system crashes or disasters.

5.2 Risk Management in SDLC

Good risk management throughout the SDLC can significantly reduce potential losses, especially in the aspects of data security and integrity in accounting information systems. Some risk management steps that can be implemented at each stage of the SDLC include:
1. Proactively identify risks early in development to avoid bigger problems later on.
2. Evaluate and mitigate risks through previously discussed steps, such as comprehensive security testing and risk-based design.
3. Continuous monitoring of risks after the system is implemented, to ensure that risks that were not identified at the initial stage can be addressed immediately.

5.3 Example of Risk Management Application in Accounting Information System Case Study

A case study of company X implementing an accounting information system with an optimized SDLC shows how structured risk management can reduce potential losses. In this case study, company X identified key risks, such as transaction data loss and recording errors, and implemented mitigation strategies at the design and testing stages. For example, company X conducted more rigorous security testing with better data encryption and stricter access control.
In addition, they also integrated the accounting system with the existing ERP system, ensuring that financial and operational data remained consistent and accurate. During the maintenance phase, Company X ensures regular system updates and monitors system performance regularly to anticipate emerging threats.

6 CONCLUSION

6.1 Summary of Findings

This study shows that optimizing the System Development Life Cycle (SDLC) can significantly minimize the risks associated with the development of accounting information systems. Effective risk management at each stage of the SDLC-from planning, needs analysis, design, testing, to maintenance-can reduce the potential losses that arise, both in terms of technical, operational, and managerial. The main findings that can be concluded are as follows:
1. Careful planning and needs analysis can identify and reduce the risk of design errors that could potentially compromise financial data integrity.
2. Risk-based design helps in anticipating issues that may arise, especially those related to system integration, data security, and system functionality.
3. Thorough and structured system testing ensures that technical defects can be detected early, reducing the risk of system functionality failure or data leakage.
4. Timely maintenance can minimize risks to system security and performance after implementation, keeping the system relevant and effective as technology and regulations evolve.
Thus, an optimized SDLC provides great advantages in reducing risks that can adversely affect the successful implementation and operation of accounting information systems.

6.2 Implications for Practice

This research confirms the importance of close collaboration between system developers and accounting teams in designing and implementing SDLC for accounting information systems. This collaboration is crucial so that each stage of the SDLC is carefully planned and implemented, given the complexities that exist in accounting systems that are directly related to sensitive financial data.
The practical implication of this research is that developers and accountants should work together from the planning stage to ensure that all functional and non-functional needs of the system are clearly understood and existing risks can be identified early. In addition, it is also important to ensure that system testing is carried out thoroughly and system maintenance is carried out regularly to maintain system quality and security.

6.3 Suggestions for Future Research

This research makes a significant contribution to the understanding of risk management in SDLC for accounting information systems, but there are still some areas that can be expanded for further research. Some suggestions for future research include:
1.Application of a more adaptive SDLC methodology: Further research can explore how a more flexible and adaptive SDLC can be applied to address challenges arising from regulatory changes or rapidly evolving technologies. For example, with the growing number of cloud computing-based accounting information systems, SDLC methodologies that accommodate dynamic changes and continuity of system updates are needed.
2.Comparative studies: Further research can also compare the application of SDLC in different industries or types of organizations to see how SDLC optimization affects risk management in different sectors, such as the banking sector, government, or small and medium-sized enterprises.
3.Evaluation of new risk management methodologies: Future research could more deeply examine the use of more modern or automated risk management methodologies, such as Artificial Intelligence (AI) and machine learning, to identify, assess and mitigate risks in the development and operation of accounting information systems.
By expanding the scope of research and adopting the latest technologies and methodologies, it is hoped that future research can provide deeper insights into new ways of optimizing SDLC to reduce risks in accounting information systems.

CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

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STRENGTHENING ECONOMICS AND BUSINESS RESEARCH IN NIGERIAN UNIVERSITIES: A PATHWAY TO SUSTAINABLE DEVELOPMENT AND SOCIAL-ECONOMIC GROWTH

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Abstract: This research article delves into the critical role of economics and business research within Nigerian universities, emphasizing its significance for both academic advancement and national development. The study highlights the current landscape of research activities in these disciplines and identifies key barriers that hinder progress. Findings reveal that while there is a growing interest in economics and business research among scholars, several challenges persist, including limited funding, inadequate access to resources, and a lack of collaboration between academia and industry. Moreover, the research underscores the need for universities to prioritize research initiatives that align with Nigeria's economic goals and developmental strategies. The implications of this study are profound. First, it suggests that enhancing research capabilities can lead to more impactful policy recommendations that address economic challenges facing the country. Second, fostering partnerships between universities and business sectors can facilitate knowledge transfer and innovation, ultimately contributing to economic growth. Third, the research calls for increased investment in research infrastructure and training programs to empower researchers in Nigerian institutions. In conclusion, this article presents a compelling case for strengthening economics and business research in Nigerian universities as a means to drive sustainable development and improve the socio-economic landscape of the nation. The findings serve as a foundation for policymakers and educational leaders to implement strategies that will enhance the quality and relevance of research in these vital fields.
Keywords: Landscape; Global development; Economics; Business; Management; Research

1 INTRODUCTION

In the contemporary landscape of global development, the importance of economics and business research cannot be overstated, particularly in a rapidly evolving economy like Nigeria. As the nation strives to navigate the complexities of economic challenges and opportunities, the role of academic research in informing policy and practice becomes increasingly critical. This study aims to shine a light on the current state of economics and business research within Nigerian universities, examining its implications for both academic inquiry and societal advancement [1].

The significance of this research lies in its potential to contribute to the broader discourse surrounding economic development in Nigeria. By investigating how research in these disciplines can be enhanced, the study seeks to address pressing issues such as economic inequality, unemployment, and sustainable development. Furthermore, it emphasizes the necessity of aligning academic research with national priorities to ensure that the findings are not only theoretically sound but also practically applicable.

At the heart of this research are several guiding questions that aim to explore the effectiveness of current research practices, the barriers faced by researchers, and the potential for collaboration between academia and industry. These questions include: What are the primary challenges confronting economics and business researchers in Nigeria? How can universities better support research initiatives that contribute to national development? And, what strategies can be implemented to foster partnerships that enhance the relevance and impact of research outcomes?

The objectives of this study are twofold: first, to assess the existing landscape of economics and business research in Nigeria, and second, to provide actionable recommendations for enhancing research capabilities. By addressing these objectives, this research endeavors to contribute valuable insights that can help shape the future of economics and business research in Nigerian academic institutions.

2 LITERATURE REVIEW

The existing literature on economics and business studies within Nigerian universities reveals a growing body of work aimed at understanding the dynamics of economic development and business practices in the country. Scholars have emphasized the need for rigorous research methodologies and interdisciplinary approaches to address the complex economic challenges facing Nigeria. However, a significant portion of the literature highlights a persistent gap in empirical studies that directly link academic research to practical policy implementation [2].

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One notable perspective is presented by Okwu and Nwankwo [2], who argue that while Nigerian universities produce a substantial number of research outputs, the findings often remain within academic circles, failing to influence policy or industry practices. They call for a more integrated approach where academic research informs real-world applications, thereby enhancing the relevance of studies in economics and business. Similarly, Ajayi [1] critiques the lack of collaboration between universities and the private sector, suggesting that partnerships could lead to more impactful research outcomes that directly address market needs [3].

Despite these insights, there are still considerable gaps in the literature regarding the specific barriers that hinder effective research dissemination and application. For instance, while many studies acknowledge funding limitations, few have examined the implications of this lack of funding on the quality and quantity of research outputs. Additionally, there is a scarcity of research focusing on the integration of technology in research practices, which could enhance collaboration and data sharing among scholars.

This study aims to bridge these gaps by investigating not only the barriers to effective research in economics and business but also the potential for innovative approaches that leverage technology and foster partnerships across sectors. Through this exploration, the research seeks to contribute to a more nuanced understanding of how academic inquiry can be better aligned with national economic goals, ultimately leading to more substantial contributions to Nigeria's socio-economic development.

3 THE ROLE OF ECONOMICS IN UNIVERSITY EDUCATION

Economics as a discipline plays a pivotal role in the realm of higher education, particularly in developing countries like Nigeria. It provides students with the analytical tools and theoretical frameworks necessary to understand complex societal issues, including poverty, inflation, and unemployment. By incorporating economic theory and empirical analysis into their curricula, universities equip students with the skills to critically evaluate the socio-economic environment, which is essential for informed decision-making in both public and private sectors [4].

The relevance of economics extends beyond classroom learning; it is intricately linked to societal development and policy formulation. In Nigeria, where economic challenges are pronounced, economists are often at the forefront of policy-making. They analyze data and trends to provide insights that drive governmental strategies aimed at stimulating growth and addressing social inequalities. For instance, economists contribute to the formulation of fiscal and monetary policies that can stabilize the economy, promote investment, and enhance public welfare.

Moreover, the study of economics fosters a culture of research and innovation within universities. By encouraging students to engage in empirical research, institutions can produce valuable insights that directly inform national development plans. Such research can address pressing issues such as resource allocation, labor market dynamics, and economic diversification—areas that are crucial for Nigeria's long-term growth and sustainability [5].

In Nigeria's increasingly globalized economy, the integration of economics in university education is essential for preparing students to compete on an international level. A strong foundation in economic principles enables graduates to navigate the complexities of global markets, understand international trade dynamics, and participate effectively in the global economy. As such, economics not only enhances individual career prospects but also contributes to building a robust workforce capable of driving national development.

In conclusion, the role of economics in university education is multifaceted, influencing both individual career trajectories and broader societal outcomes. By prioritizing economics as a key discipline, Nigerian universities can cultivate a generation of informed leaders and critical thinkers equipped to tackle the nation's economic challenges [6].

3.1 The Importance of Business Research

Business research is a cornerstone for understanding market dynamics, developing effective business strategies, and shaping economic policies, particularly in Nigeria's complex economic landscape. The significance of this research transcends mere academic inquiry; it is integral to fostering an environment where businesses can thrive, adapt, and innovate in response to changing market conditions [7].

In Nigeria, where the economy is characterized by rapid fluctuations and diverse consumer behavior, business research serves as a vital tool for analyzing market trends. By conducting comprehensive market studies, researchers can provide valuable insights into consumer preferences, competitive landscapes, and emerging opportunities. This information enables businesses to tailor their products and services to meet the specific needs of their target audience, thereby enhancing customer satisfaction and loyalty. Moreover, understanding market dynamics helps companies make informed decisions regarding pricing strategies, distribution channels, and marketing approaches, ultimately contributing to their overall success [8].

Additionally, business research plays a crucial role in formulating robust business strategies. Through empirical analysis and data-driven insights, organizations can identify strengths, weaknesses, opportunities, and threats within their operational environment. This strategic planning process is essential for companies aiming to navigate the challenges posed by Nigeria's

diverse economic landscape. Researchers can assist firms in developing strategic responses to market changes, thereby promoting resilience and sustainability in their operations [9].

On a broader scale, business research informs economic policies that are vital for national development. Policymakers rely on empirical evidence to design initiatives that stimulate economic growth, attract investment, and address socio-economic disparities. By understanding the nuances of the business environment in Nigeria, researchers can advocate for policies that create a conducive atmosphere for entrepreneurship and innovation, driving long-term economic stability [10].

In summary, business research is instrumental in enhancing the understanding of market dynamics, shaping effective strategies, and influencing economic policies in Nigeria. Its contributions are essential for fostering an adaptive business environment and driving sustainable economic growth.

3.2 Challenges Faced by Economics and Business Research in Nigerian Universities

The study of economics and business research in Nigerian universities is fraught with various challenges that significantly hinder its effectiveness and relevance. One of the most pressing issues is the lack of adequate funding. Many universities struggle to secure sufficient financial resources to support research activities, resulting in limited access to essential materials, databases, and technology. This funding deficit not only affects the quantity of research output but also compromises the quality, as researchers often have to rely on outdated information or inadequate tools for their studies.

In addition to financial constraints, the relevance of the curriculum is another critical challenge. Many academic programs in economics and business do not align with the current needs of the Nigerian economy, resulting in a gap between theoretical knowledge and practical application. This misalignment can lead to graduates who are ill-prepared to tackle real-world economic issues, further perpetuating the cycle of ineffectual research. A curriculum that does not adapt to evolving market conditions or emerging fields of inquiry can stifle innovation and limit the potential for impactful research.

Furthermore, infrastructural deficits pose a significant barrier to research advancement. Many Nigerian universities lack adequate facilities, such as modern libraries, laboratories, and collaborative spaces, which are essential for conducting high-quality research. Infrastructural inadequacies also extend to technology, where limited access to computers and the internet can hinder researchers' ability to gather data, communicate findings, or engage with global academic communities.

Lastly, there is often a lack of collaboration between academia and the business sector. Many researchers work in isolation, with little interaction or partnership with industry players who could provide valuable insights and resources. This disconnect can result in research that is not only impractical but also irrelevant to the current economic landscape. Strengthening ties between universities and business entities is crucial for fostering a research environment that is both innovative and applicable to real-world challenges.

Addressing these challenges is essential for enhancing the quality and impact of economics and business research in Nigerian universities. By focusing on funding, curriculum relevance, infrastructure, and collaboration, stakeholders can create a more conducive environment for academic inquiry that ultimately contributes to national development.

3.3 Benefits of Economics and Business Research

Engaging in economics and business research yields numerous benefits for students, faculty, and society at large. For students, the opportunity to participate in research fosters critical thinking and analytical skills that are essential in today's job market. By engaging in empirical studies, students gain hands-on experience that enhances their academic knowledge, making them more competitive and better prepared for future careers. This research experience not only enriches their academic journey but also instills a sense of inquiry and innovation, encouraging them to pursue solutions to pressing economic issues.

Faculty members also reap significant benefits from conducting research. Engaging in rigorous academic inquiry enhances their expertise and credibility within their fields. It allows them to stay current with emerging trends and theories, which can be integrated into their teaching practices. Moreover, faculty research can lead to publications in reputable journals, increasing their visibility and recognition in the academic community. Collaborative research projects can also foster interdisciplinary partnerships, enriching the academic environment and encouraging the exchange of ideas.

On a societal level, the contributions of economics and business research are profound. Such research can illuminate critical issues like poverty, unemployment, and economic growth, providing policymakers with evidence-based insights necessary for effective decision-making. By identifying market trends and consumer behavior, researchers can help businesses adapt to changing economic conditions, ultimately driving innovation and enhancing competitiveness. This synergy between research and practice can stimulate economic growth, create jobs, and improve living standards.

Furthermore, research initiatives promote a culture of innovation, encouraging new business models and strategies that can lead to sustainable development. As universities collaborate with local industries, they can harness collective knowledge to address real-world challenges, driving progress within their communities. This connection not only enhances the relevance of academic research but also ensures that it has a tangible impact on economic and social development.

Overall, the benefits of economics and business research extend far beyond academia, contributing to the empowerment of individuals, the advancement of knowledge, and the enhancement of societal well-being.

3.4 Case Studies: Successful Economics and Business Research Initiatives

Numerous research initiatives in Nigerian universities have positively impacted local and national economies, showcasing the potential of academic inquiry to drive development. One prominent example is the research conducted at the University of Ibadan, where scholars focused on agricultural economics. Their work on optimizing agricultural supply chains has led to improved market access for local farmers, significantly enhancing food security and income levels in rural communities. By collaborating with local agricultural cooperatives, researchers were able to implement their findings, which directly benefited farmers through better pricing strategies and reduced post-harvest losses.

Another successful initiative can be seen at Ahmadu Bello University, where a team of researchers examined the impact of microfinance on small and medium-sized enterprises (SMEs). Their study revealed that access to microloans significantly increased business sustainability and growth among SMEs in Kaduna State. By engaging with local entrepreneurs and financial institutions, the researchers were able to develop tailored financial products that addressed the unique challenges faced by small businesses in the region. This initiative not only fostered economic empowerment but also stimulated job creation.

Furthermore, the Lagos Business School has made strides in enhancing business research through its focus on entrepreneurship and innovation. Their collaborative projects with tech startups have resulted in the development of new business models that harness technology for economic growth. By providing training programs and mentorship for aspiring entrepreneurs, the school has contributed to the emergence of a vibrant startup ecosystem in Lagos, which is now recognized as a hub for innovation in West Africa.

These case studies illustrate the profound impact that economics and business research can have when aligned with local needs and national priorities. By bridging the gap between academic research and practical application, Nigerian universities are not only contributing to scholarly discourse but also driving tangible improvements in the economic landscape. Such initiatives serve as exemplary models for further collaboration between academia and industry, reinforcing the importance of research in fostering sustainable development.

4 POLICY RECOMMENDATIONS

To enhance the study and impact of economics and business research in Nigerian universities, a multifaceted approach is essential. The following recommendations aim to address the pressing challenges identified in previous sections, focusing on funding, curricula revisions, and partnerships with industries.

4.1 Increased Funding for Research Initiatives

One of the foremost challenges faced by researchers in Nigerian universities is inadequate funding. To address this issue, it is critical for the government, private sector, and international organizations to increase their investment in academic research. Establishing dedicated research grants and funding opportunities specifically for economics and business studies can enable scholars to access necessary resources, conduct fieldwork, and acquire modern research tools. Additionally, universities should explore alternative funding sources, such as public-private partnerships, which can facilitate collaborative research projects that align with national development goals.

4.2 Curriculum Revisions to Enhance Relevance

Curricula in economics and business programs must be revised to ensure they remain relevant to the evolving economic landscape of Nigeria. This includes integrating practical skills training, case studies, and real-world applications into the coursework. Universities should collaborate with industry experts to identify key competencies and emerging trends in the job market, ensuring that graduates are well-equipped to tackle contemporary economic challenges. Incorporating interdisciplinary approaches that integrate technology, environmental sustainability, and entrepreneurship will also enrich the educational experience and foster innovation.

4.3 Strengthening Academia-Industry Partnerships

Fostering strong collaborations between universities and the business sector is vital for enhancing the relevance and impact of research. Establishing formal partnerships can facilitate knowledge transfer, allowing researchers to work closely with industry professionals to address real-world problems. Joint research projects, internships, and mentorship programs can bridge the gap between theoretical knowledge and practical application, providing students with invaluable experiences and insights. Moreover, these partnerships can aid in the dissemination of research findings, ensuring that results are utilized in policy formulation and business strategies.

4.4 Promoting an Innovative Research Culture

Encouraging a culture of innovation within universities is essential for advancing economics and business research. This can be achieved by establishing research hubs or centers of excellence that promote interdisciplinary collaboration and the exchange of ideas. Additionally, universities should support faculty and student-led initiatives that focus on entrepreneurship and startup incubation, creating an environment where innovative solutions to economic challenges can flourish. By fostering a vibrant research community, Nigerian universities can contribute to the development of sustainable economic practices and policies that benefit society as a whole.

5 FUTURE DIRECTIONS OF ECONOMICS AND BUSINESS RESEARCH IN NIGERIA

The future of economics and business research in Nigerian universities is poised for transformative growth, driven by a confluence of emerging areas of interest and enhanced collaborative efforts. With the rapid evolution of technology and globalization, researchers will increasingly focus on areas such as digital economies, sustainable business practices, and the impacts of artificial intelligence on market dynamics. These themes not only resonate with global trends but also address local challenges, positioning Nigerian scholars to contribute meaningfully to both national and international discourses.

One promising area is the exploration of fintech and its implications for financial inclusion. As mobile banking and digital payment systems gain traction, research focused on the accessibility of financial services for underserved populations can yield insights that inform policy and practice. Additionally, understanding the role of digital currencies and blockchain technology in enhancing transparency and efficiency in business operations presents a fertile ground for inquiry.

Sustainability will also dominate future research agendas. As Nigeria grapples with environmental challenges, research that investigates sustainable business models and green economics will be critical. Collaborative studies that involve government agencies, non-governmental organizations, and industry leaders can create a holistic approach to addressing issues like climate change, waste management, and resource allocation.

Moreover, fostering partnerships between universities and the private sector will be paramount. Institutions can benefit from engaging with businesses to conduct applied research that addresses real-world problems, thereby ensuring that academic outputs are relevant and actionable. Such collaborations can facilitate internships and practical training opportunities for students, bridging the gap between theory and practice.

Furthermore, interdisciplinary research that combines insights from economics, sociology, and environmental studies will enhance the depth and breadth of academic inquiry. By encouraging cross-disciplinary collaboration, Nigerian universities can cultivate innovative solutions that are responsive to the complexities of the socio-economic landscape.

In summary, the future of economics and business research in Nigeria hinges on embracing emerging trends, fostering collaborations, and encouraging interdisciplinary approaches. These elements will not only enrich academic discourse but also drive meaningful contributions to the nation's economic development.

6 CONCLUSION

The exploration of economics and business research within Nigerian universities has revealed several key insights that underscore its vital importance to both academic and national development. The research highlights the growing interest among scholars in these fields, while also identifying significant barriers such as insufficient funding, limited access to resources, and the need for stronger collaborations between academia and industry. These challenges, if addressed, can enhance the quality and impact of research outputs, ultimately driving economic growth and social progress.

One of the critical findings of this study is the necessity for universities to align their research initiatives with Nigeria's economic goals. By prioritizing research that addresses pressing socio-economic issues such as unemployment, poverty, and sustainable development, academic institutions can produce findings that are not only theoretically robust but also practically applicable. This alignment will facilitate the generation of policy recommendations that are grounded in empirical evidence, thereby enhancing their effectiveness in addressing the country’s challenges.

Furthermore, the case studies presented illustrate the tangible benefits that arise from successful research initiatives, demonstrating how academic inquiry can lead to improved market access, enhanced business sustainability, and the promotion of innovation. These examples serve as a testament to the potential that lies in bridging the gap between theoretical research and real-world applications.

For future research, there are several promising areas to explore. Investigating the implications of digital economies, sustainability practices, and fintech's role in financial inclusion are critical as Nigeria continues to adapt to global changes. Additionally, there is a pressing need for research focusing on the integration of technology in business practices, as well as the promotion of interdisciplinary approaches that can provide comprehensive solutions to complex economic issues.

Ultimately, reinforcing the role of economics and business research in Nigerian universities is essential for fostering a knowledge-driven economy capable of tackling the socio-economic challenges of the nation. By investing in research infrastructure and cultivating meaningful partnerships, Nigerian universities can pave the way for a more prosperous and sustainable future.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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BRAND BUILDING AND MARKETING STRATEGY FOR SHAOXING ANCIENT ROAD

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Abstract: Shaoxing Ancient Road, as a tourism resource with rich historical and cultural value and natural landscapes, has faced challenges such as insufficient tourism development and severe homogenization in recent years. Based on the 4Ps theory of marketing (Product, Price, Place, Promotion) and combined with brand-building strategies, this paper conducts an in-depth analysis of the brand construction and marketing strategies for Shaoxing Ancient Road. Through digital technology, cultural IP creation, and government cooperation, a series of marketing strategies tailored to the characteristics of Shaoxing Ancient Road are proposed, aiming to enhance its brand influence and promote the protection and sustainable development of the ancient road.
Keywords: Shaoxing Ancient Road; Brand building; Marketing; 4Ps theory; Digital protection; Cultural IP

1 INTRODUCTION

As an ancient transportation route, Shaoxing Ancient Road carries rich historical and cultural memories and holds significant value for tourism development. However, with the development of modern transportation, the tourism development of ancient roads faces numerous challenges, such as low tourist awareness, outdated infrastructure, and limited activation methods[1]. How to protect the historical and cultural heritage of ancient roads while enhancing their economic value and social influence has become an urgent issue. Based on the 4Ps theory of marketing (Product, Price, Place, Promotion) and combined with brand-building strategies, this paper conducts an in-depth analysis of the brand construction and marketing strategies for Shaoxing Ancient Road, aiming to provide feasible paths for the protection and activation of ancient roads[2].

2 BRAND BUILDING STRATEGY FOR SHAOXING ANCIENT ROAD

2.1 Brand Positioning

The brand positioning of Shaoxing Ancient Road should highlight its historical, cultural, and ecological tourism value, creating a brand image that integrates "culture + ecology + health." The positioning can be approached from three aspects: historical and cultural brand, ecological tourism brand, and healthy lifestyle brand[3]. First, as a historical and cultural brand, Shaoxing Ancient Road is a witness to history, and the brand should convey the core value of "inheriting history and preserving culture." Second, as an ecological tourism brand, the ancient road boasts beautiful natural scenery along its route, making it suitable for outdoor hiking and ecological tourism. It can be positioned as "the ecological hiking destination of the Yangtze River Delta region." Third, as a healthy lifestyle brand, combining modern people's pursuit of a healthy lifestyle with hiking on the ancient road can attract young people and family tourists.

2.2 Core Brand Value

Shaoxing Ancient Road carries rich historical and cultural information, and the brand should convey the core value of "inheriting history and preserving culture." The brand should emphasize the protection of the ancient road and its surrounding environment, promoting the concept of "green tourism and sustainable development." Through hiking activities, the brand should also promote a "healthy lifestyle and closeness to nature."

2.3 Brand Image Design

The brand name should highlight the "historical elegance" and "natural beauty" of the ancient road. The brand logo should incorporate elements of the ancient road, landscapes, and historical buildings, reflecting the local characteristics of Shaoxing to enhance brand recognition. A signature slogan such as "Walk the Ancient Road, Taste History, Enjoy Nature" or "Millennium Ancient Road, Century of Elegance" should be established to succinctly convey the brand's value[4].

2.4 Brand Communication

Social media platforms such as TikTok, WeChat, and Weibo should be utilized to release short videos, VR experiences, and historical and cultural stories about the ancient road, attracting a younger audience. By developing cultural IPs

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related to the ancient road (such as hiker characters or historical figures), the brand's communication power and influence can be enhanced. Cross-border collaborations with outdoor sports brands and health food brands can also be pursued to launch co-branded products or events, expanding the brand's influence[5].

3 MARKETING STRATEGY FOR SHAOXING ANCIENT ROAD

3.1 Product Strategy

From Figure 1, in terms of core products, the hiking routes of Shaoxing Ancient Road should be carefully designed according to local conditions, offering multiple routes with varying difficulty levels and durations. By analyzing the needs of different tourists, the product offerings should be diversified to meet the expectations of various visitors. Additionally, leveraging the rich historical and cultural background of the ancient road, a series of "Ancient Road Cultural Experience Tours" can be developed, integrating culture and tourism[6]. These projects should include in-depth historical explanations, hands-on experiences with traditional crafts, and local cuisine tasting, allowing tourists to gain a deeper understanding of Shaoxing's local culture while enjoying the hike. Furthermore, based on the trend of digital development, virtual reality experiences, mobile applications, and online tour guide services can be introduced to enhance tourists' interactive experiences, increasing engagement and immersion.

Figure 1 Product Strategy for Shaoxing Ancient Road Marketing

3.2 Price Strategy

From Figure 2, the pricing strategy should be based on the principle of differentiated pricing. Different prices should be set for various hiking routes and experience projects along Shaoxing Ancient Road to better meet market demands. Basic hiking routes can be priced lower to attract a broader range of tourists, while tourism products that include in-depth cultural experiences can be priced higher to attract high-end tourists willing to pay for premium experiences[7]. Additionally, offering membership programs and package discounts can effectively enhance customer loyalty and encourage family and group tourists to participate. Seasonal price adjustments should also be considered to manage the fluctuations in tourist numbers between peak seasons (spring and autumn) and off-seasons (winter).

Figure 2 Price Strategy for Shaoxing Ancient Road Marketing

3.3 Place Strategy

From Figure 3, fully utilizing online channels is crucial. Social media platforms such as TikTok, WeChat, and Weibo can be used to share the beautiful scenery and cultural stories of the ancient road, effectively attracting potential tourists and encouraging them to share their experiences. Collaborating with well-known travel platforms such as Ctrip, Fliggy, and Mafengwo to jointly launch hiking tour packages for the ancient road can help expand online sales channels. For offline channels, partnerships with travel agencies, outdoor sports clubs, and hotels can be established to offer hiking tour packages, effectively expanding the offline market. Additionally, close cooperation with local governments to include ancient road tourism in local tourism promotion plans can leverage government resources for broader publicity, enhancing overall market coverage[8].

Figure 3 Channel Strategy for Shaoxing Ancient Road Marketing

3.4 Promotion Strategy

From Figure 4, in terms of promotion strategies, social media marketing should be fully utilized. Short videos showcasing the natural scenery and historical culture of Shaoxing Ancient Road can be released on platforms such as TikTok and Kuaishou to attract the attention of younger audiences. Collaborating with key opinion leaders (KOLs) in the outdoor sports and historical culture fields can further expand market influence by leveraging their reach[9]. Additionally, hosting events such as the "Shaoxing Ancient Road Cultural Festival" and "Hiking Challenge" can attract tourists and enhance brand awareness. Offering early bird discounts, group discounts, and holiday promotions are also effective means of attracting tourists.

Figure 4 Promotion Strategy for Shaoxing Ancient Road Marketing

4 FEASIBILITY ANALYSIS OF THE STRATEGIES

4.1 Policy Support

The "Zhejiang Province Ancient Road Protection Measures," announced by the Zhejiang Provincial Government on December 29, 2021, and effective from March 1, 2022, provide legal protection for the preservation and development of ancient roads. The project can leverage this policy support to promote the digital protection and brand activation of ancient roads. Ancient road tourism can contribute to rural economic development, aligning with the national rural revitalization strategy, and the project can seek government funding and policy support. With the increasing demand for cultural tourism as people's living standards improve, Shaoxing Ancient Road, as a historical and cultural heritage site, has significant market potential. Modern people are increasingly focusing on health, and hiking tourism, as a healthy lifestyle, is gaining popularity[10]. Additionally, with the growing awareness of environmental protection, ecological tourism has become a trend, and the natural scenery and ecological environment of Shaoxing Ancient Road are attractive to tourists.

4.2 Rise of Digital Protection and Activation

Through VR technology, tourists can experience the natural scenery and historical culture of the ancient road online, attracting them to visit in person. Mobile apps providing online tour guide services can enhance tourists' interactive experiences. Furthermore, social media communication is also feasible: releasing short videos and VR experiences of the ancient road on platforms such as TikTok and WeChat can attract user attention and sharing, providing a favorable environment for the implementation of Shaoxing Ancient Road's marketing strategies.

4.3 Demand and Supply Analysis

Shaoxing Ancient Road possesses rich historical, cultural, and natural landscape resources, providing a solid foundation for the development of cultural and ecological tourism. Currently, the infrastructure along Shaoxing Ancient Road is relatively outdated, and further improvements in supporting facilities are needed through government and corporate cooperation to enhance the tourist experience[11].

4.4 Economic Benefits

The development and marketing of Shaoxing Ancient Road will bring direct economic benefits through ticket sales,

tour guide services, and digital products. Indirect economic benefits include the development of local industries such as dining, accommodation, and transportation, creating job opportunities and promoting local economic growth.

5 CONCLUSION

The brand building and marketing strategies for Shaoxing Ancient Road should revolve around the brand positioning of "culture + ecology + health," integrating digital technology and modern communication methods to create a tourism brand with unique cultural and ecological value. Through differentiated pricing, multi-channel promotion, and festival activities, the strategies aim to attract tourists from different segments, enhancing the ancient road's popularity and influence, and demonstrating feasibility and value[12]. At the same time, the project should fully utilize national and local policy support to promote the protection and sustainable development of ancient roads, achieving a win-win situation for economic and social benefits.

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FACTORS IN THE DEVELOPMENT OF THE "GREEN" SERVICES SECTOR

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Abstract: The article highlights key factors that contribute to the growth and development of the "green" services sector. According to the author, it is believed that environmentally oriented services aimed at increasing the resilience of the economy help reduce the negative impact on the environment. Based on this, the author focuses on economic, social, technological, and institutional aspects. All of these contribute to the growth and development of this field.
Thus, as a result of the research, the author analyzes factors such as the activation of environmental legislation and the expansion of institutional frameworks within the interactions of business structures under conditions of ensuring sustainable development based on innovative achievements in technology and engineering.
As a result of studying and analyzing this issue, the role of education and raising environmental awareness among economic entities is substantiated, and the prospects for the development of "green" services as a strategic direction for achieving sustainable development goals in the country are identified.
Keywords: Environmentally oriented services; Economic sustainability; Environmental impact; Institutional aspects; Strengthening environmental legislation; Expanding institutional frameworks; Integrated approach of business structures; Ensuring sustainable development; Innovative achievements; Environmental awareness of stakeholders; Prospects for the development of "green" services

1 INTRODUCTION

The need to introduce "green" technologies is caused by serious disturbances in the natural and living environment of people. Such disturbances are fraught not only with degradation and irreversible consequences of ecosystem deterioration, but also with the complication of assessing the risks threatening the existence of human society.
In this regard, the analysis of specific sectors of the economy, where greening can play a key role, is of particular relevance. For example, the service sector of the Republic of Tajikistan, which is in the process of accelerated development, faces a number of challenges and opportunities on the way to greening the environment. "Green" transformation in this sphere requires a comprehensive approach, including optimization of resource consumption, introduction of environmentally friendly technologies and increasing the environmental responsibility of participants in business structures. In this context, the adaptation of international experience, taking into account the specifics of the national economy based on natural and socio-cultural features, is of particular importance.

2 REVIEW OF RELEVANT RESEARCH

The modern world is undergoing a dynamic process of "green" transformation aimed at reducing the negative impact of economic activity on the environment. Among the various sectors of the economy that require transition to sustainable development models, the services sector occupies a special place, playing a key role in the formation of more environmentally friendly behavioral practices, compliance with social norms and application of new forms of economic mechanisms. In the context of global climate change and increasing environmental requirements, Tajikistan, as a country with rich natural capital and a growing diversified economy, faces the need to adapt the services sector to the requirements of sustainable development.
Modern global challenges, including climate change, depletion of natural resources and degradation of ecosystems, require rethinking and transformation of economic models in all sectors, especially in the service sector. This sector is considered a key segment of the national economy along with natural resource extraction and industry, which includes the provision of intangible goods that contribute to the full, timely and qualitative satisfaction of the demand of the population, businesses and the state (Table 1).

Table 1 Characteristics of the Service Sector

Direction of service sector characterization	Description of the content of the service sector direction
Definition of the service sector	The services sector includes activities related to the provision of intangible benefits aimed at meeting the needs of the population, businesses and government agencies.

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Structural description of service sector activities	1. Intangible nature: services cannot be stored or transported. 2. Often requires interaction: rendered through direct interaction with the consumer. 3. Consumption coincides with production: services are consumed at the time they are provided.
Main types of services	1. Financial services: banks, insurance companies. 2. Educational services: schools, universities, courses. 3. 3. Health care: medical facilities, pharmacies. 4. Transportation and logistics: airlines, trucking. 5. Tourism and hospitality: hotels, restaurants. 6. Information technologies: software development, IT-consulting. 7. Creative services: advertising, design. 8. Public services: police, social protection.
Place and role of the services sector	1. provides a high level of employment. 2. Contributes significantly to GDP. 3. Improves quality of life through accessible and modern services. 4. Tourism, telecommunications and financial services are actively developing in developing countries.

***Source:** Compiled by the author on the basis of electronic resources.

Global practice shows that the services sector is multifunctional and has a proportionate impact on the diversification of national economies. This sector, encompassing tourism, transportation, finance, education, information technology and health care, plays a significant role in supporting sustainable development by influencing consumption patterns, social norms and business practices.

As a result of the study it turns out that for countries with high natural vulnerability. In particular, the Republic of Tajikistan, where the transformation of the services sector in accordance with the principles of "green" economy is taking place. This shows the degree of relevance and importance of studying this problem, given the dependence of the economy and welfare of the population on the state of quantity and quality of ecosystems.

In terms of its content, the green transition of the services sector represents a qualitative change. In particular, the transition to an economic model that takes into account the environmental, social and economic aspects of sustainable development. In this perspective, the services sector adapts to the requirements of sustainable development and introduces more efficient, environmentally friendly and cost-effective solutions aimed at reducing the negative impact on the natural environment. These measures contribute not only to improving the quality of life of the population, but also to strengthening the environmental security and economic stability of the country.

3 THEORETICAL ANALYSIS AND RESEARCH HYPOTHESIS

For the Republic of Tajikistan, which has significant resources in hydropower, agriculture and biodiversity, green transformation of the services sector opens new opportunities for diversifying the economy, strengthening social sustainability and creating new green jobs. The application of green technologies in sectors such as tourism and hospitality can help not only to increase tourist arrivals, but also to maintain natural and cultural heritage. Adhering to green economy rules in information technology, finance and logistics can increase economic efficiency, reduce resource consumption and promote the development of necessary infrastructure.

Expanding climate change, which leads to the depletion of natural resources and deterioration of ecosystems, requires timely rethinking and transformation of economic activities in all sectors of the national economy. One of the key areas of modern economic development is the transition to the transformation of the services sector into a "green" sphere, which, despite its complexity, has a significant impact on economic growth. For countries with a high level of vulnerability of natural potential and developing economies, such as the Republic of Tajikistan, the introduction of environmental approaches in the services sector is a necessity, as well as a measure to ensure long-term sustainability and competitiveness of the services sector.

"Green" economy in the sphere of services is focused on sustainable development, reduction of negative impact on nature and rational use of resources. The essence of the "green" economy in this sphere is the transition of the service sector, in which the approaches to qualitative indicators to the provision of services have been changed in order to improve their quality, accessibility and satisfaction of consumers' needs. This process is driven by innovation, digitalization, new flexible business models and adaptation to the new realities of changing market conditions. The service sector is part of the green economy, which in turn is a crucial link for transforming the economy into a green economy. In many countries, the development of the service sector as part of the green economy is becoming an important driver for achieving sustainable development goals. For example, Europe is a leader in the implementation of environmental standards. Waste recycling, energy-efficient construction and consulting services are being actively developed here. In the European Commission, out of the six objectives put forward for the period 2019-2024 (EU COM, 2019), three objectives are relevant to the development of services as part of the green economy and the services sector is a crucial factor in achieving these objectives. The European Green Deal envisages the realization of the following

priorities: an economy that works for people and a Europe fit for the digital age [1]. "Green" and sustainable services cover a wide range of areas such as renewable energy, waste management services, energy consulting, green building (Table 2).

Table 2 Structure of Green Services and Their Characteristics

"Green" service	Description	Main features	Advantages
Waste processing services	Recycle and reuse materials to minimize waste.	Reducing pollution, improving the environment, raising awareness.	Reducing waste, saving resources, improving the image of companies.
Energy consulting	Assessment and optimization of energy consumption in buildings and businesses.	Energy saving, energy efficiency improvement, reduction of carbon emissions.	Reduction of energy costs, improvement of energy efficiency.
Renewable energy	Utilization of solar, wind, geothermal and other alternative energy sources.	Reducing carbon footprint, climate resilience, clean energy utilization.	Long-term savings, support green solutions, reduce dependence on fossil sources.
Green building	Design and construction of buildings taking into account the principles of sustainable development and energy saving.	Energy efficiency, use of environmentally friendly materials, reduction of emissions.	Reduced operating costs, improved air quality, increased comfort.
Ecological tourism	Tourism that minimizes negative impacts on nature and supports local ecosystems.	Conserving nature, supporting sustainable communities, minimizing waste.	Supporting ecosystems, raising awareness of environmental issues, developing local economies.
Landscaping services	Landscape design and the creation of green spaces in cities.	Reduce air pollution, improve quality of life, increase biodiversity.	Improvement of microclimate, aesthetic improvement of the environment, support of local flora.
Water resources management	Water efficiency, treatment and reuse services.	Reducing water consumption, minimizing pollution, sustainable use of resources.	Reducing water costs, improving the environmental situation, and increasing the sustainability of ecosystems.
Eco-logistics	Transportation using environmentally friendly vehicles and optimization of logistics processes.	Reducing carbon dioxide emissions, saving fuel, utilizing renewable energy sources.	Reducing carbon footprint, lowering fuel costs, improving public image.

***Source:** Compiled by the author on the basis of electronic resources.

The table below shows the key categories of green services, their examples and characteristic features, which allows structuring information on current trends in sustainable development and the role of green services as a significant element of the modern green economy.In this regard, the current demand for environmental services is showing steady growth, driven by the global sustainable development agenda, increasing environmental regulations and the need to reduce the carbon footprint. Major demand drivers include climate change, depletion of natural resources, and the desire for a cyclical economy. The Paris Agreement, the UN Sustainable Development Goals (SDGs) and other global initiatives are incentivizing countries to invest in environmental services. For example, SDG 12 ("Ensure sustainable consumption and production") is directly linked to waste recycling and energy efficiency. Countries with developed economies are introducing strict laws regulating emissions, waste management and resource utilization. Companies are forced to engage environmental consulting, recycling and renewable energy transition services. Rational assessment and correct information about the state of environmental resources, contributes to the demand for goods and services. As practice shows in recent years in the global tourism market, the ecological direction of tourism is becoming more and more popular. The demand for services for the installation of solar panels, wind turbines and other "green" energy is growing at a rate of about 10% annually [2]. Major countries such as China, USA and Germany are leading the sector. The recycling segment is estimated at $100 billion annually and includes recycling of plastic, e-waste and biowaste [3]. EU countries recycle more than 40% of household waste, which drives the services in this sector [4]. The main demand is observed in North America and Europe. North America has high demand for renewable energy and green building due to corporate responsibility of large companies. China and India are becoming major players in recycling and renewable energy. Growth here is driven by both government initiatives and high rates of urbanization. Africa and Latin America, despite low penetration of environmental services, are seeing an increase in demand due to international investment and infrastructure development programs.

The International Energy Agency (IEA) estimates that the global market for environmental services will increase to $1 trillion by 2030 [5].

In this regard, in our opinion, the global demand for environmental services will only increase as the transition to a green economy becomes a priority for all countries, including the Republic of Tajikistan. This approach will create huge opportunities for businesses implementing innovations in the field of sustainable development

Gretchen Daly, a distinguished scholar of ecology and economic valuation of natural resources, in her paper "Natures Services: Societal Dependence on Natural Ecosystems", is one of the first major works to address the concept of ecosystem services-benefits that humans derive from nature. The focus is on developing methodologies for assessing the value of ecosystem services in order to integrate them into decision-making. Daly emphasized that protecting these natural processes is vital to the long-term well-being of humanity. These services include climate regulation, soil

fertility, pollination, pest control, and water purification. This paper focuses on developing methodologies to estimate the value of ecosystem services in order to integrate them into decision making [6]. The valuation methodologies proposed in this paper provide a framework for integrating ecosystem services into economic planning and environmental policy, allowing for the integration of ecological considerations into land use, urban planning and natural resource management decisions. This work remains relevant today and is an important reference point for research in the field of ecological economics and environmental protection.

Robert Constanza is an American academic environmental economist has worked on the integration of ecological and economic systems for sustainable management of natural resources. Robert Constanza, in his article "The Value of the World's Ecosystem Services and Natural Capital," estimates the global economic value of ecosystem services and natural capital. According to the study, the value of services such as pollination, climate regulation and water purification is about 33 trillion dollars per year [7]. Constanza's research has made a fundamental contribution to the realization of the role of ecosystem services as a key element of natural capital. His work linking economics and ecology provides a framework for decision-making for conservation and sustainable development.

The transition to a green economy in the service sector is not only urgent, but also strategically important for achieving sustainable development. Today's global challenges require countries and companies to reconsider their approaches to resource use, implement innovative technologies and switch to models that minimize environmental damage.

Several key conclusions can be drawn from the analysis:

1. Adoption of green technologies and approaches not only reduces carbon footprint, but also contributes to job creation, enhances the competitiveness of companies and improves the quality of life of the population.
2. Integration of modern technologies, digitalization of processes, and active participation in international programs and projects are important for successful implementation of green initiatives.
3. Developing economies such as the Republic of Tajikistan face limited resources and insufficient infrastructure. However, utilizing global best practices and investing in green services can be the basis for sustainable economic growth.

The transition to a "green" model requires not only economic investment, but also a change in outlook.

Companies, governments and society as a whole must embrace the ideology of sustainable development as the basis for their actions. It is important to understand that greening the economy is not just an obligation to future generations, but also an opportunity to ensure people's well-being and preserve the planet's natural capital today.

4 EMPIRICAL RESULTS AND ANALYSIS

The prospects for further research and implementation of the green economy offer tremendous opportunities for business, science and international cooperation. "Green transformation in services can be a key tool for building a more harmonious world where environmental sustainability goes hand in hand with economic progress.

With the digitalization of the economy, the introduction of "green" technologies in all spheres of the economy is becoming increasingly relevant. The service sector plays an important role in the sustainable development of the economy as a whole, and it also has significant potential for the introduction of green technologies and sustainable practices. "Green" technologies, also known as eco-technologies or clean technologies, are innovative methods, materials and processes designed to reduce the negative impact on the environment. They aim to reduce pollutant emissions, energy consumption, resource utilization and waste creation. "Green" technologies help to reduce energy consumption by optimizing processes and using energy efficient devices, are based on the use of renewable energy sources such as solar, wind, hydropower and biomass. Green technologies also help to reduce greenhouse gas emissions and other harmful substances in the atmosphere, which helps to combat climate change. "Green technologies include recycling techniques and recycling, which helps reduce the amount of waste going into landfills.

In their writings, Charlotte Brin and Stephen Carter focus their attention on the dual impact of the IT sector on the environment and the need to develop sustainable practices and technologies that will help minimize the negative impact [8]. The introduction of sustainable IT practices is considered necessary, as the transition to a "green" economy cannot be imagined without IT technologies. For the Republic of Tajikistan, the role of the IT sector in sustainable development is particularly relevant, as the country is just beginning to actively introduce digital technologies in various spheres of the economy. The development of IT infrastructure contributes to increased efficiency and productivity in key sectors such as agriculture, industry and energy. However, as Brin and Carter point out, with the growth of the IT sector also comes environmental challenges related to increased energy consumption and the need to dispose of e-waste [9]. The implementation of sustainable practices in the country, in general, needs to take into account the limited natural resources and the peculiarities of the energy sector in the country, which has a significant impact from hydropower. The implementation of sustainable practices in the information and communication sector includes the need to utilize energy efficient technologies and effective e-waste management. Dr. Akira Yoshino, Director of the Center for Zero Emissions Research (GZR), emphasized the importance of developing innovative technologies to address global environmental challenges, including those related to the service sector. He noted that the use of advanced technologies, such as multilayer solar panels and lithium-ion batteries, can help improve efficiency and sustainability in areas where traditional methods have been limited, including buildings, transportation, and ICT devices [5]. Dr. Yoshino also emphasized that the adoption of cleantech represents a "golden business opportunity", creating new markets and stimulating economic growth. He argued that integrating green technologies, including energy and waste management, into services can be a key step towards sustainable development [5]. Dr. Yoshino focuses on the fact that innovative

technologies such as multilayer solar panels and lithium-ion batteries can solve major environmental problems in sectors with traditional constraints. For the service sector, this is of particular importance, as such technologies can improve the energy efficiency of hotels, office buildings, transportation services and ICT devices, which are increasingly in demand. Energy-saving technologies can help the hospitality industry reduce energy consumption, especially in regions with limited access to energy resources. The use of solar panels can be the basis for sustainable tourism development in remote mountainous areas. "Green technologies as drivers of economic growth" Yoshino emphasizes the dual benefits of adopting environmentally friendly technologies, on the one hand it is the reduction of environmental burden and on the other hand it is the creation of new market opportunities. "Golden Business Opportunity" reflects the need to look at environmental solutions not as an additional expense, but as an investment in the future. Implementing waste and energy management in the service sector can stimulate economic growth by creating jobs in technology and sustainable design. Dr. Yoshino's statement on the importance of integrating green technologies into the service sector emphasizes that sustainable development is not possible without rethinking basic approaches to energy and waste management. The integration of these technologies can be an important step to improve the sustainability of hotel chains, transportation companies and other services. For example, the use of ICT devices for energy management in buildings reduces costs and contributes to reducing carbon footprints. The ideas of Dr. Akira Yoshino are important for understanding the role of the service sector in the global environmental context. The development and implementation of environmentally friendly technologies is not only a tool for addressing global challenges, but also a source of economic opportunities. For the Republic of Tajikistan, this approach can become key in achieving sustainable development goals, especially given the growing interest in eco-tourism and sustainable urbanization.

These data illustrate key aspects including energy consumption, waste management, economic benefits and environmental impacts (Table 3).

Table 3 Indicators for Analyzing the Introduction of Environmentally Friendly Technologies in the Services Sector

Indicator	Description	Units of measurement	Data source	Utilization practice
Share of clean energy utilization	Share of renewable energy sources (solar, wind, hydro) in the company's total energy consumption	%	Energy companies, IEA reports, ISO 50001	Analysis of energy consumption of hotels and cafes
Number of implemented environmental technologies	Number of implemented solutions to reduce emissions, save resources (LED lighting, eco-filters, etc.)	Quantity	Internal company reports, data from environmental agencies	Evaluation of technology adoption in shopping centers
CO_2 emission reduction level	Reduction of carbon dioxide emissions after the implementation of technologies	Tons of CO_2	Environmental agencies, emission calculation software	Comparison of emissions before and after modernization
Investments in environmental technologies	Amount of funds allocated for the acquisition, development and implementation of "green" technologies	US dollars, Euros	Company financial reports, grant data	Economic feasibility assessment
Share of recycled waste	Percentage of waste that is recycled or reused	%	Local recycling services, environmental reports	Comparison of recycling in restaurants and offices
Energy consumption level	Average amount of energy consumed by to provide a service or operate a facility	kW · h /service	Energy companies, IoT sensors	Comparison of energy consumption per square meter
Awareness level of employees	Percentage of personnel trained in environmental standards and technologies	%	HR reports, test and questionnaire results	Evaluating the effectiveness of training in companies
Level of customer satisfaction	Percentage of clients who positively evaluate the company's environmental efforts	%	Customer surveys, feedback on platforms	The impact of sustainability on customer loyalty
Number of "green" certificates	Number of certificates confirming compliance with environmental standards (e.g. LEED, ISO 14001)	Quantity	Certification organizations, internal reports	Comparison between competitors in the services sector
Water saving	Volume of water saved due to new technologies (e.g. installation of water saving faucets)	Liters/year	Water utilities, internal reports	Evaluation of implementation in the hospitality industry

***Source:** Compiled by the author on the basis of electronic resources.

5 CONCLUSION

Bill McDonagh, renowned architect and author of the concept of "Circular Economy", vividly emphasizes the importance of green technologies: "The design of the future must be based on principles that not only minimize harm, but also benefit ecosystems and society. Green technology is not just a way to reduce negative impacts, it is an

opportunity to create a positive footprint" [6]. This statement says that implementing green in services is not just a way to solve environmental problems, but a strategic opportunity to create sustainable systems that work for the benefit of people and nature. It is an approach that transforms the very basis of economic activity, shifting the focus from the traditional model of resource consumption to cyclical, innovative and resource-efficient development. "Green" technologies make it possible to integrate environmental aspects into all stages of service provision: from design and production to final consumption and utilization. This approach minimizes the negative impact on the environment and at the same time opens up new prospects for economic growth, creating green jobs and stimulating investment in sustainable technologies. Moreover, it enables service companies to become leaders of environmental change, shaping a new quality standard based on environmental safety, social responsibility and innovation. This is why green technology is becoming a key element of strategic planning to achieve sustainable development goals. This is why green technologies are becoming a key element of strategic planning aimed at achieving sustainable development goals. Their integration into economic and social activities contributes not only to the reduction of anthropogenic impact on the environment, but also to the creation of an innovative growth model that balances economic efficiency, environmental sustainability and social justice.

In the service sector, the application of green technologies can transform traditional business processes by introducing environmentally friendly and resource-efficient practices. This includes optimizing energy consumption, reducing waste, increasing digitalization and adopting renewable energy sources. In addition, green technologies help businesses adapt to changes in consumer preferences, which are increasingly oriented towards environmentally responsible companies and services.

Thus, the strategic implementation of green technologies not only meets today's environmental and economic challenges, but also forms the basis for long-term sustainable development. It is a way to create innovative solutions that will be relevant in the context of global environmental transformation, strengthening the competitiveness and sustainability of economic sectors, including the service sector.

Economics, at first glance, has no relation to ecology. Historically, it has also developed relatively independently of environmental indicators. However, the connection between economics and ecology can be traced already in the interpretation of these terms. Translated from Greek, ecology means the doctrine of the home, and economics means the art of housekeeping. The economy of society has always depended on natural resources, their quality and availability. The deep connection between economics and ecology became apparent when the reverse impact of nature (and not just nature) changed by people on man and his economy became obvious [10]. In this regard, countries and regions began to introduce sustainable "green" practices, model sustainable business models, and create green economy indices for various segments of services. Thus, in order to implement "green" business models that can reduce energy consumption and greenhouse gas emissions, it is necessary to "green" the policy of economic management of the economy as a whole. Examples of implementing green business models are circular models, production of environmentally friendly products, energy efficient technologies, and product take-back models. By applying "green" business models [11-12], it is possible to achieve a reduction in the negative impact on the environment, rational use of resources and energy, and meet the needs of consumers in environmentally friendly products and services.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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HARNESSING INTELLECTUAL CAPITAL FOR INNOVATION: THE MODERATING EFFECT OF DIGITAL TRANSFORMATION IN MANUFACTURING INDUSTRIES

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Abstract: This study explores the interplay between intellectual capital (IC), digital transformation (DT), and innovation in Chinese manufacturing firms, emphasizing the moderating role of DT. Utilizing data from Shenzhen Stock Exchange-listed firms from 2013 to 2023, the research employs Ordinary Least Squares (OLS) and Partial Least Squares (PLS) regression models to test the hypotheses. The findings reveal that DT significantly enhances the positive effect of IC on innovation. The study underscores the importance of fostering IC through human, structural, and relational capital and leveraging DT to maximize innovative outcomes. These insights are particularly relevant for policymakers and business leaders aiming to boost innovation in the knowledge economy. The results advocate for regulatory frameworks and incentives that support innovation driven by IC and DT, highlighting the substantial economic benefits these elements can bring. This research contributes to a deeper understanding of how IC and DT interact to drive innovation, offering valuable implications for technology management, entrepreneurship, and economic policy.
Keywords: Intellectual capital; Digital transformation; Innovation; Manufacturing firms; Economic benefits

1 INTRODUCTION

The emergence of the 'new economy,' fueled by information and knowledge, has led to a growing focus on intellectual capital (IC). IC is vital in creating value, shaped by and further developed through unique organizational structures, innovation, and human resources[1]. The existing literature generally categorizes IC into three dimensions: human capital, relational capital, and structural capital[2,3]. Despite a broad consensus that IC enhances organizational value, the specific mechanisms by which it does so remain relatively understudied. Innovation has emerged as a critical outcome of IC's contribution to organizational success[4].

Innovation encompasses the knowledge initiatives, skills, techniques, and ideas that create new capabilities, thereby establishing competitive advantages for organizations and combining and reorganizing knowledge into advanced and beneficial products, services, and procedures[5]. Many studies have explored the relationship between intellectual capital (IC) and organizational innovation, yielding inconsistent results [6]. While much of the existing literature has examined IC and innovation broadly, few studies have delved into the specific factors that mediate this relationship. One such factor that has garnered significant attention from both academia and industry is digital transformation.

Digital transformation (DT) has become a focal point of research and a crucial catalyst for innovation in recent years. Researchers describe DT as the strategic integration of digital technologies like Artificial Intelligence (AI), cloud computing, big data, and blockchain to create new digital business models that enhance value creation for firms[7]. Studies have shown that big data plays a moderating role in the relationship between intellectual capital (IC) and innovation[8], while others have explored how DT influences entrepreneurship and the innovation process[9]. Despite these findings, there is a significant gap in the literature regarding the specific impact of DT on the interplay between IC and innovation.

In this paper, we aim to explore the interplay between intellectual capital (IC), digital transformation (DT), and innovation by examining the relationship between IC and innovation, as well as the influence of DT on this dynamic for several reasons. Firstly, the ongoing shift towards a 'new economy' driven by information and knowledge underscores the importance of IC as a fundamental driver of value creation. Understanding how DT affects IC is essential for organizations striving to succeed in this evolving landscape. DT has been a critical focus of China's government policy and industry development over the past decade. President Xi Jinping has repeatedly emphasized integrating the digital economy with the traditional manufacturing sector[10]. He asserts that China's progress toward becoming a developed nation depends on its transition from a high-speed growth industrial economy to a qualitatively advanced digital economy Xi further remarks that innovation is both the realization and manifestation of DT[11]. Thirdly, given the inconsistent findings in prior studies on IC and innovation[12,13], introducing DT as a moderating factor could provide new insights. This research aims to determine whether DT facilitates innovation and, if so, whether it enhances the positive correlation between IC and innovation. Such insights would help validate the effectiveness of DT and support further investment in DT-related projects and policies. Conversely, if DT does not significantly contribute to the IC-innovation relationship, it would prompt a reevaluation of current DT implementation strategies at governmental,

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industrial, and organizational levels. This study ultimately seeks to inform policy-making and strategic planning by leveraging the full potential of DT to foster innovation and economic growth.

The data for this research are derived from Shenzhen A-share listed manufacturing firms, spanning 2013 to 2023. We investigate the interplay between intellectual capital (IC), digital transformation (DT), and innovation within China's manufacturing sector, a sector actively encouraged to pursue more significant innovation. This research enhances our understanding of the optimal integration of IC and DT in the manufacturing sector and elucidates how DT influences the relationship between IC and innovation. Our empirical findings indicate that digital transformation (DT) strengthens the relationship between intellectual capital (IC) and innovation. Specifically, we observe that both human and structural capital positively correlate with innovation, with DT as a positive moderator in these relationships.

The structure of the paper is outlined as follows: Section 2 presents a comprehensive literature review, synthesizing existing research on the interplay between intellectual capital, digital transformation, and innovation. Section 3 develops the research framework and hypotheses based on insights from the literature review. Section 4 delineates the methodology employed in the study, including data collection procedures, analytical techniques, and model specifications. The findings of the empirical analysis are presented in Section 5, followed by a thorough discussion of the results in Section 6. Finally, Section 7 offers concluding remarks, summarizing key findings, discussing their implications, and suggesting avenues for future research.

2 LITERATURE REVIEW

The literature on digital transformation (DT) and its implications for firm innovation has witnessed considerable growth and attention in recent years. As organizations navigate the complexities of an increasingly digitalized landscape, scholars have sought to elucidate the mechanisms through which DT influences innovation processes and outcomes [14]. Many conceptual frameworks have emerged, aiming to capture the multifaceted nature of DT and its impact on organizational dynamics. While qualitative analyses have offered valuable insights into the conceptual underpinnings of DT and innovation, a notable gap persists in the quantitative exploration of this relationship. Thus, this literature review endeavors to bridge this gap by synthesizing existing research and providing a comprehensive understanding of the quantitative dimensions of the DT-innovation nexus. By examining empirical studies that employ quantitative methodologies, this review seeks to unravel the intricate interplay between DT and firm innovation, shedding light on the factors that drive and inhibit innovative activities within organizations [15,16].

The exploration of Intellectual Capital (IC) and its role in fostering innovation has been a focal point of scholarly inquiry in management, economics, and organizational behavior. IC, comprising human, structural, and relational capital, is a critical resource for organizations seeking to enhance their innovative capabilities and gain a competitive edge in dynamic market environments[17]. Extensive research has underscored the positive correlation between IC and innovation, highlighting the pivotal role played by human capital in driving organizational learning and knowledge creation. However, while the relationship between IC and innovation has garnered significant attention in the literature, the influence of DT and political connections on this relationship remains underexplored, particularly within the context of emerging economies such as China [18]. Thus, this literature review aims to fill this gap by examining the extant literature on IC, DT, and innovation, specifically focusing on the Chinese context. By synthesizing existing research findings, this review seeks to provide insights into the mechanisms through which DT and political connections shape the dynamics of IC and innovation, thereby contributing to a more nuanced understanding of innovation processes within the Chinese business ecosystem.

2.1 Intellectual Capital and Innovation

Intellectual Capital (IC) has emerged as a pivotal instrument for value creation, prompting interdisciplinary research endeavors to explore how the capital market responds to its potential to enhance firm value. IC underscores the strategic utilization of resources and human capital to develop competitive products and services, thereby driving firm solid performance and value creation [19]. In extant literature, various studies have illuminated the multifaceted impact of IC on innovation. For instance, Hayton (2005) identified a positive correlation between human capital and corporate innovation[20]. Cabrillo and Dahms (2018) delved into the moderating role of strategic knowledge management on the relationship between IC and firm innovation and market performance, revealing nuanced interactions[21].

Similarly, Hayaeian et al. (2022) and Zhang et al. (2018) explored the moderating effects of knowledge management strategies and supplier knowledge integration on the relationship between IC and innovation, uncovering positive associations[8,22]. Furthermore, Li et al. (2019) investigated the intricate relationship among IC, knowledge sharing, and innovation performance in construction firms in China, demonstrating the direct and indirect pathways through which IC influences innovation[13]. These studies collectively contribute to a deeper understanding of how IC fuels innovation and underscore the importance of strategic knowledge management practices in harnessing its full potential.

In examining the significance of Intellectual Capital (IC), we adhere to the three established dimensions advocated by numerous contemporary IC scholars[23]: human capital, structural capital, and relational capital. Human capital, considered the foundation of IC, encompasses the knowledge and learning capabilities inherent in human resources and their capacity to generate tangible and intangible assets. Widely regarded as the most valuable asset for firms seeking to enhance their value, human capital efficiency reflects how effectively a firm's human resources contribute to its overall value. For instance, Elsharnouby and Elbanna (2021) demonstrated how human capital fosters corporate innovation by

streamlining existing organizational structures and spearheading the development of novel products and services[24]. Additionally, Chatterji and Patro (2014) highlighted that valuable human resources bolster innovation and perpetuate itself by retaining current staff and attracting new talent, fostering a culture of innovation within firms[25]. Furthermore, extending beyond the confines of individual firms, Han and Li (2015) posited that robust human capital enables firms to adapt and reconfigure in response to the dynamic and ever-evolving business landscape[26].

Structural capital encompasses the knowledge embedded within organizational structures and processes, encompassing organizational strategy, networks, corporate culture, technology infrastructure, data repositories, publications, and management processes. As highlighted by Bontis (2001), structural capital constitutes a vital component of intellectual capital (IC), which comprises communicative capital (customer relations) and organizational capital[27]. The organizational structure is a control mechanism, providing the framework for implementing strategic objectives. As defined by Bontis, strategy entails delineating long-term goals, devising action plans, and allocating resources to achieve these objectives. Structural capital plays a pivotal role in fostering the innovative capacity of firms, as documented by research. For instance, Farzaneh et al. (2022) elucidate that structural capital positively correlates with human capital, fostering organizational learning and ultimately driving innovation within firms[28].

Relational capital refers to the dynamics of "who you reach and how you reach," as Bian and Zhang (2014) articulated, emphasizing the cultivation of mutual trust and goodwill through prior interactions to gain preferential access to valuable resources[29]. Within social capital, relational capital is distinguished by its focus on the networks forged by enterprises with relevant stakeholders[30]. In corporate innovation, Zhou et al. (2024) suggest that relational capital provides firms and employees greater access to timely information, thereby augmenting the acquisition and application of new knowledge and expertise[31]. In the contemporary Chinese landscape, Chen and Chen (2004) assert that the social networks embedded in enterprises significantly influence their economic behavior[32]. Furthermore, a robust social network grants enterprises access to invaluable information and opportunities[33], fostering a deeper understanding of the dynamic external environment and enhancing receptivity to innovative changes [34].

2.2 Digital Transformation and Innovation

Digital technologies have ushered in new opportunities for innovators and entrepreneurs, concurrently generating and capturing significant economic and social value [35]. Warner and Wäger (2019) posit that digital transformation (DT) constitutes an ongoing process wherein organizations integrate new digital technologies into their daily operations, with agility as a fundamental mechanism for driving strategic renewal across various dimensions—business models, collaborative approaches, and organizational culture[36]. Hinings et al. (2018) also delineated three novel institutional arrangements for DT: digital organizational forms, digital institutional infrastructure, and institutional building blocks[37]. Frank et al. (2019), on the other hand, proposed a conceptual framework that bridges the concepts of Servitization (value addition to the customer) and Industry 4.0 (value addition to the manufacturing process) from a business innovation perspective. Their framework delineates three levels of Servitization (smoothing, adapting, and substituting) and three levels of digitization (low, moderate, and high), facilitating a comprehensive understanding of the synergies between these two transformative paradigms[38].

Researchers have observed a positive impact of digital transformation (DT) on entrepreneurship and the innovation process[9]. Moreover, DT plays a vital role in expanding companies' access to global markets, thereby fostering international trade and competition, which, in turn, acts as a catalyst for innovation, leading to growth and entrepreneurship benefits[39]. As Nambisan (2022) highlighted, the emergence of novel and potent digital technologies, platforms, and infrastructures has profoundly transformed the landscape of innovation and entrepreneurship. The effectiveness of DT is contingent upon the extent to which organizations utilize digital technologies effectively. By facilitating seamless access to global markets, DT enhances firms' competitiveness and stimulates innovation, unlocking growth opportunities and fostering an entrepreneurial ecosystem conducive to sustained economic development[40].

The preceding discussion underscores the acknowledgment that digital transformation (DT) holds sway over firm innovation to a certain degree. However, while existing literature has furnished conceptual frameworks of DT and innovation and conducted qualitative analyses, quantitative examinations of the relationship between DT and corporate innovation have been scarce. Moreover, while the relationship between Intellectual Capital (IC) and innovation has garnered attention, the Chinese context remains underexplored, particularly regarding the influence of DT and political connections on IC and innovation [41]. This absence of research leaves a gap in understanding the nuanced dynamics in the Chinese business ecosystem. Therefore, there is a pressing need for empirical studies that delve into the quantitative aspects of the DT-innovation nexus and explore the intricate interplay between IC, DT, and political connections in driving innovation within the Chinese context. Such research endeavors would contribute to a more comprehensive understanding of the factors shaping innovation dynamics and inform strategic decision-making in academia and industry.

3 RESEARCH FRAMEWORK AND HYPOTHESES DEVELOPMENT

The research framework for this study is built on the intersection of intellectual capital (IC), digital transformation (DT), and innovation within the context of Chinese manufacturing firms. By drawing on resource-based theory, this framework examines how various components of IC—human capital efficiency (HCE), structural capital efficiency (SCE), and relational capital efficiency (RCE)—interact with DT to influence firm innovation. Building on the existing

literature, our research framework posits several hypotheses to explore these relationships. Firstly, we hypothesize that each component of IC (HCE, SCE, and RCE) positively correlates with different innovation outputs, such as utility models, designs, and inventions (H1, H2, H3). Secondly, we propose that DT acts as both a driver and an enhancer of IC, creating a positive feedback loop that fosters greater innovation (H4).

3.1 Intellectual Capital and Innovation

Resource-based theory (RBT), also known as the theory of firms, originated in economics through the seminal work of Penrose (1959)[42]. The theory centers on two key concepts: resources and capabilities. Resource-based theorists have variously defined resources, including tangible and intangible items [43]. RBT provides a valuable framework for understanding the relationship between Intellectual Capital (IC) and innovation by highlighting the importance of valuable, rare, and difficult-to-imitate resources in achieving and sustaining a competitive advantage [44]. IC is viewed as a critical resource conducive to creating competitive advantages because it is inherently difficult to imitate and substitute [45].

IC drives innovation by cultivating a culture of continuous learning, problem-solving, and creativity[46]. Employees with specialized knowledge and expertise play a crucial role in developing new ideas and technologies. RBT recognizes that specific knowledge within organizations is tacit and thus difficult for competitors to replicate. This implicit knowledge, often embedded in the skills and experience of employees, serves as a unique source of innovation. Furthermore, RBT acknowledges that the unique organizational culture—another component of IC—that promotes knowledge sharing, collaboration, and learning can be a rare and difficult-to-imitate facet of IC. Such a culture significantly enhances the firm's innovation capabilities by fostering an environment where creative and innovative ideas can thrive. Resource-based theory suggests that Intellectual Capital (IC) is a valuable, rare, and difficult-to-imitate resource that significantly enhances a firm's innovation capabilities. By effectively leveraging and managing IC, organizations can differentiate themselves, cultivate a culture of innovation, and maintain a competitive edge in dynamic markets. Therefore, this paper predicts the following hypothesis:

H1: IC is positively associated with innovation.

3.2 Digital Transformation and Innovation

In addition to intellectual capital (IC), the intangible capital component of resource-based theory (RBT) also recognizes the competitive advantages information technology brings. Researcher emphasized that information technology is an "information processing system that has the potential to provide a lasting competitive advantage," which is very pertinent to digital transformation (DT) and innovation. Within this framework, we redefine the notion of intangible capital to underscore the significance of innovation as a comparably crucial aspect of other types of IC. The Resource-Based Theory (RBT) offers valuable insights into the correlation between Dynamic Capabilities (DT) and innovation by emphasizing the strategic significance of resources and capabilities in attaining and maintaining a competitive advantage. According to RBT (Resource-Based Theory), resources refer to all the assets, capacities, organizational processes, information, and knowledge over which a corporation controls[47]. When digital resources contribute to a competitive advantage, they are regarded as strategic assets. Companies with advanced digital resources are better positioned to innovate and adjust to the always-changing business environment [40].

The concept of dynamic capabilities, introduced by RBT, pertains to a company's capacity to effectively incorporate, construct, and adapt internal and external skills to tackle swiftly evolving circumstances. Digital transformation (DT) is a dynamic capability that allows organizations to create adaptable and flexible processes, systems, and structures [38]. Adaptability is essential for promoting innovation, enabling companies to react quickly to shifts in the market, new technology, and client needs. In addition, RBT asserts that sustained competitive advantage is derived from resources that possess value rarity and are challenging to replicate [44]. Digital transformation (DT) can provide distinctive skills, such as sophisticated analytics, artificial intelligence, and instantaneous data processing, significantly improving a company's innovation ability. Efficiently managing and strategically utilizing digital resources allows companies to innovate, adjust to evolving conditions, and sustain a competitive edge in the digital age. This study examines the impact of digital transformation (DT) on company innovation by analyzing data from industrial companies listed in the Chinese A-share market. We thus have the following hypothesis:

H2: DT is positively associated with innovation.

3.3 The Influence of Digital Transformation

Managers must strategically choose, cultivate, and combine all valuable resources to establish company management capabilities. Grant (1991) defines capabilities as the amalgamation of resources that are the foundation for organizations to generate and maintain value and competitive advantages. These material and intangible resources are combined to cultivate capabilities[48]. For example, integrating technology, scientific equipment, and human resources results in establishing research and development capacities. Organizations must comprehend the connections between resources, capabilities, and performance to determine their strengths and shortcomings [45].

Effective identification and management of digital transformation (DT) are crucial for successful innovation. Digital transformation (DT) involves the application of artificial intelligence (AI), big data, cloud computing, and blockchain technology to achieve different corporate goals, such as innovation [39]. Furthermore, digital transformation (DT)

improves intellectual capital (IC) resources, establishing a favorable feedback loop where DT encourages the generation and advancement of IC, ultimately contributing to innovation.

Digital transformation (DT) processes play a crucial role in preserving competitive advantages within manufacturing companies, mainly due to the industry's distinct difficulties in embracing novel procedures and practices. For instance, artificial intelligence (AI), big data, cloud computing, and blockchain have the potential to optimize and improve management procedures, thereby adding value to the organization's intellectual assets and promoting innovation. DT enhances human capital by utilizing AI and big data to improve employees' learning efficiency, fostering a competitive environment that motivates them to work harder and think more strategically. This ultimately leads to increased business creativity[36].

Moreover, DT enhances business connections with other parties, enabling prompt communication and precise forecasts. By leveraging big data and AI technologies, companies can accurately forecast product demand, reducing transportation costs and improving operational efficiency. Digital technologies aid companies in preserving their financial well-being while enhancing their connections with funding sources. As a result, DT improves the amount of relational capital, leading to a higher level of corporate creativity. A limited amount of research has investigated the role of DT in influencing the connection between IC and innovation. Buenechea-Elberdin et al. (2018) emphasized the need to consider the technological level of companies as a variable that influences the relationship between intellectual capital (IC) and innovation[49]. This should be considered in future studies. Consequently, companies are highly interested in the methods by which intellectual capital (IC) might be utilized for innovation and the influence that digital technology (DT) has in this procedure. Consequently, our objective is to investigate the impact of intellectual capital (IC) on innovation in manufacturing companies, considering the moderating influence of dynamic capabilities (DT). Based on the discussion above, we expect the following:

H3. DT positively moderates the relationship between IC and innovation.

Figure 1 illustrates the relationships between Chinese firms' intellectual capital (IC), invention, and digital transformation (DT). It posits that components of IC—human capital efficiency (HCE), structural capital efficiency (SCE), and relational capital efficiency (RCE)—positively influence invention categories such as utility models, designs, and inventions. The model also highlights a bidirectional relationship between IC and DT, suggesting that advancements in digital technologies like AI, blockchain, big data, and cloud computing enhance IC, which drives further digital transformation.

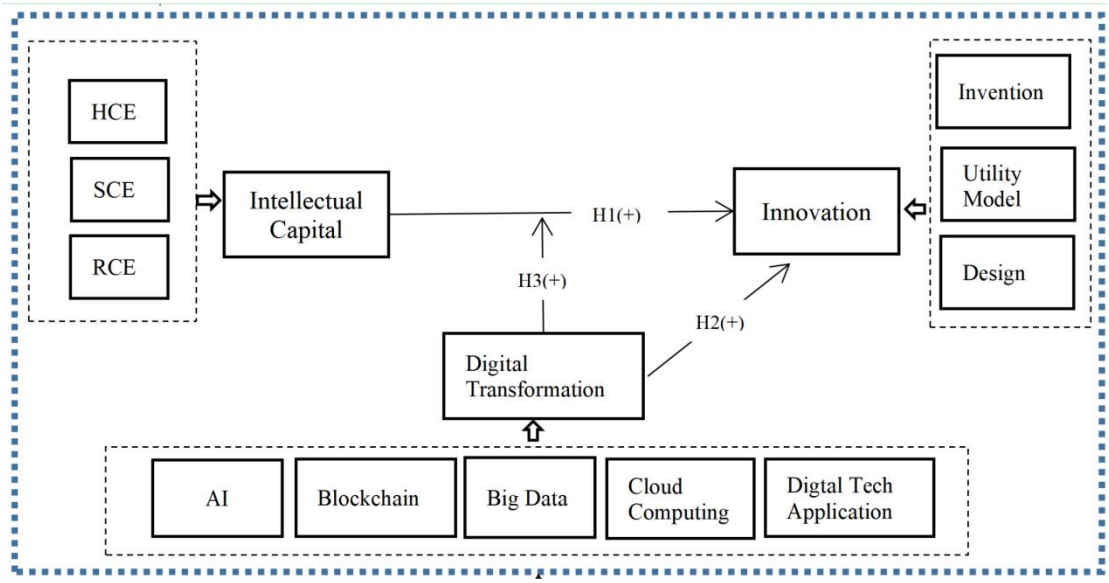

Figure 1 The Research Framework of This Study

4 METHODOLOGY

The research framework, founded on antecedent literature and theoretical underpinnings, directs the selection of variables and data collection procedures. This study employs a quantitative approach and utilizes data from manufacturing firms listed on the A-share market in Shenzhen from 2013 to 2023. The selection of this dataset is strategic, as it is consistent with the research's emphasis on a sector essential to China's economic landscape. In 2013, a critical juncture occurred when listed firms were required to disclose patent information, facilitating a thorough examination of innovation. Data on financial indicators, innovation metrics, and digital transformation elements were obtained from reputable sources, such as the CSMAR database and the official website of the Shenzhen Stock Exchange. The extraction of digital transformation data from annual reports was facilitated by Python programming, which employed predetermined keywords indicative of digital technologies prevalent in the manufacturing sector. The study assures temporal depth and breadth to elucidate the dynamics of IC, DT, and innovation over the study period by combining these disparate datasets to construct a robust sample of 5140 observations.

The methodology explores the operationalization of critical constructs and the establishment of measurement mechanisms in greater detail. Human capital, structural capital, and relational capital are the three dimensions through which intellectual capital (IC) is operationalized. These dimensions are quantified using established proxies, including the complexity of the organizational structure, employee education levels, and marketing expenditure. Annual reports implement a systematic keyword-based search strategy to identify digital transformation (DT) elements, including artificial intelligence, big data, cloud computing, blockchain, and digital technology applications. Ensuring exhaustive coverage of pertinent digital technologies, these keywords are derived from a synthesis of academic literature, public policies, and market reports. The number of patents submitted by firms, encompassing inventions, designs, and utility models, is the operationalization of innovation, the focal outcome variable. This quantitative indicator is a tangible representation of firms' technological advancements and inventive activity. This study elucidates the complex relationship between IC, DT, and innovation using thorough statistical analyses and data processing techniques. It provides valuable insights into the mechanisms that drive innovation in China's manufacturing sector.

4.1 Data and Sample

We used the sample of manufacturing firms listed on the A-share Shenzhen Stock Exchange. The data we analyzed spanned from 2013 to 2023. The emphasis on the manufacturing sector stemmed from China's position as the leading manufacturing nation worldwide. This sector is highly knowledge-intensive, rapidly expanding, and crucial to the Chinese economy[50].

We obtained financial and innovation data from the China Stock Market & Accounting Research (CSMAR) database. Data for digital transformation (DT) was collected using Python programming to extract information from the official website of the Shenzhen Stock Exchange. The annual reports were initially extracted using Python, and a content analysis was then conducted based on predefined DT elements. We did not include Special Treatment (ST and ST*) firms in the sample. We performed data cleaning and processing using Stata, where we eliminated observations with missing data and excluded the top 1% of outliers to ensure the reliability of our results. Combining the CSMAR data and the findings from the content analysis, we created a thorough dataset consisting of 5,140 observations spanning from 2013 to 2023.

4.2 Measurement of IC

Most prior studies have measured intellectual capital (IC) through three elements: human capital, structural capital, and relational capital [21]. Building on this established framework, our paper also considers these three main components of IC: human capital, structural capital, and relational capital. The calculation of the IC model is as follows:

The initial step involves assessing the company's capacity to generate value added (VA) for all parties involved. Building on prior research [21,22,35], VA can be expressed as follows: VA=S-B (1)

where S is net sales revenues (output); B is the cost of goods sold (input).

4.2.1 Human capital (HCE)

The concept of human capital encompasses a range of valuable attributes such as knowledge, experiences, skills, productivity, and employee competence. Various researchers have extensively studied these attributes [21.22.35]. HCE is calculated as: HCE = VA/HC (2)

HC refers to employee compensation at a specific moment, as discussed by various researchers. HCE reflects the value of VA produced per dollar invested in HC.

4.2.2 Structural capital (SCE)

IC items, including strategy, organizational networks, patents, and brand names, are all included in structural capital (SC). Based on past research, this paper calculates SCE as follows: SCE = SC/VA (3)

SC is calculated by subtracting HC from VA. Consequently, SCE serves as an indicator of the value of SC within the organization for each dollar of value generated. As HCE increases, SCE also increases.

4.2.3 Relational capital (RCE)

Relational capital encompasses connections with stakeholders, including suppliers, clients, governments, and the broader society. It also includes additional relational assets such as firm image and customer loyalty. We used marketing, selling, and advertising expenses to proxy relational capital. Relational capital efficiency (RCE) was calculated as the ratio of these expenses to value-added (VA).

This study measures RCE as follows: RCE=RC/VA (4)

RC refers to relational capital, assessed through marketing, selling, and advertising expenditures, while RCE denotes relational efficiency. IC comprises four individual efficiencies and encompasses the aggregation of these three efficiencies: IC= HCE + SCE+RCE (5)

Enhanced IC signifies increased efficiency in utilizing intellectual capital resources, resulting in more significant value generation for the firm.

4.2.4 Measurement of digital transformation

This study employed the Python programming language to collect DT data from manufacturing firms' annual reports on the Shenzhen Stock Exchange. The selection of relevant keywords about DT characteristics was informed by scholarly research and practical market insights. Drawing from academic literature [51] governmental policies, and analytical reports (such as 'The Implementation Plan for Promoting the Actions of 'Migrating to Cloud, Using Digital Tools and

Enable Intelligence and Fostering the Development of New Economy'; 'Reports On The Work of The Government'; 'The 2020 Digital Trends Report'), five essential elements (i.e., AI, Big data, Cloud computing, Blockchain, Digital tech application) along with associated keywords for each DT component were identified. Using Python, the researchers searched for the predetermined keywords in the annual reports to assess the overall frequency count of DT-related keywords for each observation annually, thereby capturing the degree of DT.

Table 1 presents a comprehensive compilation of key words associated with different facets of digital transformation (DT), including Artificial Intelligence (AI), Big Data, Cloud Computing, Blockchain, and Digital Tech Application. Each category encompasses a wide array of terms that reflect the diverse technological landscape within DT. For instance, under AI, terms such as machine learning, deep learning, and natural language processing signify advanced techniques utilized in AI applications, showcasing its sophistication across domains like business intelligence and data analysis. Similarly, the Big Data section features keywords like data mining and data visualization, emphasizing the significance of processing large datasets for valuable insights, spanning applications from text mining to augmented reality. Cloud Computing terms range from stream computing to green computing, showcasing the versatility of cloud-based solutions in real-time data processing and energy efficiency. Blockchain-related keywords, including distributed computing and intelligent financial contracts, underscore its role in secure transactions and financial services. Lastly, Digital Tech Application keywords like mobile internet and smart transportation highlight the pervasive influence of digital technologies in modern life, encompassing areas from e-commerce to smart city initiatives.

Table 1 Keywords of DT

Elements	Keywords
AI	AI, business intelligence, image understanding, investment decision support systems, intelligent data analysis, intelligent robots, machine learning, deep learning, semantic search, biometric technology, face recognition, speech recognition, identity verification, automatic driving, natural language processing
Big Data	Big data, data mining, text mining, data visualization, heterogeneous data, credit checking, augmented reality, mixed reality, virtual reality
Cloud Computing	Cloud computing, stream computing, graph computing, memory computing, multi-party secure computing, brain-inspired computing, green computing, cognitive computing, converged architecture, hundreds of millions of concurrency, exabytes of storage, internet of things, cyber-physical systems
Blockchain	Blockchain, digital currency, distributed computing, differential privacy technology, smart financial contracts
Digital Tech Application	Mobile internet, industrial internet, internet medical, E-commerce, mobile payment, third-party payment, NFC payment, smart energy, B2B, B2C, C2B, C2C, O2O, network union, smart wear, smart agriculture, smart transportation, smart customer service, smart home, smart investment, smart environmental protection, smart marketing, digital marketing, internet finance, digital finance, fintech, financial technology

4.2.5 Measurement of innovation

Drawing from prior studies[51] this research assessed innovation levels by examining the number of patents generated by firms. The study included three patent types: inventions, designs, and utility models produced by the firms. Data on innovation were gathered from the CSMAR database. The decision to utilize patent counts, covering inventions, designs, and utility models, was aligned with the research objectives, which aimed to elucidate the impact of input intellectual capital (IC) on innovation outcomes, as well as the mediating role of digital transformation (DT) in this relationship. The choice of patent counts as a measure of innovation output has been widely accepted within the research community, thus making it a suitable metric for assessing innovation outcomes in this study.

4.2.6 Empirical models to test hypotheses

This paper developed the following models to test the main hypotheses of this study:

$$INNO_{j,t}=\beta_0+\beta_1 IC_{j,t}+\beta_{2\text{-}8}Controls_{j,t}+\varepsilon_{j,t} \quad (1)$$

$$INNO_{j,t}=\beta_0+\beta_1 DT_{j,t}+\beta_{2\text{-}8}Controls_{j,t}+\varepsilon_{j,t} \quad (2)$$

$$INNO_{j,t}=\beta_0+\beta_1 IC_{j,t}+\beta_2 DT_{j,t}+\beta_3 DT_{j,t}*IC_{j,t}+\beta_{4\text{-}10}Controls_{j,t}+\varepsilon_{j,t} \quad (3)$$

Where $INNO_{j,t}$ represents the firm's innovation in firm j, year t, measured by ln (total number of patents +1). $IC_{j,t}$ represents the intellectual capital in firm j, year t, measured by the sum of human, structural, and relational capital. $DT_{j,t}$ is the overall frequency count of the key words related to DT elements in table 1, measured by ln (total number of DT feature words+1). $DT_{j,t}*IC_{j,t}$ represents the interaction between DT and IC. The control variables in this study include $Sales_{j,t}$, which is measured according to the sales growth of firm j in year t; $Size_{j,t}$ is measured using the natural logarithm of the total assets of firm j in the beginning of year t; $IND_{j,t}$ is measured according to the percentage of independent directors on the board; $Education_{j,t}$ is measured according to the number of years of overseas education experience that managers have; and $R\&D_{j,t}$ is measured according to the R&D expenses divided by the total sales of firm j, year t. $Leverage_{j,t}$ is the leverage ratio of firm j, year t, and $ROA_{j,t}$ is the return on assets of firm j, year t.

5 RESULTS

5.1 Main Findings

Table 2 presents the correlations among the variables under study, providing insights into the relationships between intellectual capital (IC), digital transformation (DT), innovation, and other firm-specific characteristics. INNOj,t, ICj,t, and DTj,t are positively correlated with each other. Specifically, the correlation between INNOj,t, and ICj,t is 0.027 (p =

0.052), and between INNOj,t, and DTj,t is 0.020 (p = 0.001), indicating significant relationships. Moreover, ICj,t and DTj,t are positively correlated (correlation = 0.082, p = 0.000), suggesting a complementary relationship between intellectual capital and digital transformation. Additionally, R&D expenditure demonstrates a significant positive correlation with both innovation (r = 0.022, p < 0.05) and intellectual capital (r = 0.074, p < 0.001), highlighting the importance of research and development activities in fostering innovation and building intellectual capital. Conversely, leverage exhibits a weak and insignificant correlation with most variables, implying that firms' financial leverage may not strongly influence innovation, intellectual capital, or digital transformation. These correlations provide valuable insights into the interrelationships among crucial variables and offer a foundation for further multivariate analysis to elucidate the underlying mechanisms driving firm-level innovation in the context of intellectual capital and digital transformation.

Table 2 Descriptive Statistics and the Correlations of the Variables

	$INNO_{j,t}$	$IC_{j,t}$	$DT_{j,t}$	$Education_{j,t}$	$R\&D_{j,t}$	$Leverage_{j,t}$	$Size_{j,t}$	$Growth_{j,t}$	$ROA_{j,t}$	$IND_{j,t}$
$INNO_{j,t}$	1.000									
$IC_{j,t}$	0.027*	1.000								
	(0.052)									
$DT_{j,t}$	0.020***	0.082***	1.000							
	(0.001)	(0.000)								
$Education_{j,t}$	0.020	0.029**	-0.004	1.000						
	(0.153)	(0.036)	(0.795)							
$R\&D_{j,t}$	0.022	0.074***	0.176***	0.054***	1.000					
	(0.116)	(0.000)	(0.000)	(0.000)						
$Leverage_{i,t}$	-0.008	-0.021	-0.003	-0.008	-0.008	1.000				
	(0.554)	(0.127)	(0.808)	(0.547)	(0.547)					
$Size_{j,t}$	0.103***	0.071***	0.112***	0.047***	0.116***	0.056***	1.000			
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)				
$Growth_{j,t}$	0.009	-0.020	0.001	-0.021	0.060***	0.007	-0.036**	1.000		
	(0.582)	(0.210)	(0.936)	(0.179)	(0.000)	(0.683)	(0.025)			
$ROA_{j,t}$	0.033***	0.416***	-0.017	0.020	0.014	-0.104***	-0.063***	-0.049***	1.000	
	(0.019)	(0.000)	(0.216)	(0.153)	(0.329)	(0.000)	(0.000)	(0.002)		
$IND_{j,t}$	0.039***	0.057***	0.047***	-0.036**	0.043***	0.026*	0.011	0.027*	-0.012	1.000
	(0.005)	(0.000)	(0.001)	(0.010)	(0.002)	(0.060)	(0.442)	(0.094)	(0.371)	

Note: p statistics in parentheses.
*p < 0.10, **p < 0.05, ***p < 0.01.

Table 3 provides a comprehensive overview of the H1, H2, and H3 regression outcomes. As indicated in the table, the results confirm hypotheses H2 and H3, as both digital transformation (DTj,t) and its interaction with intellectual capital (DTj,t*ICj,t) have substantial positive coefficients about innovation (INNOj,t). Specifically, DTj,t exhibits a significant positive effect on INNOj,t (coefficient=0.245; p=0.050), as shown in Model 2, while the interaction term DTj,t*ICj,t demonstrates an even more substantial impact (coefficient=0.288; p=0.004), as depicted in Model 3. Additionally, although intellectual capital (ICj,t) shows a slightly significant positive relationship with innovation (INNOj,t) in Model 1 (coefficient=1.177; p=0.089), this effect becomes statistically insignificant when considering the interaction with digital transformation. These findings highlight the facilitating role of digital transformation in enhancing intellectual capital and fostering firm innovation. Moreover, the inclusion of control variables such as Educationj,t, R&Dj,t, Leveragej,t, Sizej,t, Growthj,t, ROAj,t, and INDj,t in the regression models unveils further insights into the determinants of innovation outcomes. Educationj,t and R&Dj,t demonstrate significant positive impacts on innovation, while variables such as Leveragej,t exhibit no considerable influence.

Table 3 The Regression Results of H1, H2, and H3

	Model 1		Model 2		Model 3	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t	Coef.	P>t
$IC_{j,t}$	1.177*	0.089			2.672	0.137
$DT_{j,t}$			0.245**	0.050	0.628*	0.053
$DT_{i,t}*IC_{i,t}$					0.288***	0.004
$Education_{j,t}$	8.027**	0.035	8.131**	0.032	8.276**	0.029

$R\&D_{j,t}$	1.587**	0.034	1.349*	0.074	1.521**	0.047
$Leverage_{j,t}$	-0.332	0.560	-0.328	0.565	-0.307	0.591
$Size_{j,t}$	6.886	0.394	6.496	0.411	6.851	0.396
$Growth_{j,t}$	2.741***	0.000	2.696***	0.000	2.667***	0.000
$ROA_{j,t}$	1.596*	0.059	1.376*	0.068	1.508*	0.074
$IND_{i,t}$	1.102*	0.057	1.081*	0.062	1.021*	0.078
Year	Yes		Yes		Yes	
N	5140		5140		5140	
Adj R-squared	30%		30%		31%	

Note:*p < 0.10, **p < 0.05, ***p < 0.01.

5.2 Additional Tests

Table 4 reveals the regression findings regarding the three components of intellectual capital (IC) and their interaction with digital transformation (DT) concerning their influence on innovation (INNOj,t). In Model 4, human capital efficiency (HCEj,t) and structural capital efficiency (SCEj,t) exhibit significant relationships with INNOj,t (HCEj,t coefficient=2.861, p=0.087; SCEj,t coefficient=2.955, p=0.063), while relational capital efficiency (RCEj,t) demonstrates a positive yet insignificant association. Conversely, Model 5 delves into the interaction effects, revealing that HCEj,t*DTj,t (coefficient=0.793, p=0.000) and SCEj,t*DTj,t (coefficient=2.399, p=0.006) significantly bolster innovation, emphasizing the role of digital transformation in amplifying the impact of human and structural capital on innovation. However, the interaction term RCEj,t*DTj,t does not yield significant results. Additionally, control variables such as Educationj,t, R&Dj,t, Sizej,t, Growthj,t, ROAj,t, and INDj,t demonstrate varying degrees of significance across models, further elucidating their contributions to innovation outcomes. Overall, Model 5 exhibits a superior explanatory power (33%) compared to Model 4 (29%), underlining the added value of incorporating interaction terms in understanding the drivers of innovation in the context of intellectual capital and digital transformation.

Table 4 The Regression Results of Three IC Elements

	Model 4		Model 5	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t
$HCE_{j,t}$	2.861*	0.087	6.430***	0.009
$SCE_{j,t}$	2.955*	0.063	3.341**	0.021
$RCE_{j,t}$	3.213	0.130	4.876*	0.080
$DT_{j,t}$			0.216	0.586
$HCE_{i,t}*DT_{i,t}$			0.793***	0.000
$SCE_{j,t}*DT_{j,t}$			2.399***	0.006
$RCE_{j,t}*DT_{j,t}$			0.809	0.443
$Education_{j,t}$	7.719**	0.043	8.084**	0.034
$R\&D_{j,t}$	1.468**	0.050	1.406*	0.067
$Leverage_{j,t}$	-0.325	0.571	-0.304	0.596
$Size_{i,t}$	9.335	0.257	9.506	0.248
$Growth_{j,t}$	2.535***	0.001	2.440***	0.001
$ROA_{j,t}$	1.959**	0.025	1.956**	0.025
$IND_{j,t}$	1.107*	0.056	1.065*	0.066
Year	Yes		Yes	
N	5140		5140	
Adj R-squared	29%		33%	

Note:*p < 0.10, **p < 0.05, ***p < 0.01.

The province of Guangdong is the source of the most significant number of observations in our sample, with 28%. Guangdong has pioneered the new development concept in recent years, leading initiatives to promote dynamic transformation, efficiency improvement, and qualitative change. The province has been actively pursuing high-quality development to improve standards in various areas, such as efficiency, fairness, sustainability, and security. It is worth noting that Guangdong has been at the forefront of national efforts to promote innovation-driven development and digital transformation (DT). The province has experienced a significant increase in research and development (R&D) expenditure during the 13th Five-Year Plan period, with a rise from CNY 180 billion to CNY 320 billion. This

increased its proportion of GDP from 2.4% to 2.9%. This substantial investment has catapulted the province to the vanguard of regional innovation prowess, as evidenced by a significant increase in valid invention patents and PCT international patent applications. Guangdong is home to seven trillion-level industrial clusters encompassing various industries, including electronics information, green petrochemicals, intelligent home appliances, and advanced materials. Guangdong has transitioned from "old manufacturing" to "intelligent manufacturing" with over 55,000 large-scale industrial enterprises, solidifying its pivotal position in China's innovation landscape. As a result, this paper explores the complex relationship between intellectual capital (IC), digital transformation (DT), and innovation in the dynamic context of Guangdong province.

Table 5 presents the regression results of hypotheses specifically tailored for Guangdong province, offering valuable insights into the dynamics of intellectual capital (IC), digital transformation (DT), and their influence on innovation (INNOj,t) within this region. In Model 6, ICj,t emerges as a significant predictor of innovation, with a positive coefficient (Coef. = 3.601; p = 0.039), underscoring the role of intellectual capital in driving innovative endeavors within Guangdong. However, DTj,t fails to achieve statistical significance in this model, suggesting that standalone digital transformation may not significantly impact innovation within the province. Intriguingly, in Model 7, the interaction term DTj,t*ICj,t exhibits statistical significance (Coef. = 1.080; p = 0.000), indicating that the combined effect of digital transformation and intellectual capital significantly enhances innovation outcomes in Guangdong. This finding underscores the synergistic relationship between DT and IC, highlighting the importance of leveraging both factors in driving innovation within the province's dynamic ecosystem. Furthermore, control variables such as Educationj,t and R&Dj,t demonstrate varying degrees of significance across models, emphasizing their respective impacts on innovation outcomes. Model 8 exhibits the highest adjusted R-squared value (49%), indicating that including interaction terms substantially enhances the model's explanatory power, providing a more comprehensive understanding of the factors driving innovation within Guangdong province.

Table 5 The regression results of hypotheses for Guangdong province

	Guangdong Province					
	Model 6		Model 7		Model 8	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t	Coef.	P>t
$IC_{j,t}$	3.601**	0.039			1.210	0.869
$DT_{j,t}$			0.309*	0.067	2.674***	0.002
$DT_{j,t}$*$IC_{j,t}$					1.080***	0.000
$Education_{j,t}$	5.499*	0.055	6.480*	0.060	6.518*	0.056
$R\&D_{j,t}$	0.607**	0.016	0.538**	0.040	1.226**	0.047
$Leverage_{j,t}$	-0.307	0.848	-0.038	0.981	-0.132	0.934
$Size_{j,t}$	3.558	0.208	5.345**	0.047	3.585	0.203
$Growth_{j,t}$	4.669*	0.073	2.990	0.228	4.501*	0.082
$ROA_{j,t}$	0.820	0.779	3.805	0.141	1.812	0.536
$IND_{j,t}$	1.315	0.494	1.064	0.580	0.885	0.645
Year	Yes		Yes		Yes	
N	1445		1445		1445	
Adj R-squared	41%		38%		49%	

Note:*p < 0.10, **p < 0.05, ***p < 0.01.

Table 6 presents regression results examining the influence of COVID-19 on intellectual capital (IC), digital transformation (DT), and their interaction, alongside other control variables, on innovation (INNOj,t). The findings reveal nuanced relationships between these factors and innovation outcomes. Initially, in Model 10 and Model 11, COVID exhibits a negative and statistically significant coefficient (Model 10: coefficient= -1.837; p=0.028; Model 11: coefficient= -2.893; p=0.014), indicating that the presence of COVID-19 has a detrimental impact on innovation. However, the interaction term COVID*$DT_{j,t}$ yields intriguing results, with a negative and significant coefficient in Model 10 (coefficient= -0.061; p=0.037), suggesting that COVID-19 impedes the ability of digital transformation to foster innovation. Notably, Model 11 introduces the interaction term DTj,t*ICj,t, which exhibits a positive and statistically significant coefficient (coefficient= 0.286; p=0.004), indicating that the combined effect of digital transformation and intellectual capital positively influences innovation outcomes, albeit COVID-19's presence. However, the interaction term COVID*DTj,t*ICj,t does not attain statistical significance, suggesting that the joint impact of COVID-19, digital transformation, and intellectual capital on innovation is insignificant. Additionally, control variables such as Educationj,t and R&Dj,t demonstrate varying degrees of significance across models, emphasizing their respective impacts on innovation outcomes. Notably, Model 11 achieves the highest adjusted R-squared value (33%), indicating that the inclusion of interaction terms substantially enhances the explanatory power, providing deeper insights into the complex interplay between COVID-19, IC, DT, and innovation.

Table 6 The Regression Results of COVID-19

	Model 9		Model 10		Model 11	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t	Coef.	P>t
$IC_{j,t}$	0.719	0.698			2.582	0.150
COVID	-2.959	0.369	-1.837**	0.028	-2.893**	0.014
COVID*$IC_{j,t}$	1.499	0.687				
$DT_{j,t}$			0.203*	0.075	0.724**	0.029
COVID*$DT_{j,t}$			-0.061**	0.037		
$DT_{j,t}$*$IC_{j,t}$					0.286***	0.004
COVID*$DT_{j,t}$*$IC_{j,t}$					0.092	0.294
$Education_{j,t}$	7.686**	0.040	7.753**	0.038	7.847**	0.036
$R\&D_{j,t}$	1.411*	0.058	1.174	0.119	1.359*	0.075
$Leverage_{i,t}$	-0.388	0.497	-0.377	0.509	-0.355	0.533
$Size_{j,t}$	8.388	0.297	8.001	0.309	8.036	0.317
$Growth_{j,t}$	2.481***	0.001	2.427***	0.001	2.409***	0.001
$ROA_{j,t}$	1.714**	0.042	1.527**	0.042	1.605*	0.057
$IND_{j,t}$	1.073*	0.064	1.054*	0.069	0.988*	0.088
N	5140		5140		5140	
Adj R-squared	28%		28%		33%	

Note: *p < 0.10, **p < 0.05, ***p < 0.01.

5.3 Robustness Tests

We utilized Partial Least Squares Structural Equation Modeling (PLS-SEM) to ensure the reliability of our findings. Smart PLS 3.0 software was employed for hypothesis testing, using the bootstrapping method with 5,000 subsamples. Additionally, we explored the lag effect within our models by substituting the dependent variable ($INNO_{j,t}$) with $INNO_{j,t+1}$, $INNO_{j,t+2}$, and $INNO_{j,t+3}$, respectively. The results of our robustness tests, available upon request, indicate qualitative consistency with our primary findings. Notably, the relationship among intellectual capital (IC), digital transformation (DT), and innovation exhibit greater significance when the dependent variable is extended to $INNO_{j,t+2}$ and $INNO_{j,t+3}$.

6 DISCUSSION

In recent years, the intersection of innovation, Digital Transformation (DT), and Intellectual Capital (IC) has become a critical area of research within the context of strategic development and organizational management (Izzo et al.,2022). Intellectual capital encompasses an organization's collective knowledge, expertise, and intangible assets and has been acknowledged as a critical factor in establishing a competitive advantage and innovation. Simultaneously, the rapid development of digital technologies has prompted significant transformations in various sectors, reshaping business processes, consumer interactions, and value propositions. Firms that strive to navigate a dynamic and increasingly digitized business landscape are presented with new opportunities and challenges by the synergy between IC and DT. It is imperative for organizations that are endeavoring to remain relevant and prosper in the current fiercely competitive market to comprehend how these elements interact and impact innovation outcomes.

This study aimed to examine the impact of Intellectual Capital (IC) on innovation and the role of Digital Transformation (DT) and political connections in enhancing the effects of IC on innovation. Our research examined IC and DT in individual and collective contexts within Chinese manufacturing firms, contributing to the IC literature. Our analysis indicated that innovation was positively influenced by both IC and DT and that DT moderated the relationship between IC and innovation positively. Additionally, we observed that Human Capital Efficiency (HCE) had a beneficial impact on innovation. Furthermore, Structural Capital Efficiency (SCE) had a direct positive effect on innovation, which posited that structural capital was a critical factor in the exploitation process to facilitate innovation production. This study underscored the significance of integrating IC components and DT, as these strategies had the potential to optimize the impact of IC elements on innovation and support each other. The interaction between IC and DT functioned as a strategic management toolbox for innovation.

Based on the findings of this study, several recommendations can be proposed to enhance the innovation capabilities. Firstly, organizations should prioritize investments in intellectual capital (IC), particularly human and structural capital, as these elements have been identified as significant drivers of innovation. Efforts should be made to recruit and retain talented individuals and develop organizational structures and processes that facilitate knowledge creation and sharing. Additionally, recognizing the crucial role of digital transformation (DT) in moderating the relationship between IC and innovation, businesses should embrace technological advancements and integrate digital strategies into their operations.

This may involve adopting new digital tools and platforms, enhancing data analytics capabilities, and fostering a culture of innovation and experimentation. Moreover, policymakers and industry stakeholders should consider providing support and incentives to encourage manufacturing sectors where innovation is critical for economic growth. Organizations can position themselves competitively in today's rapidly evolving business landscape by fostering a conducive environment for innovation and digitalization.

This research explores the dynamics of the knowledge-based economy by analyzing the interplay between Intellectual Capital (IC), Digital Transformation (DT), and innovation within Chinese manufacturing firms. It illuminates how economic development and competitiveness are influenced by the creation, diffusion, and application of knowledge at the systemic level. It examines how firms utilize IC and DT to promote innovation and improve their competitive advantage at the organizational level. Furthermore, the role of human capital in fostering organizational success and innovation is investigated at the individual level.

7 CONCLUSION

This study comprehensively analyzes existing literature to explore how Chinese manufacturing firms operate. It focuses on how Intellectual Capital (IC) aligns with Digital Transformation (DT) initiatives to drive innovation in a rapidly evolving market. Additionally, it investigates how political connections affect the intricate relationship between intellectual capital, digital transformation, and innovation. By utilizing data from the A-listed share market in the Shenzhen stock exchange from 2013 to 2023 and employing Python programming to extract relevant information on AI, blockchain, cloud computing, big data, and digital technology applications, the study sheds light on the impact of both intellectual capital (IC) and dynamic capabilities (DT) on innovation. It reveals that dynamic capabilities significantly strengthen the link between intellectual capital and innovation outcomes. The findings suggest that human and structural capital positively influence innovation, with digital technology (DT) further enhancing these effects.

This study on the operational dynamics of Chinese manufacturing firms, particularly their alignment of Intellectual Capital (IC) with Digital Transformation (DT) for innovation, resonates deeply with the context of rapid globalization and technological advancement. In today's knowledge-driven economy, where innovation is pivotal in creating wealth and addressing global challenges, this research contributes valuable insights into how IC and DT intersect to drive innovation. By drawing from diverse disciplines such as economics, management, law, sociology, anthropology, psychology, and political science, the study sheds new light on the evolving role of knowledge in economic development and addresses pressing issues like environmental sustainability and education. By exploring IC and DT's impact on innovation within Chinese manufacturing, this study exemplifies how innovation can be leveraged to address complex global challenges and foster sustainable economic growth.

7.1 Theoretical Implications

The theoretical implications of this study extend to several critical areas within the realms of intellectual capital (IC), digital transformation (DT), and innovation. The findings contribute to the literature by elucidating the interplay between IC and DT strategies in driving innovation within Chinese manufacturing firms, offering a nuanced understanding of their combined effects on organizational performance. Secondly, by highlighting the moderating role of DT on the relationship between IC and innovation, the study enriches theoretical perspectives on dynamic capabilities and their impact on innovation outcomes.

7.2 Managerial Implications

The findings of this study have significant managerial implications for shareholders, managers, and policymakers within Chinese manufacturing firms. Recognizing the pivotal role of Intellectual Capital (IC) and Digital Transformation (DT) in fostering innovation, stakeholders at all levels should prioritize and allocate resources toward implementing IC- and DT-focused strategies and policies. Policymakers, including government officials and those involved in setting accounting standards, can leverage these findings to enforce regulations and incentives that promote innovation driven by IC and DT, thereby capturing the associated economic benefits.

7.3 Ideas for Future Research

Future research avenues stemming from this study's findings may explore several intriguing areas within intellectual capital (IC), digital transformation (DT), and innovation in Chinese manufacturing firms. Firstly, investigating the mediating mechanisms through which IC and DT influence innovation outcomes could provide deeper insights into the underlying processes driving this relationship. Additionally, exploring the role of organizational culture and leadership styles in facilitating the effective integration of IC and DT strategies for innovation could offer valuable managerial insights. Furthermore, longitudinal studies tracking the evolution of IC and DT practices over time and their impact on innovation performance could provide a more comprehensive understanding of their dynamic interplay. Moreover, comparative studies across different industries and regions within China could elucidate industry-specific nuances and regional variations in the relationship between IC, DT, and innovation. Lastly, examining the moderating effects of external environmental factors, such as regulatory frameworks and market competition, on the relationship between IC,

DT, and innovation could enrich our understanding of the contextual factors shaping innovation dynamics in Chinese manufacturing firms.

7.4 Limitations

While this study offers valuable insights into the interplay between Intellectual Capital (IC), Digital Transformation (DT), and innovation within Chinese manufacturing firms, several limitations should be acknowledged. Firstly, the research is constrained by the availability and scope of the data collected from the A-listed share market in the Shenzhen stock exchange, which may not fully capture the diversity of firms operating in the sector. Additionally, the study's focus on a specific time frame from 2013 to 2023 may limit the generalizability of the findings to other periods characterized by different economic conditions or technological landscapes. Moreover, the analysis primarily relies on secondary data, which may be subject to inherent biases or inaccuracies. Furthermore, while efforts were made to control for relevant variables, there may still be unobserved factors influencing the relationships examined in the study. Finally, the study's methodology, including the use of Python programming for data extraction and analysis, may introduce technical challenges or limitations that could affect the robustness of the results.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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POLICY-DRIVEN SUSTAINABLE PROPERTY DEVELOPMENT: STRATEGIC PATHWAYS AND SYSTEMIC CHALLENGES IN CHINA'S DUAL CARBON TRANSITION

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Abstract: Under the synergistic drive of China's "Dual Carbon" strategy and macro-control policies such as "housing is for living, not speculation" and the "three red lines" regulation, the real estate industry faces dual challenges and opportunities in green transformation and sustainable development. As a pillar of the national economy, real estate enterprises urgently need to resolve contradictions and bottlenecks in low-carbon transition through management innovation and technological upgrading. This study systematically examines the intrinsic connection between carbon neutrality goals and the real estate sector, revealing practical challenges including carbon footprint measurement deficiencies, green technology application gaps, intensified financing constraints, and policy adaptation dilemmas. The research proposes a multidimensional implementation framework: Strengthening corporate awareness of green transition while establishing a carbon-neutral business ecosystem; enhancing carbon accounting capabilities and energy efficiency through technological innovation, complemented by carbon offset and compensation mechanisms; deepening ESG practices to reduce debt financing costs, with empirical evidence demonstrating that improved ESG ratings significantly optimize credit asset structures under green finance policies. Furthermore, the study outlines actionable pathways such as low-carbon building standards and green supply chain management, aligning with macro-control objectives. These findings provide theoretical support for real estate enterprises to balance regulatory compliance with market opportunities, formulate carbon reduction strategies, and accelerate the realization of China's "Dual Carbon" vision through industry-wide sustainable transformation.
Keywords: Green real estate development; Dual carbon goals; Policy instruments; Low-carbon transition; Interest coordination

1 INTRODUCTION

1.1 Background of the Study

Against the backdrop of the global response to climate change, China has actively assumed the responsibility of a great power and put forward a "dual-carbon" strategic goal, i.e., striving to achieve carbon peaking by 2030 and carbon neutrality by 2060. The proposal of this strategic goal is not only an important contribution of China to global climate governance, but also has far-reaching impacts on the development of various domestic industries. As one of the pillar industries of China's national economy, the real estate industry occupies an important position in economic and social development. However, the traditional real estate development model is often accompanied by high energy consumption and high emissions. From the production and transportation of building materials, to energy consumption during building construction, to daily energy consumption during the use phase of buildings, the real estate industry generates a large amount of carbon emissions throughout its life cycle[1]. According to relevant statistics, carbon emissions from the real estate industry account for a large proportion of China's total social carbon emissions. At the same time, in order to promote the stable and healthy development of the real estate market, the Chinese government has issued a series of macro-control policies, in which the positioning of "housing without speculation" clarifies the residential property of real estate, curbing speculative behavior in the real estate market and guiding the market back to rationality. The "three red lines" policy has imposed strict restrictions on the financing of real estate enterprises, aiming to reduce the leverage of enterprises and prevent financial risks. The implementation of these policies has caused real estate enterprises to face unprecedented financial pressure and market competition challenges. Driven by the synergy of the "dual-carbon" strategy and macro-control policies, the real estate industry is facing the dual challenges and opportunities of green transformation and sustainable development. On the one hand, enterprises need to cope with the strict requirements of the policy to solve the various contradictions and bottlenecks encountered in the process of low-carbon transformation; on the other hand, the green transformation has also brought new market opportunities and development space for enterprises. For example, as consumers' awareness of environmental protection increases, there is a growing demand for green, low-carbon and healthy real estate products[2].

1.2 Current Status of Related Research at Home and Abroad

Overseas, many developed countries have carried out a great deal of research and practice in the low-carbon development of the real estate sector. Some studies focus on the development and application of green building

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technologies, such as highly efficient insulation materials and solar photovoltaic systems, to improve the energy efficiency of buildings. There are also studies focusing on the sustainable development strategies of real estate companies, exploring how to achieve low-carbon transformation through management innovation and technological upgrading. For example, some European countries have promoted the active adoption of green building technologies by real estate companies through the formulation of strict building energy consumption standards and carbon emission regulations.

Domestically, with the proposal of the "double carbon" goal, the research on the low-carbon development of the real estate industry is also increasing[3]. Domestic studies mainly focus on the path and strategy of low-carbon transformation of the real estate industry, such as how to promote low-carbon development of real estate enterprises through policy guidance, technological innovation and market mechanisms. In addition, some studies also focus on the accounting methods and standards for carbon emissions in the real estate industry, in order to accurately assess the carbon emissions of real estate projects. However, the current domestic studies still have certain deficiencies in the accuracy of carbon footprint measurement, the practical application effect of green technologies, and the adaptability of policies, which require further in-depth research.

1.3 Impact of the "Dual-Carbon" Strategy on the Real Estate Sector

Opportunities for green transformation: The real estate industry is one of China's pillar industries and a major contributor to energy consumption and carbon emissions. The implementation of the "dual-carbon" strategy will prompt real estate companies to accelerate the pace of green transformation, promote the development of green buildings, assembly buildings and other new building forms, and improve the energy efficiency and environmental performance of buildings. This will not only help reduce carbon emissions in the real estate industry, but also meet consumer demand for green, healthy and comfortable living environments and enhance the market competitiveness of enterprises. Therefore, an in-depth study of the intrinsic links between the carbon peak and carbon neutral targets and the real estate industry, revealing the practical challenges faced by real estate companies in the process of low-carbon transformation and proposing corresponding strategic paths and solutions, is essential for real estate companies to balance compliance regulation and market opportunities, formulate effective carbon emission reduction strategies, and promote the sustainable transformation of the industry as a whole in order to realize the vision of " Double Carbon" in China. It is of great theoretical and practical significance for real estate enterprises to balance compliance regulation and market opportunities, formulate effective carbon reduction strategies, and promote the sustainable transformation of the whole industry to realize China's "dual carbon" vision.

2 TECHNOLOGIES RELATED TO SUSTAINABLE DEVELOPMENT IN THE REAL ESTATE INDUSTRY

2.1 Techniques for Accurate Carbon Footprint Measurement

Measurement method innovation: At present, China's real estate industry has obvious deficiencies in carbon footprint measurement, and lacks a unified and accurate measurement method. Therefore, it is necessary to develop a carbon footprint measurement model that is suitable for the whole life cycle of real estate projects in China by combining international advanced experience with China's national conditions. For example, drawing on the Life Cycle Assessment (LCA) methodology, the carbon emissions of building materials production, transportation, construction, operation and demolition should be comprehensively considered at each stage. Introducing big data and Internet of Things (IoT) technology to collect real-time data on building energy consumption and building materials usage to improve the accuracy and timeliness of carbon footprint measurement. By installing smart sensors in buildings, real-time monitoring of energy consumption, water usage, etc., and uploading the data to the cloud for analysis[4].

Formulation of measurement standards: Promote the establishment of unified carbon footprint measurement standards for the industry, and clarify the calculation methods and boundaries of carbon emissions at various stages. Relevant government departments, industry associations and research institutes should work together to formulate a real estate carbon footprint measurement standard system that meets China's "dual-carbon" goal. Strengthen the qualification and supervision of measurement organizations to ensure the reliability and comparability of measurement results. Establish an access mechanism and a monitoring and evaluation system for measurement organizations, and regularly evaluate their measurement capabilities and results.

2.2 Green Technology Application and Innovation

1. Promotion of energy-saving technologies: vigorously promote energy-efficient building designs and technologies, such as solar photovoltaic integration, ground-source heat pumps, and high-efficiency thermal insulation materials. In new buildings, it is mandatory to adopt a certain percentage of energy-saving technologies and products to improve the energy utilization efficiency of buildings. Carry out energy-saving renovation of existing buildings to reduce building energy consumption by replacing windows and doors, adding insulation and optimizing HVAC systems. Subsidy policies and incentives for energy-saving renovation of existing buildings have been formulated to encourage owners and enterprises to actively participate in the renovation.

2. Research and development and application of green building materials: Increase investment in research and

development of green building materials and encourage enterprises to develop new environmentally friendly and low-carbon building materials. For example, research and development of recyclable building materials, bio-based materials, etc., to reduce carbon emissions during the production of traditional building materials. Establish a certification system for green building materials and strengthen the supervision of the green building materials market to ensure the quality and performance of green building materials. Through the certification mark and market access system, guide real estate enterprises to prioritize the use of green building materials.
3. Intelligent management technology application: the introduction of building intelligent management system realizes intelligent monitoring and management of building energy, equipment and environment. Through the intelligent control system, energy consumption is automatically adjusted according to the actual use of the building, and energy utilization efficiency is improved. Using big data and artificial intelligence technology, it analyzes and predicts building operation data to provide decision support for optimal operation and maintenance of the building. For example, by analyzing historical energy consumption data, it predicts future energy demand and adjusts energy supply strategies in advance.

2.3. Carbon Offset and Compensation Technologies

1. Carbon sink project development: Encourage real estate companies to participate in the development of carbon sink projects, such as tree planting and wetland protection. By investing in the construction of carbon sink projects, they can offset the carbon emissions of their own projects. Enterprises can cooperate with forestry departments and environmental protection organizations to jointly develop carbon sink projects and obtain corresponding carbon emission reduction credits. Establish a carbon sink trading market to provide real estate enterprises with a carbon sink trading platform. Through the market mechanism, promote the rational allocation and effective utilization of carbon sink resources.
2. Alternative technologies for renewable energy: Promote the use of renewable energy in real estate projects as an alternative to traditional energy sources, such as solar energy, wind energy and water energy[5]. In building design, reserve space and interfaces for the installation of renewable energy equipment, and encourage owners and enterprises to install and use renewable energy equipment. Developing distributed energy systems to realize the local production and utilization of energy. For example, distributed solar power stations are being built in residential communities to provide clean energy for residents.

2.4 Technology Integration and Collaborative Innovation

1. Multi-technology integrated application: Integrate carbon footprint measurement, green technology application, carbon offset and compensation and other technologies to form an integrated low-carbon technology solution. Through system integration, realize the synergistic effect of various technologies and improve the low-carbon level of real estate projects. Establish a technology integration platform to promote information sharing and exchange between different technologies. For example, through the establishment of a digitization platform, real-time sharing of information such as carbon footprint measurement data and the effect of green technology application can be realized.
2. Collaborative innovation among industry, academia, research and application: Strengthening cooperation among real estate enterprises, scientific research institutions and universities to carry out research and development and innovation of low-carbon technologies. Through the cooperation between industry, academia and research institutes, scientific research results will be transformed into practical applications, and the technological progress of the real estate industry will be promoted. Establish an industry-university-research-utilization cooperation mechanism to jointly undertake scientific research projects and carry out technological innovation activities. For example, enterprises provide practical application scenarios and financial support, while research institutions and universities provide technical research and development and talent training services. Figure 1 shows the relevant technologies for the sustainable development of the real estate industry.

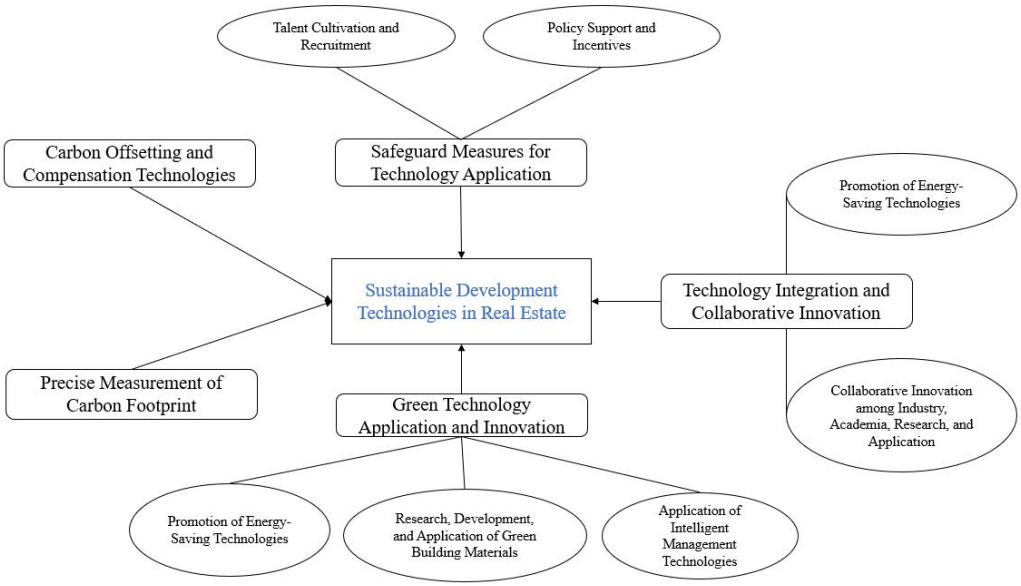

Figure 1 The Technologies Related to Sustainable Development in the Real Estate Industry

2.5. Safeguards for the Application of Technology

1. Cultivation and introduction of talents: Strengthen the cultivation of professionals related to low-carbon technology, open relevant majors and courses in colleges and vocational schools, and cultivate professionals adapted to the needs of low-carbon transformation of the real estate industry. Introduce advanced low-carbon technology talents from home and abroad to improve the technological innovation ability of enterprises. Attract high-end talents to join real estate enterprises through preferential policies and favorable working environment.
2. Policy support and incentives: The government has issued relevant policies to support real estate projects that adopt low-carbon technologies with tax incentives and financial subsidies. For example, enterprises constructing green buildings are given a certain percentage of tax breaks, and financial subsidies are given to projects adopting renewable energy. Establish a technological innovation incentive mechanism to recognize and reward enterprises and individuals who have made outstanding achievements in the research, development and application of low-carbon technologies.

3 FIT BETWEEN THE "NO SPECULATION ON HOUSING" POLICY AND GREEN DEVELOPMENT

As an important macro-control tool, the policy of "housing without speculation" is closely linked to the green development of the real estate industry. This section will explore the interface between the policy of "housing without speculation" and green development, in order to reveal the potential opportunities and feasible paths for the real estate industry to realize green transformation in the context of this policy.

3.1 The Role of the "Housing Without Speculation" Policy in Regulating the Real Estate Market

The policy of "housing without speculation" is aimed at returning to the residential property of housing, curbing speculation in the real estate market and promoting the stable and healthy development of the real estate market. The implementation of this policy has rationalized the relationship between supply and demand in the real estate market and reduced market bubbles and instability[6]. From the demand side, the policy has guided consumers to focus more on the actual use value and living quality of housing rather than pure investment returns. This has prompted real estate companies to focus more on improving the quality and performance of housing, creating market demand for green development. From the supply side, the policy restricts the blind expansion and over-development of real estate enterprises, prompting them to pay more attention to the long-term benefits and sustainability of their projects, which provides an intrinsic motivation for green development.

3.2 Market Opportunities for Green Development under the Policy of "Housing without Speculation"

The implementation of the policy of "housing without speculation" has made the real estate market more focused on quality and service, which has brought broad market opportunities for green development. On the one hand, consumers' awareness of and demand for green housing is increasing, and they are willing to pay higher prices for green housing. Real estate companies can meet consumer demand and improve market competitiveness by developing green projects. On the other hand, the government's support for green development has been increasing, and a series of preferential policies and incentives have been introduced, such as financial subsidies, tax reductions and exemptions, and volume rate incentives. Real estate companies can take advantage of these policies to reduce the cost of green development and

improve the economic efficiency of their projects.

3.3 Synergies between the Policy of "Housing without Speculation" and Green Development in Terms of Policy Objectives

The goal of the "housing without speculation" policy is to promote the stable and healthy development of the real estate market and to safeguard the housing needs of residents, while the goal of green development is to achieve sustainable development of the economy, society and the environment. Both have synergies in terms of policy objectives, and both are committed to promoting high-quality development of the real estate industry. These points of convergence provide favorable conditions for the green transformation and sustainable development of the real estate industry. By combining the policy of "housing without speculation" with green development, we can achieve a balance between supply and demand in the real estate market, a reasonable allocation of resources and effective protection of the environment, and contribute to the realization of China's "dual-carbon" goal. This will contribute to the realization of China's "dual-carbon" goal.

4 FORCING MECHANISM OF THE "THREE RED LINES" POLICY FOR LOW-CARBON TRANSFORMATION OF ENTERPRISES

4.1 Overview of the "Three Red Lines" Policy

The "Three Red Lines" policy is an important initiative of China's macro-control of real estate, including the gearing ratio after excluding advance receipts shall not be greater than 70%, the net debt ratio shall not be greater than 100%, and the cash-to-short-debt ratio shall not be less than one times. The introduction of this policy aims to regulate the financing behavior of real estate enterprises, control the financial risks of the real estate industry, and guide enterprises to rationally arrange funds to avoid over-indebtedness and blind expansion. The implementation of this policy has had a far-reaching impact on the financial situation and business strategies of real estate enterprises, prompting them to re-examine their own development model and strategic direction.

4.2 Financial Pressure on Enterprises under the "Three Red Lines" Policy

Under the constraints of the "three red lines" policy, real estate enterprises are facing tremendous financial pressure. As many enterprises have long relied on a high-debt, high-turnover development model, after the implementation of the policy, the gearing ratio, net debt ratio and other indicators may exceed the requirements of the red line, resulting in restricted financing channels. Banks and other financial institutions have become more stringent in approving loans for enterprises stepping on the line, and the scale of new financing for enterprises has been restricted, and the cost of financing has increased accordingly. At the same time, in order to meet the policy requirements, enterprises need to accelerate sales returns and reduce the level of indebtedness, which further aggravates the enterprise's financial constraints. This financial pressure makes enterprises have to seek new development paths to alleviate financial difficulties. Table 1 shows the sustainable real estate development paths, key challenges and countermeasures under the policy-driven.

Table 1 Policy-Driven Sustainable Property Development in China's Dual Carbon Transition

Policy Category	Strategic Pathways	Systemic Challenges	Key Implementation Measures	Case/Data Support
Dual Carbon Targets	1. low carbon building standardization and certification 2. Green technology innovation and application (e.g. BIPV, smart energy system)	1. Lack of standards for carbon footprint measurement 2. High cost and difficulty in promoting green technologies	1. Establishment of industry carbon accounting systems 2. Government subsidies and tax incentives	By 2022, China's certified green building area will exceed 6.6 billion square meters (Source: Ministry of Housing and Construction)
"Housing for Living" Regulations	1. Green renovation of stock housing 2. Sustainable design for sheltered housing	1. Inadequate funding for energy efficiency retrofits in older buildings 2. Significant regional differences in policy implementation	1. Issuance of green bonds to support urban renewal 2. Development of local guidelines on low-carbon buildings	Pilot "zero-carbon community" projects in Beijing and Shanghai (e.g., Beijing Urban Vice Center)
Green Finance Policies	1. ESG ratings linked to financing costs 2. Carbon market participation	1. Weak ESG disclosure capacity of SMEs 2. Low liquidity of carbon assets	1. Development of an ESG disclosure framework for the real estate sector 2. Innovation in carbon financial instruments (e.g. carbon mortgages)	Green bond issuance scale of real estate enterprises increased by 23% year-on-year in 2023 (Source: Wind Data)

Supply Chain Sustainability	1. Proportion of mandatory procurement of green building materials 2. Supplier carbon footprint tracking	1. Insufficient supply of low-carbon alternatives for building materials 2. Low supply chain transparency	1. Establishment of green building materials database 2. Blockchain technology enables supply chain traceability	Vanke's "Green Chain Action" covers 80% of its suppliers (Source: Enterprise Annual Report)
Regional Coordination	1. Pilot trans-regional carbon emissions trading 2. Eco-compensation mechanisms	1. Uneven regional development makes policy synergies difficult 2. Local protectionism hinders resource flows	1. Interconnection of carbon emissions trading in the Yangtze River Delta/Great Bay Region 2. Targeted support from central financial transfers	Guangdong Province will account for 28% of the country's carbon emission quota turnover in 2022 (Source: Guangdong Carbon Exchange)

Looking ahead, with the in-depth promotion of the "dual-carbon" strategy, the forcing effect of the "three red lines" policy on the low-carbon transformation of enterprises will become more obvious. Enterprises need to further strengthen technological innovation, increase capital investment, and improve the management system of low-carbon transformation to adapt to policy and market requirements. The government should also continue to improve the relevant policies to provide more support and guidance for the low-carbon transformation of enterprises, and jointly promote the sustainable development of the real estate industry to achieve China's "dual-carbon" goal[7].

5 SYSTEMIC CHALLENGES OF LOW CARBON TRANSITION IN CHINA'S REAL ESTATE SECTOR

5.1 Numerous Shortcomings in Carbon Footprint Measurement

In the context of the real estate industry's transition to low-carbon and sustainable development, accurate carbon footprint measurement is of critical importance. First of all, carbon footprint measurement is the basis for enterprises to formulate scientific and reasonable emission reduction targets and strategies. Real estate development involves a number of complex processes, such as land acquisition, building construction, and operation and management, each of which generates different levels of carbon emissions. By accurately measuring the carbon footprint, companies can clearly understand the carbon emissions of each link, so that they can take targeted emission reduction measures, avoid blind actions, and improve the efficiency of emission reduction. However, there are many shortcomings in the current carbon footprint measurement 1. Uniform measurement standards: At present, China's real estate industry lacks uniform and authoritative carbon footprint measurement standards. Different measurement organizations may adopt different methods and parameters, resulting in a lack of comparability and accuracy of measurement results. For example, when calculating carbon emissions during building construction, some organizations only consider carbon emissions during the production and transportation of building materials, while ignoring the energy consumption of construction machinery and carbon emissions during waste disposal. Such inconsistency in standards makes it difficult for enterprises to accurately assess their carbon emission levels, and also brings difficulties to governmental supervision.2. Difficulty in obtaining data: Carbon footprint measurement requires the support of a large amount of accurate data, including data on the production of construction materials, energy consumption, and data on waste disposal, etc. In practice, however, it is difficult to obtain data for the measurement of carbon footprint. However, in practice, there are many difficulties in data acquisition. On the one hand, some enterprises have not established a perfect data collection and recording system due to the lack of data management awareness, resulting in missing or inaccurate data. On the other hand, some data involve commercial secrets of enterprises, which enterprises are reluctant to disclose to the public, further increasing the difficulty of data acquisition. For example, suppliers of construction materials may be reluctant to provide detailed carbon emission data during their production process, making it difficult for real estate companies to calculate the carbon footprint of construction materials.3. Inadequate measurement methods: Existing carbon footprint measurement methods have certain limitations and are unable to comprehensively and accurately reflect the carbon emissions of real estate projects. For example, the current measurement methods mainly focus on the calculation of direct carbon emissions and give insufficient consideration to indirect carbon emissions. Indirect carbon emissions from real estate projects include carbon emissions from upstream and downstream enterprises in the supply chain, carbon emissions during consumer use, etc. These indirect carbon emissions often account for a large proportion of the total carbon emissions of the project. In addition, the existing measurement methods are not mature enough to calculate the carbon emissions of some emerging technologies and materials, leading to bias in the measurement results.

Suggestions for solving the carbon footprint measurement problem are as follows: 1. Establish a unified measurement standard: The government should take the lead in organizing relevant departments and industry associations to formulate a unified and authoritative carbon footprint measurement standard for the real estate industry. The standards should specify the measurement scope, methods and parameters to ensure the comparability and accuracy of the measurement results. At the same time, publicity and training on the measurement standards should be strengthened to enhance the understanding and application capabilities of enterprises and measurement organizations.2. Strengthen data management: Real estate enterprises should set up a comprehensive data collection and recording system to strengthen data management on the production of building materials, energy consumption, and waste disposal. The government

can encourage enterprises to adopt advanced information technology means to realize real-time data collection, transmission and analysis through policy guidance and financial support[8]. In addition, the construction of a data-sharing platform should be strengthened to promote data sharing among enterprises and between enterprises and the government, and to improve the efficiency of data utilization.3. Improvement of Measurement Methods: Scientific research institutes and enterprises should strengthen the research and innovation of carbon footprint measurement methods, and continually improve the measurement methods. Consideration should be given to including indirect carbon emissions in the scope of measurement and adopting more advanced technologies and models to improve the accuracy and comprehensiveness of measurement. At the same time, research on the carbon emissions of emerging technologies and materials should be strengthened and reasonable carbon emission calculation methods should be developed for them.

5.2 Bottlenecks in the Application of Green Technologies

5.2.1 Barriers to the promotion of green building technology

In the green transformation process of China's real estate industry, the promotion of green building technology faces many difficulties. First, the green building technology standard system is not perfect. At present, although China has introduced a series of standards and norms related to green building, there are some problems in the practical application of these standards. For example, there are differences in the standards of different regions, which makes it difficult for real estate enterprises to apply green building technology uniformly when developing projects across regions. Moreover, the updating speed of some of the standards cannot keep up with the pace of technological development and cannot provide effective guidance and specifications for the latest green building technologies.

Secondly, the cost of green building technology is higher. Compared with traditional building technologies, green building technologies require higher inputs in terms of materials, equipment and construction techniques. Energy-efficient glass, for example, is usually 30% - 50% more expensive than ordinary glass. For real estate companies, the adoption of green building technology will significantly increase the construction cost of the project, which to a certain extent reduces the motivation of companies to apply green technology. In addition, the research and development and application of green building technologies require professional talents and technical teams, which also increases the labor costs of enterprises. In addition, the lack of market awareness and acceptance of green building is also an important issue. Most consumers do not have a deep enough understanding of the concepts and advantages of green building, and they are more concerned about traditional factors such as the price, location and house type of the house, and lack sufficient attention to the energy-saving and environmentally friendly features of green building. This makes real estate companies face certain difficulties in selling green building projects, further inhibiting the promotion of green building technology.

5.3 Intelligent Technology Integration Challenges

With the continuous development of science and technology, the application of intelligent technology in the field of real estate is getting more and more attention. However, the integration of intelligent technology faces many challenges in practical application. On the one hand, the compatibility of intelligentized systems is poor. Real estate projects involve a number of intelligent subsystems, such as security systems, energy management systems, smart home systems, and so on. These subsystems are often provided by different suppliers, and there are differences in communication protocols and data formats between them, making it difficult to achieve effective integration and cooperative work between the various systems. For example, the data collected by the security system cannot be timely and accurately transmitted to the energy management system, which affects the operational efficiency of the entire intelligent system. On the other hand, the maintenance and management of intelligent technology is difficult. Intelligent systems contain a large number of devices and software, which require professional technicians for maintenance and management. However, at present, China's real estate industry lacks composite talents who know both real estate and intelligent technology, which leads to the failure of the intelligent system in the operation process can not be repaired in time. Moreover, the intelligent technology is updated quickly, real estate enterprises need to continuously invest in system upgrades and updates, which also increases the operating costs of enterprises.

In addition, the security of intelligent technology is an issue that cannot be ignored. With the increase of intelligentized equipment and systems in real estate projects, the risk of data leakage and cyberattacks also increases. If the security measures of the intelligentized system are not in place, it may lead to problems such as the leakage of owners' personal information and the malicious control of equipment, which will bring great inconvenience and security risks to owners' lives.

5.4 Limitations of Renewable Energy Utilization

The application of renewable energy in real estate projects is one of the important ways to realize low-carbon transformation, but at present, there are certain limitations in the use of renewable energy in China's real estate industry. First, the stability of renewable energy is poor. Solar, wind and other renewable energy generation is greatly affected by natural conditions, for example, solar power generation can only be carried out during the day when there is sunlight, and wind power generation also requires sufficient wind conditions. This makes it difficult for renewable energy sources to meet the continuous power demand of real estate projects in practical application, and it needs to be

complemented with traditional energy sources. Second, the installation and maintenance costs of renewable energy equipment are high. The initial investment in renewable energy equipment such as solar photovoltaic panels and wind turbines is large, and their installation and maintenance require specialized technicians and equipment. For some small real estate companies, it is difficult to afford such high costs. In addition, renewable energy equipment has a relatively short service life and requires regular replacement and maintenance, which also increases the operating costs of the enterprise[9]. In addition, the grid connection problem of renewable energy is also an important issue. At present, China's power grid system is mainly designed for traditional energy sources, renewable energy power generation into the grid needs to meet certain technical standards and requirements. Due to the large intermittency and volatility of renewable energy power generation, it brings certain challenges to the stable operation of the grid. As a result, grid companies are more cautious about accessing renewable energy power generation, which to a certain extent limits the application of renewable energy in real estate projects.

5.5 The Policy Adaptation Dilemma

China's "dual carbon" transition and real estate macro-control policies, such as "housing without speculation" and the "three red lines", are intertwined and constantly updated, forming a complex system of policies. These policies are intertwined and constantly updated, forming a complex policy system. Real estate companies are faced with the challenge of how to accurately understand the intent of these policies and how to effectively integrate them into their daily operations and strategic planning. Different policies have different objectives and focuses. For example, the "dual carbon" policy emphasizes low-carbon development and green transformation, while the "three red lines" focuses more on financial health and debt risk control. Enterprises need to find a balance between the two to ensure that they meet low-carbon requirements without violating financial regulations. However, due to the subjectivity of policy interpretation and the limitations of enterprises' own capacity, many enterprises have deviated from the implementation process. Some enterprises may focus too much on low-carbon targets and neglect financial risks, resulting in a tight financial chain; others may be too conservative and make slow progress in low-carbon transformation, missing out on market opportunities. In addition, frequent policy adjustments increase the difficulty for enterprises to adapt. The government continuously optimizes policies based on market dynamics and national strategic goals, which requires companies to have the ability to react and adjust quickly. However, real estate projects are characterized by long construction cycles and large-scale investments. Once an enterprise has planned a project in accordance with the original policy, changes in the policy may result in the feasibility and economic benefits of the project being affected, and the enterprise will have to reevaluate and adjust the project plan, which undoubtedly increases the enterprise's operating costs and risks.

There are also differences in the level of development and resource endowment of the real estate market in different regions. In some economically developed regions, the market demand for green real estate is higher, enterprises are motivated to carry out low-carbon transformation, and the role of policy promotion is relatively obvious. In some economically underdeveloped regions, consumer awareness and acceptance of green building is low, market demand is insufficient, and the enthusiasm of enterprises to carry out low-carbon transformation is not high. At this time, if the government imposes uniform policy standards, it may lead to increased costs for enterprises and inhibit market vitality. Therefore, how to formulate more flexible and targeted policies to adapt to the actual situation of different enterprises and regions is an important issue that current policy makers need to address.

6 CONSTRUCTION OF A MULTIDIMENSIONAL IMPLEMENTATION FRAMEWORK

6.1 Enhancing Corporate Green Transition Awareness and Building Carbon Neutral Business Ecosystems

6.1.1 Importance of enhancing awareness of green transformation in enterprises

Under the synergistic promotion of the "dual-carbon" strategy and macro-control policies such as "housing without speculation" and "three red lines", real estate enterprises, as pillars of the national economy, have a great significance in enhancing their awareness of green transformation. Enhancement of real estate enterprises as the pillar of the national economy, its green transformation awareness is of great significance. On the one hand, from the perspective of the enterprise's own development, green transformation is the key to deal with the dual challenges and opportunities facing the industry. As consumers' awareness of environmental protection continues to improve, the market demand for green and sustainable real estate projects is increasing. If enterprises can enhance the awareness of green transformation in a timely manner, and develop real estate products that meet environmental standards and consumer demand, it will help to enhance the market competitiveness of enterprises and expand market share. On the other hand, from the social level, the real estate industry is one of the important areas of carbon emissions. Real estate enterprises to enhance the awareness of green transformation, and actively participate in low-carbon development, will help promote the green change of the industry as a whole, and contribute to the realization of the national "dual-carbon" goal. At the same time, this is also in line with the national macro-control guidance, which is conducive to the enterprises and the policy environment, to avoid the business risks brought about by policy adjustments.

6.1.2 Ways to Enhance Enterprises' Awareness of Green Transformation

Strengthening policy publicity and training: The Government and industry associations should strengthen the publicity

of the "dual-carbon" policy and the relevant requirements for green development, and organize real estate enterprises to participate in policy interpretation and training activities. Through these activities, enterprise managers can gain a deeper understanding of the policy background, objectives and specific requirements, and clarify the responsibilities and obligations of enterprises in green transformation. For example, policy seminars can be organized on a regular basis, inviting relevant policymakers and experts to give explanations and answer questions, helping enterprises to accurately grasp the direction of the policy.

Setting up industry benchmarks and role models: The industry should actively set up benchmark enterprises and successful cases of green transformation, and show the effectiveness and experience of green transformation to other enterprises through media publicity and industry exchanges. The demonstration effect of these benchmark enterprises can stimulate the enthusiasm and initiative of other enterprises, prompting them to learn from advanced green development concepts and practice methods. For example, a "green real estate enterprise" award can be selected to recognize and publicize enterprises with outstanding performance in green transformation.

Promote the construction of internal culture: real estate enterprises should actively create a cultural atmosphere of green development internally, and integrate the concept of green transformation into the values and development strategies of the enterprise. By carrying out internal training, publicity activities, etc., to improve the knowledge and understanding of all employees on green transformation, so that green development has become the conscious action of all employees of the enterprise. For example, a green development publicity column can be set up within the enterprise to regularly release knowledge and information related to green development.

6.2 Technological Innovation to Enhance Carbon Accounting Capacity and Energy Efficiency

In the process of low-carbon transformation of the real estate industry, accurate carbon accounting is crucial. However, there are currently many deficiencies in carbon accounting in China's real estate sector, such as inconsistent carbon footprint measurement methods and difficulties in data collection. Technological innovation provides an effective way to solve these problems. Advanced Internet of Things (IoT) technology can be applied to all aspects of real estate projects to realize real-time and accurate monitoring of energy consumption and carbon emission data. By installing various types of sensors in buildings, it is possible to collect data on a wide range of aspects, including power consumption, water usage, and the operation of air conditioning systems. These data can be integrated and analyzed through the IoT platform to clearly present the carbon footprint of a real estate project. For example, in a large commercial complex, the use of IoT sensors can be used to monitor the energy usage of each store in real time and accurately calculate the carbon emissions of different areas[10].

Big data analysis technology also plays an important role in carbon accounting. By deeply mining and analyzing a large amount of carbon emission data, more scientific and accurate carbon accounting models can be established. These models can take into account the characteristics of different regions and types of real estate projects and improve the accuracy of carbon accounting. At the same time, big data analysis can also predict the carbon emission trends of real estate projects at different stages, providing a basis for enterprises to formulate carbon reduction strategies.

Improving energy efficiency is key to achieving low-carbon development in the real estate sector. Technological innovation has great potential in this regard.

6.3 Alignment of Carbon Offsets with Compensation Mechanisms

In addition to enhancing carbon accounting capacity and energy efficiency through technological innovation, carbon offsetting and compensation mechanisms are important additions to the real estate industry's efforts to achieve low-carbon development. Carbon offsetting refers to enterprises offsetting their own carbon emissions by purchasing carbon emission reductions. Real estate enterprises can invest in some renewable energy projects, forest carbon sink projects, etc., in order to obtain the corresponding carbon emission reductions. For example, enterprises can participate in tree planting projects to absorb carbon dioxide through photosynthesis of trees, thus offsetting their own carbon emissions in the process of real estate development and operation. Carbon offsetting mechanism refers to the fact that enterprises reduce carbon emissions by adopting some measures and use the reduced carbon emissions to compensate for other unavoidable carbon emissions. For example, real estate enterprises can adopt more environmentally friendly building materials and construction techniques in the project development process to reduce carbon emissions during the construction process. At the same time, companies can use these reduced carbon emissions to compensate for unavoidable carbon emissions during project operations. Technology innovation, carbon offset and compensation mechanisms work together to form a complete low-carbon development system, helping real estate companies to better achieve carbon emission reduction targets and enhance the sustainable development of enterprises. Against the background of China's "dual-carbon" goal, real estate companies should actively embrace technological innovation, make full use of carbon offset and compensation mechanisms, and accelerate the pace of green transformation and sustainable development.

6.4 Deepening ESG Practices to Reduce Debt Financing Costs

6.4.1 Conceptualization of ESG practices

ESG stands for Environment, Social and Governance, which constitute an important system of indicators for measuring corporate sustainability. In the context of the real estate industry, ESG practices have rich and specific connotations.

From the environmental dimension, the ESG practices of real estate companies are mainly reflected in the protection of the environment and the sustainable use of resources. In the process of project development, companies need to consider how to reduce excessive consumption of natural resources such as land and water. For example, they can reduce energy consumption by adopting green building design concepts, optimizing the layout and orientation of buildings to improve natural lighting and ventilation, and reducing the use of artificial lighting and air-conditioning systems. Meanwhile, in the selection of building materials, priority should be given to environmentally friendly and renewable materials to reduce the generation of construction waste and pollution of the environment. During the operation phase of the project, an effective waste management and treatment mechanism should be established to collect and treat construction waste and domestic waste in a categorized manner, so as to improve the recycling rate of resources.

Under the current "dual-carbon" strategy and related macro-control policies, real estate enterprises should firstly strengthen their knowledge of ESG concepts in order to deepen their ESG practices. The management should fully realize that ESG is not only the embodiment of social responsibility, but also the key to achieving sustainable development and responding to market changes and policy requirements. By organizing internal training and seminars, all employees should understand the meaning and importance of ESG concepts and integrate ESG awareness into the corporate culture. At the same time, ESG strategy should be deeply integrated with the overall development strategy of the enterprise. ESG objectives and specific measures should be clearly defined in the long-term plan and annual plan of the enterprise, so as to ensure that ESG practices are closely integrated with the business operations and investment decisions of the enterprise. For example, ESG factors such as environmental impact assessment and social responsibility considerations should be included in the planning stage before project development, so as to promote the sustainable development of the project from the source.

6.4.2 Theoretical linkages between ESG practices and Debt financing of real estate firms

In today's economic environment, ESG (Environmental, Social and Governance) concepts have gradually become an important measure of corporate sustainability. For real estate companies, ESG practices are particularly critical as their operations involve a large number of issues such as resource consumption, community impact and internal management. From a theoretical perspective, good ESG practices can convey to the market a company's sustainability and social responsibility. Financial institutions will take ESG factors into consideration when assessing the credit risk of real estate companies. When a company has a high ESG performance, it means that it is able to effectively control carbon emissions and reduce resource wastage in environmental management, actively participate in community building and safeguard the rights and interests of employees in social responsibility, and have a sound internal control and decision-making mechanism in corporate governance. These positive factors will make financial institutions perceive the enterprise as having lower operational and default risks, and thus be more willing to provide debt financing to it, and may offer more favorable financing terms, such as lower interest rates and longer repayment periods.

6.4.3 Status of ESG practices of Chinese real estate enterprises

Currently, Chinese real estate companies have made some progress in ESG practices, but there are still many deficiencies. Some large real estate companies have begun to pay attention to ESG management and publish ESG reports to disclose their environmental, social and governance performance. For example, some enterprises are actively promoting the development of green buildings, adopting environmentally friendly materials and energy-saving technologies, and reducing carbon emissions throughout the life cycle of buildings. In terms of social responsibility, enterprises have also increased their investment in community building and public welfare. However, on the whole, a considerable number of real estate enterprises still do not have a deep enough understanding of ESG practices and lack a systematic ESG management system. Some companies only use ESG as a superficial means of publicity, but do not really integrate it into their strategies and daily operations. On the environmental front, some enterprises still have high energy consumption and high pollution development modes; on the social front, labor disputes and project quality problems occur from time to time; and on the governance front, problems such as imperfect internal control and non-transparent information disclosure still exist.

6.4.4 Strategies to deepen ESG practices to reduce debt financing costs

Based on the above analysis, real estate enterprises should adopt the following strategies to deepen ESG practices and reduce debt financing costs. First, they should strengthen ESG strategic planning, integrate ESG concepts into their overall development strategies, and formulate clear ESG goals and action plans. Secondly, they should strengthen ESG information disclosure, improve the quality and transparency of information disclosure, and convey to the market the image of enterprises actively fulfilling their social responsibilities and focusing on sustainable development. Furthermore, they should invest more in green building technology research and development, community building, and corporate governance to continuously improve their ESG performance. In addition, enterprises should actively communicate and cooperate with financial institutions to understand the requirements and directions of green financial policies, and strive to obtain more green financial support. By deepening ESG practices, real estate enterprises can not only reduce debt financing costs and optimize the credit asset structure, but also enhance their brand image and market competitiveness and achieve sustainable development, thus better meeting the requirements of China's "dual-carbon" strategy and macro-control policies, and contributing to promoting the green transformation and sustainable development of the entire real estate industry. It also contributes to the green transformation and sustainable development of the entire real estate industry.

Through the implementation of the above strategies, real estate companies can deepen ESG practices, reduce debt financing costs, optimize credit asset structure, and make positive contributions to the realization of China's

"dual-carbon" goal while achieving their own sustainable development.

7 CASE STUDIES

7.1 Criteria and Methodology for Case Selection

When studying the sustainable development of Chinese real estate companies in the context of the "dual-carbon" transition, it is important to select typical cases that are representative and useful. In order to ensure that the selected cases fully reflect the current situation, challenges and development path of the industry under the policy-driven environment, we have developed the following detailed criteria and methodology for case selection. In terms of enterprise size, it covers large, medium and small real estate enterprises. Large enterprises usually have stronger financial strength, wider business layout and stronger social influence, and are often able to play a leading role in green transformation, such as Vanke and BGL. They have the ability to invest a lot of resources in green technology R&D and application, and establish a perfect green supply chain system. Medium-sized enterprises have a certain degree of competitiveness and flexibility in the market, and their transformation experience is a direct reference value for many enterprises of the same size. Small-sized enterprises, on the other hand, face more resource constraints and market pressures, and their exploration and attempts in the transformation process can provide ideas for other small-sized enterprises in the industry to cope with the challenges. The geographical distribution of enterprises is also an important consideration. China is a vast country, and there are significant differences in the level of economic development, policy environment and market demand in different regions. The selection of cases from developed eastern coastal regions, central regions and western regions can fully reflect the characteristics and differences of real estate enterprises in different regions in the "dual-carbon" transition. For example, the eastern coastal region is economically developed, with strong policy support and high market acceptance of green real estate, and the enterprises started earlier and developed relatively maturely in green transformation; while the western region may face unique challenges in resource utilization and ecological protection, and the transformation practices of its enterprises are also characterized by regional characteristics. The extent of enterprises' green development practices is one of the key criteria. We will select enterprises with remarkable achievements in green building certification, energy saving and emission reduction measures, green supply chain management, etc., as well as enterprises in the exploratory stage of green transformation and facing various challenges. The former can demonstrate successful experiences and models, while the latter can reveal difficulties and problems in the transition process. Through the study of enterprises with different degrees of practice, it can provide targeted reference for real estate enterprises at different stages of development. In terms of case selection methods, extensive literature research is first conducted to collect industry reports, news reports, academic studies and other information to initially screen the list of enterprises that meet some of the criteria[11]. Then, through the official website of the enterprises, annual reports, sustainability reports and other channels, we further understand the detailed information of the enterprises, including their green development strategies, project practices, technology applications and other aspects. At the same time, combined with the opinions and suggestions of industry experts, the preliminary screened enterprises are evaluated and screened to determine the final typical cases.

7.2 Introduction of Typical Case Companies

As one of the leading companies in China's real estate industry, Vanke has always been a leader in green development. The company put forward its green building development strategy many years ago and is committed to creating high-quality green residential and commercial projects. Up to now, Vanke has developed a large number of green building certified projects in several cities across China, such as Shanghai Vanke Jade Riverside and Shenzhen Vanke Cloud City. These projects have adopted a series of advanced green technologies, such as solar photovoltaic power generation system, ground source heat pump technology, rainwater collection system, etc., which effectively reduce energy consumption and carbon emissions. In terms of green supply chain management, Vanke actively cooperates with suppliers to promote green procurement and sustainable production. The company has formulated strict supplier evaluation criteria and prioritized suppliers with environmental awareness and green production capacity. Vanke also strengthens environmental management at construction sites and promotes green construction techniques to reduce environmental pollution and resource waste during the construction process. In response to the "double carbon" target, Vanke further clarified its carbon reduction target and action plan. The company plans to gradually increase the proportion of green building projects in the next few years, increase the use of renewable energy, and strengthen carbon emission accounting and management. Through these initiatives, Vanke has not only set an example of green development for the industry, but also made positive contributions to the realization of the "double carbon" goal.

Lanson Green Properties focuses on the development of green technology homes with the product concept of "Green, Healthy and Comfortable". The company has independently developed a number of green building technologies, such as constant temperature, humidity and oxygen systems and highly efficient exterior wall insulation systems, to provide residents with a high-quality living environment. Lanson's green residential projects have been widely recognized by the market for their outstanding performance in energy saving, environmental protection and health. In terms of green finance, Lanxess actively explores innovative financing models to provide financial support for green projects. The company has issued green bonds for the development and construction of green building projects. At the same time, Lanson also cooperates with financial institutions to carry out green supply chain finance business to help suppliers solve financing problems and promote the green development of the whole supply chain. In addition, Lanson also

focuses on corporate social responsibility and actively participates in public welfare activities to promote the popularization and dissemination of green building concepts. By organizing green building seminars and conducting green community activities, the company raises public awareness and understanding of green building, creating a good social atmosphere for the sustainable development of the industry.

7.3 Implications of the Cases for the Industry

7.3.1 Enhancing awareness of green transition and building ecosystem aspects

In this case, the enterprise has enhanced the awareness of green transformation among all employees through internal training and external cooperation, so that the green concept runs through all aspects of the enterprise's operation. For the real estate industry as a whole, companies should learn from this experience and make the cultivation of green transition awareness a regular task. Industry associations can organize regular seminars and training courses, invite experts to share the latest green development concepts and trends, and help corporate managers and employees understand the importance and urgency of green transformation[12].

7.3.3 ESG practices and financing aspects

By strengthening ESG practices, the case company improved its ESG rating and thus reduced its debt financing costs. The real estate industry should incorporate ESG practices into its strategic planning and strengthen the management and disclosure of ESG indicators. Industry associations can formulate ESG evaluation standards and guidelines to guide enterprises in ESG practices. Enterprises can improve their ESG performance by improving environmental management, enhancing social responsibility fulfillment, and improving corporate governance.

8 CONCLUSION

This study systematically analyzes the transformation path of China's real estate industry under the synergistic background of the "dual-carbon" strategy and the "housing without speculation" policy, and reveals the dual challenges and opportunities for the industry's low-carbon development. The study finds that the real estate industry is deeply related to the dual-carbon goal, but faces core problems such as the lack of carbon footprint measurement standards, lagging behind in the application of green technologies, increasing financing constraints, and policy adaptation dilemmas. The study proposes a multi-dimensional implementation framework to promote the transformation of the industry by strengthening corporate green awareness, building a carbon-neutral business ecosystem, enhancing carbon accounting capacity through technological innovation, optimizing financing structure by deepening ESG practices, and combining the development of low-carbon building standards and green supply chain management with other policy paths. However, the study is limited by the lack of completeness of carbon emission data, insufficient consideration of regional differences and sample representativeness. In the future, we need to improve the data monitoring system, strengthen the analysis of regional differences, pay attention to the transformation paths of small and medium-sized real estate enterprises, and carry out interdisciplinary research to deepen the theoretical and practical exploration of the economic effects of green technologies, policy incentives, and resource synergistic modes, so as to provide more accurate support for the sustainable transformation of the industry and the realization of the national dual-carbon goal.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ANALYSIS OF DIGITAL MARKETING STRATEGIES FOR CROSS BORDER E-COMMERCE OF HAIR DRYER PRODUCTS

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Abstract: With the rapid expansion of global e-commerce, cross-border e-commerce has become an indispensable link between global consumers and brands. Hair dryer, as a popular product in the field of personal care appliances, continues to have high market demand on cross-border e-commerce platforms. However, in the context of increasingly fierce market competition and diversified consumer demands, traditional marketing methods are no longer able to meet the pace of brand development. Therefore, exploring digital marketing strategies, especially the application of AI digital live streaming in cross-border e-commerce, has become a key path for hair dryer brands to enhance market influence, strengthen consumer interaction, and promote sales.

The beginning of this article provides an overview of the current situation, development trends, and market characteristics of the cross-border e-commerce live streaming market, as well as the market features of hair dryer products. Subsequently, an in-depth analysis was conducted on the core principles, characteristics, and unique advantages of AI digital human live streaming technology in cross-border e-commerce marketing, such as 24/7 live streaming, precise personalized recommendations, seamless cross language communication, and deep emotional interaction. These advantages endow AI digital live streaming with enormous potential in cross-border e-commerce marketing. On this basis, this article takes a well-known brand as an example to analyze in detail how the brand uses AI digital human live streaming strategy to achieve marketing breakthroughs on cross-border e-commerce platforms. Through this case, this article reveals the significant effectiveness of AI digital live streaming in enhancing brand awareness, deepening consumer interaction, and promoting product sales. Specifically, AI digital live streaming has significantly enhanced the awareness and consumer satisfaction of hair dryer brands through vivid imagery, customized product recommendations, real-time consumer interaction, and cross-cultural communication. At the same time, this article also points out the challenges that may be encountered in implementing AI digital human live streaming strategies, including technical barriers, cultural differences, and legal and regulatory restrictions. In response to these challenges, this article proposes targeted solutions, such as increasing technological research and development efforts, optimizing live streaming content design, and enhancing cross-cultural communication skills. Based on the latest developments and trends in the cross-border e-commerce market, this article explores in depth how hair dryer brands can continuously optimize their AI digital live streaming strategies.

Keywords: Cross border e-commerce; Digital human; Hair drier; Digital marketing

1 INTRODUCTION

With the continuous deepening of globalization and digitization, cross-border e-commerce has become a new highlight of global economic development. As an important component of the personal care market, hair dryer products are experiencing a dual driving force of demand growth and consumption pattern changes. The rise of cross-border e-commerce platforms has provided unprecedented opportunities for hair dryer products to cross national borders and reach global consumers. However, traditional e-commerce models face challenges in showcasing product features and enhancing user experience, making it difficult to meet the growing demand for personalization and interactivity. In this context, AI digital live streaming, as an emerging e-commerce marketing tool, is gradually becoming the new favorite for cross-border e-commerce sales of hair dryer products [1]. This technology utilizes artificial intelligence and deep learning techniques to create highly realistic and interactive virtual anchors, providing consumers with immersive and personalized product displays and shopping experiences. AI digital live streaming not only breaks through the limitations of traditional e-commerce models, but also demonstrates enormous potential in enhancing consumer shopping experience and promoting global product sales. Therefore, this study has important theoretical and practical significance and is worth further exploration and excavation.

According to statistics from the General Administration of Customs, China's cross-border e-commerce will develop rapidly in 2023, with total exports exceeding 1.8 trillion yuan, an increase of 19.6%. In 2024, China's cross-border e-commerce imports and exports increased by 10.8% year-on-year. Against the backdrop of rapid expansion in the global cross-border e-commerce market, hair dryer brands are facing the challenge of diminishing effectiveness of traditional marketing strategies [2]. With the innovation of artificial intelligence technology, especially the rise of digital AI and human technology, it has brought revolutionary changes to cross-border e-commerce live streaming. Therefore, researching the digital AI live streaming marketing strategy for hair dryers in cross-border e-commerce aims to explore innovative marketing methods and enhance brand competitiveness. Hair dryer brands can reach a wider international consumer base through cross-border e-commerce platforms, achieving sales growth and brand internationalization expansion. Digital AI live streaming, as an emerging marketing method, perfectly meets the demand of cross-border

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e-commerce platforms for innovative marketing methods. According to data from iMedia Consulting, the expected size of China's cross-border live streaming e-commerce market is 284.58 billion yuan in 2023, with a year-on-year growth rate of 155%. The market size is expected to reach 828.7 billion yuan by 2025 [3].

In the wave of globalization and digital transformation, the research on AI digital live streaming for cross-border e-commerce of hair dryer products has shown unprecedented importance. Firstly, the research and practice of AI digital live streaming for hair dryer products in cross-border e-commerce is not only an innovation in marketing models, but also a reflection of technological progress. It has promoted the continuous development and improvement of cutting-edge technologies such as deep learning, natural language processing, and computer vision, providing strong support for the intelligent transformation of the cross-border e-commerce industry. At the same time, this study also provides a reference example for other industries, promoting the upgrading and transformation of the entire e-commerce industry, and has high reference value. Secondly, the research on cross-border e-commerce AI digital live streaming of hair dryer products not only focuses on current market performance and operational effectiveness, but also on future development trends and strategic directions [4-8]. Through in-depth analysis of key factors such as consumer behavior, market demand, and technological changes, it is possible to predict and seize future market opportunities and challenges, provide strong support for strategic planning and decision-making of enterprises, and promote their long-term development, see Figure 1 and 2.

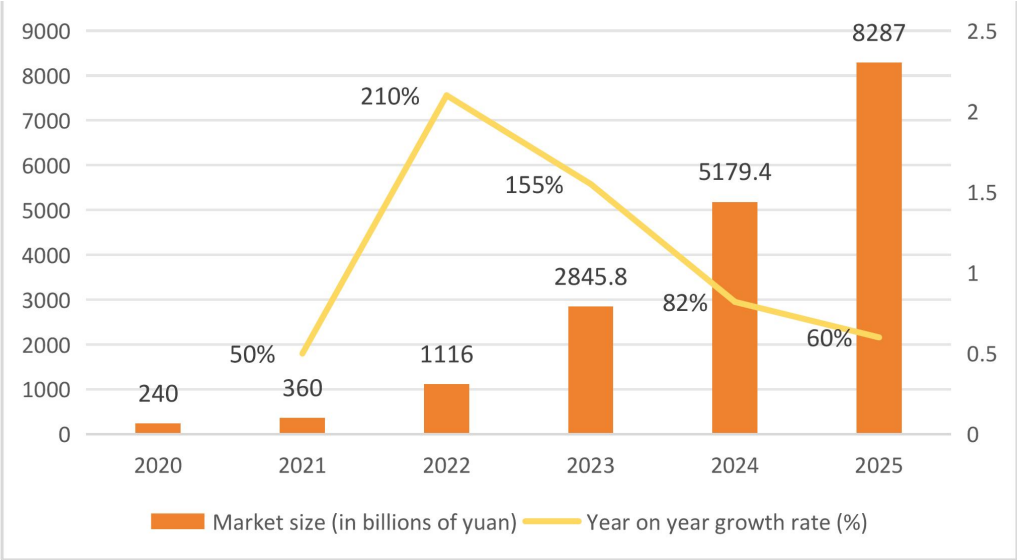

Figure 1: Scale and Forecast of China's Cross broder live Ecommerce Market from 2020 to 2025
Data source: iMedia Data Center

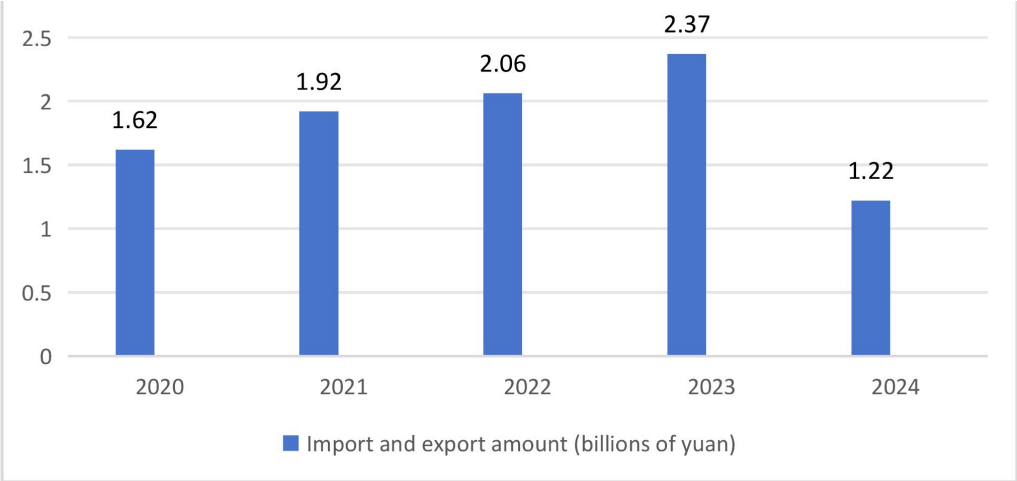

Figure 2: Statistics ofImport and ExportAmount of Cross border E-commerce in China fiom 2020 to 2024
Data source: Compiled by China Customs and China Academy of Commerce Industry Research

1.1 Current Situation of Digital Live Streaming

In China, the market size of AI digital humans continues to expand, indicating that live streaming e-commerce with digital humans is gradually becoming an important force in the field of live streaming e-commerce. This means that digital human technology is undergoing significant growth and transformation, and digital human virtual anchors are now widely used in various scenarios such as e-commerce live streaming, news reporting, exhibition explanations, etc.

The domestic research status of this article mainly focuses on the strategies of digital marketing and the challenges of AI digital live streaming [9].

1.1.1 The strategy of digital marketing

Using digital humans for live streaming activities, presenting realistic appearances, actions, and expressions through high-quality modeling and rendering technology, bringing consumers an immersive shopping experience. For example, on Double Eleven in 2021, the virtual person "ViVi Zihan" livestreamed sales, and the anchor "VIVI Zihan" had 300000 online viewers for the first live broadcast. This live broadcast was the first cooperation between JD International and the leading XR live streaming company Qile Infinite. The entire live broadcast was conducted by the virtual IP anchor "VIVI Zihan" in real-time interaction with the audience in the virtual live room. This innovative marketing approach quickly attracted widespread attention and love from users, and received positive market feedback. Given the success of this initial attempt, JD.com further expanded the application scale of digital live streaming during the subsequent "618" shopping festival. Shanjian Intelligent CEO Huapei used his clone digital person as the "spokesperson" to systematically introduce the 8 major functional highlights and series of the latest cross-border digital person live streaming product Boca Live, including AI digital person anchors and intelligent live interaction, greatly improving live streaming revenue. It is understood that in the internal stage of the system, many cross-border e-commerce sellers have achieved significant results by using digital human live streaming. A user in Nantong, Jiangsu did not have a live streaming team before, but after using BocaLive's AI digital human live streaming function to sell children's clothing on the Shopee platform, they achieved an order growth of over 2000 orders in just one month [10]. Another cross-border e-commerce practitioner in Changsha is a pioneer in exploring Southeast Asian digital live streaming in China. He excels in combining emerging market opportunities with new technologies. He set a single GMV record of up to 300 million Indonesian rupiahs by selling household daily necessities to the Indonesian market on the TikTok platform. These successful cases also fully demonstrate the enormous potential and broad application prospects of digital human technology in modern marketing. At the same time, with the support of AI big model technology, real-time interaction, data analysis, and precise marketing can be achieved, which can reduce core advantages such as human resources, 24/7 live streaming, and achieve multilingual live streaming, greatly improving the efficiency and quality of live streaming.

1.1.2 The challenges of ai digital human live streaming

Liu Xingliang, president of DCCI Internet Research Institute, believes that at present, AI digital human still lack the human touch and affinity and the trust they bring to consumers, which may affect consumers' purchase decisions. Digital live streaming may also involve false advertising, infringement of portrait rights, legal and ethical issues, and require strengthened industry supervision. Through analysis, although there are some shortcomings in digital live streaming, these shortcomings can be gradually overcome by strengthening technology research and development, optimizing algorithm models, improving interactive effects, enhancing creativity and adaptability, and responding to regulatory and legal risks, promoting the healthy development of the digital live streaming industry, see Figure 3.

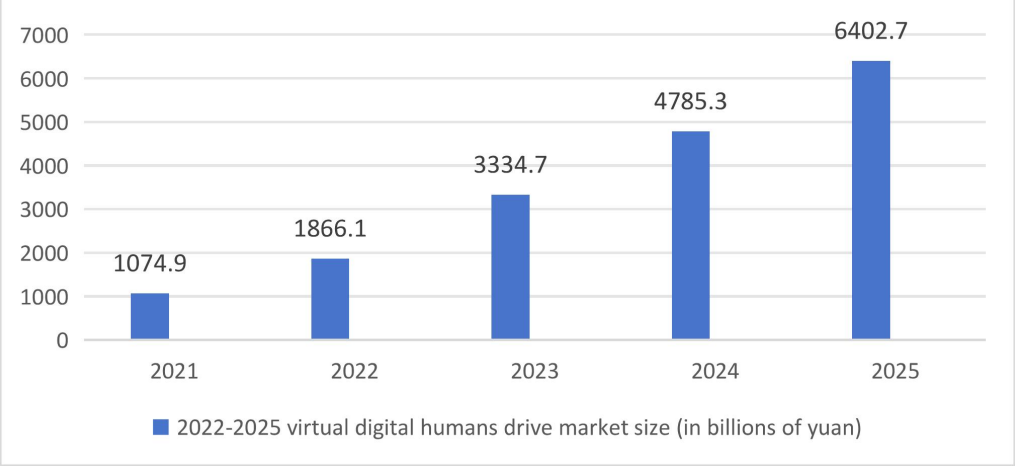

Figure 3: The Scale of China's Virtual Digital Human Market
Data sources: iMedia Data Center, Zhongtai Securities Research Institute

2 ANALYSIS OF DIGITAL MARKETING ENVIRONMENT FOR HAIR BLOWERS

2.1 PEST Analysis

2.1.1 Policy analysis

As one of the core markets for cross-border e-commerce, the North American market is full of potential. The size of the US e-commerce market is expected to continue to grow, providing huge market opportunities for Chinese sellers. The North American market has high requirements for product quality, after-sales service, and localized services, and cross-border hair dryer brands need to focus on improving these aspects. The youthful population structure and strong growth in consumer demand in Southeast Asia have made it an important growth engine for cross-border e-commerce. The e-commerce markets in countries such as Indonesia, Malaysia, and Vietnam are rapidly developing, and

cross-border hair dryer brands can develop targeted marketing strategies by gaining a deep understanding of local market demand and consumer behavior [11-15]. The cross-border e-commerce hair dryer market faces broad international market demand, and combining digital live streaming marketing can attract more overseas consumers and expand the overseas market.

The Chinese government has introduced a series of policy measures to support the development of cross-border e-commerce, such as reducing import tariffs, optimizing cross-border e-commerce tax policies, and strengthening logistics infrastructure construction. These policies provide a favorable development environment for enterprises, reduce operating costs, and enhance their competitiveness. The Chinese government encourages the development of the "cross-border e-commerce+industrial belt" model and supports more traditional industry clusters to go global. This provides an opportunity for the small home appliance industry such as hair dryers to expand overseas markets through cross-border e-commerce platforms, see Figure 4.

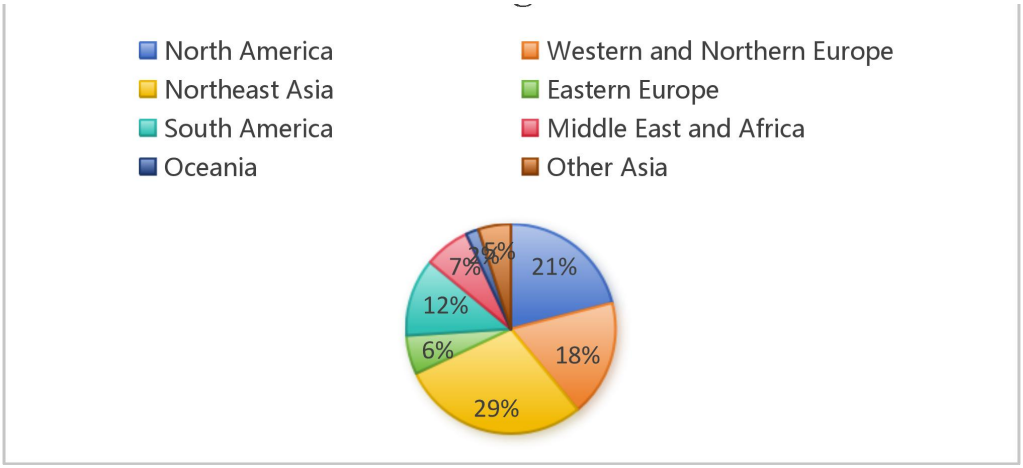

Figure 4: The Contribution Rate of Each Regionalmarket to the Global Market
Data source: China Industry Research Network

2.1.2 Economic analysis

At present, the global economy presents a complex and ever-changing economic situation, but overall world economic growth tends to stabilize, which provides broad development space for the cross-border e-commerce hair dryer market. With the rise of trade protectionism and the increase of international trade frictions, cross-border e-commerce is facing certain challenges. However, the signing of free trade agreements such as the Regional Comprehensive Economic Partnership (RCEP) also provides new opportunities for the development of cross-border e-commerce, and with the development of third-party payments and cross-border logistics, convenient logistics and payment services have been provided for the cross-border e-commerce hair dryer market [16].

2.1.3 Social analysis

The rapid development of domestic e-commerce platforms and live streaming sales has brought new opportunities to the hair dryer market. Digital live streaming, as an emerging live streaming sales model, has attracted a large number of consumers and become a new trend in the field of cross-border e-commerce. The country has also issued a series of policies and regulations on the production and sales of small household appliances, providing good guarantees for the development of the industry. In foreign countries, digital live streaming can break down time zone and language barriers, achieve global live sales and personalized recommendations, attract more overseas consumers to pay attention and purchase hair dryers [17].

With the advent of the digital age, consumers are more inclined to purchase products through online channels, especially cross-border e-commerce platforms. The cultural differences between different countries and regions pose challenges to cross-border digital live streaming marketing. Sellers need to have a deep understanding of the cultural customs and consumption habits of the target market, and develop marketing strategies that are in line with the local market.

2.1.4 Technical analysis

The continuous development and improvement of digital live streaming technology provide technical support for cross-border hair dryer digital live streaming marketing. By utilizing technologies such as deep learning and natural language processing, highly realistic virtual anchor images can be created, enabling 24/7 live streaming and personalized recommendations.

The optimization and upgrading of live streaming technology have improved the viewing experience and interactive effect of cross-border hair dryer digital person live streaming marketing. High definition picture quality, smooth playback and other live streaming technology elements are crucial for attracting consumers and improving conversion rates.

The application of big data analysis technology in cross-border hair dryer digital live streaming marketing is becoming increasingly widespread. By collecting and analyzing user data, enterprises can more accurately understand consumer needs and market dynamics, and develop targeted marketing strategies and product plans.

2.2 SWOT Analysis of Digital Marketing for Hair Dryers

2.2.1 Advantages

Digital live streaming can break down language barriers and achieve multi country and multi language live streaming. Through real-time translation function, consumers around the world can communicate in their own language. At the same time, digital human can live stream 24 hours a day without interruption, breaking the time difference restrictions of different countries and providing consumers with better shopping services. Digital human can also interact with buyers through bullet comments, messages, and other means to answer questions about products and improve the shopping experience.

Compared with traditional live streaming, digital live streaming does not require high salaries, subsidies, and other expenses, greatly reducing the cost of enterprises. As the virtual image of enterprises, digital human can interact with each other in a more professional and friendly way, enhancing brand trust.

2.2.2 Disadvantages

Digital human anchors lack the affinity of real people, making it difficult to establish emotional connections with consumers. For some buyers who require emotional resonance and emotional value, digital live streaming may not be effective. Building AI digital human anchors requires high research and development costs and strong technical support, which increases costs and technical difficulties. Digital influencers may also introduce hair dryers in a way that is not truthful and comprehensive enough, leading to a loss of consumers.

2.2.3 Opportunities

Under the wave of globalization, the cross-border e-commerce market has ushered in a new opportunity for vigorous development. The innovative sales method of digital live streaming has opened the door to the world for cross-border e-commerce enterprises, especially in regions with strong demand for personal care products such as hair dryers, which has been greatly assisted.

Technological innovation and integration, as well as the continuous advancement of cutting-edge technologies such as artificial intelligence and big data, enable digital live streaming to more accurately identify consumer needs, optimize the entire supply chain process, reduce costs, and improve efficiency. Moreover, it can seamlessly integrate with other marketing methods to build a flexible and diverse marketing network, making marketing more three-dimensional and comprehensive.

2.2.4 Threats

During the live streaming process, there may be legal issues related to intellectual property and consumer rights protection. If digital live streaming malfunctions and does not comply with laws and regulations, it may face legal action and fines. Digital humans rely on computer and network technology, which poses risks of network latency and technical failures, leading to screen freezing, live streaming interruptions, etc., affecting consumers' viewing experience and potentially triggering consumer complaints. In addition, digital live streaming still faces challenges in content innovation. How to generate interesting and creative content to attract viewers and maintain their interest is an important issue.

3 ANALYSIS OF THE CURRENT SITUATION OF DIGITAL MARKETING OF HAIR BLOWERS

3.1 Current Marketing Situation of Hair Dryers

3.1.1 Overview of the hair dryer market

In recent years, with the booming development of the global e-commerce market and the increasing demand for personal care appliances from consumers, the cross-border e-commerce hair dryer market has experienced significant growth. Especially in China, as one of the world's largest markets for hair dryer production and consumption, the size of its hair dryer market continues to expand and shows a stable growth trend. On cross-border e-commerce platforms, hair dryers, as an important category of personal care appliances, have seen their sales and revenue increase year by year. Hair dryers have matured in most global markets, creating a retail market worth billions of dollars, see Figure 5.

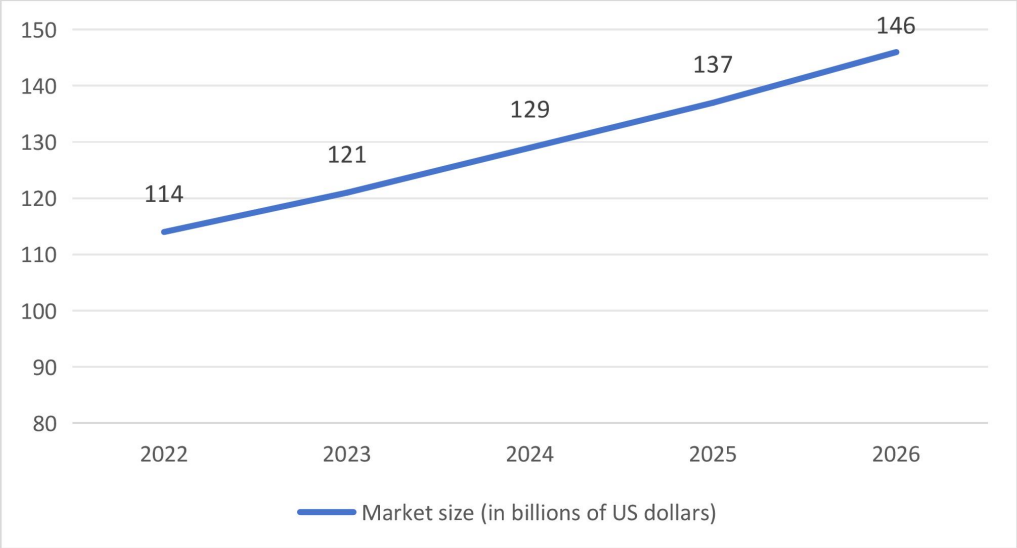

Figure 5: Global Hair Care Appliance Market Size
Data source: China Industry Research Network

3.1.2 Digital marketing status of hair dryers

With the continuous development and improvement of artificial intelligence technology, the technical threshold for digital human live streaming is getting lower and the generation effect is also getting better. The application of digital live streaming in cross-border e-commerce is becoming increasingly widespread and has become an emerging marketing method. Hair dryer brands are using digital human for cross-border live streaming to promote and sell their products. Cross border digital influencers can use multiple languages to automatically learn product language in the live broadcast room, quickly respond to questions raised by users on the public screen, and achieve one-on-one intelligent responses. This highly interactive and efficient live streaming method has attracted a large number of overseas consumers' attention and purchases.

4 PROBLEMS IN DIGITAL MARKETING OF HAIR BLOWERS

4.1 High Technical Threshold and Cost

The digital marketing of hair dryers and live streaming of digital humans require high investment in technology and manpower costs for the development of digital human technology. Currently, there are still some technical limitations in digital human technology, and the high technical costs may exceed the marketing budget, which is difficult for small and medium-sized enterprises to afford.

4.2 According to Safety

Digital marketing requires the collection and processing of a large amount of consumer information and data. Once this information and data are leaked or illegally obtained, it will pose a great threat to consumer privacy. Hair dryer brands need to strengthen data encryption technology to ensure consumer privacy and security.

4.3 User Experience Satisfaction

Although digital humans have the characteristics of vivid imagery and strong customizability, compared to real people, digital humans still lack the ability to feel real and communicate emotions, making it difficult to provide good emotional value. Therefore, some consumers have limited acceptance of digital humans.

4.4 High Market Competition

With the popularization of digital human marketing, more and more brands and sellers are adopting this live streaming method for promotion, which may lead to intensified market competition and the emergence of homogenization, weakening the advantages of digital human marketing.

4.5 SWOT Analysis of Digital Marketing for Hair Dryers

4.5.1 Advantages

Digital live streaming can break down language barriers and achieve multi country and multi language live streaming. Through real-time translation function, consumers around the world can communicate in their own language. At the same time, digital human can live stream 24 hours a day without interruption, breaking the time difference restrictions

of different countries and providing consumers with better shopping services. Digital human can also interact with buyers through bullet comments, messages, and other means to answer questions about products and improve the shopping experience.

Compared with traditional live streaming, digital live streaming does not require high salaries, subsidies, and other expenses, greatly reducing the cost of enterprises. As the virtual image of enterprises, digital human can interact with each other in a more professional and friendly way, enhancing brand trust.

4.5.2 Disadvantages

Digital human anchors lack the affinity of real people, making it difficult to establish emotional connections with consumers. For some buyers who require emotional resonance and emotional value, digital live streaming may not be effective. Building AI digital human anchors requires high research and development costs and strong technical support, which increases costs and technical difficulties. Digital influencers may also introduce hair dryers in a way that is not truthful and comprehensive enough, leading to a loss of consumers.

4.5.3 Opportunities

Under the wave of globalization, the cross-border e-commerce market has ushered in a new opportunity for vigorous development. The innovative sales method of digital live streaming has opened the door to the world for cross-border e-commerce enterprises, especially in regions with strong demand for personal care products such as hair dryers, which has been greatly assisted.

Technological innovation and integration, as well as the continuous advancement of cutting-edge technologies such as artificial intelligence and big data, enable digital live streaming to more accurately identify consumer needs, optimize the entire supply chain process, reduce costs, and improve efficiency. Moreover, it can seamlessly integrate with other marketing methods to build a flexible and diverse marketing network, making marketing more three-dimensional and comprehensive.

4.5.4 Threats

During the live streaming process, there may be legal issues related to intellectual property and consumer rights protection. If digital live streaming malfunctions and does not comply with laws and regulations, it may face legal action and fines. Digital humans rely on computer and network technology, which poses risks of network latency and technical failures, leading to screen freezing, live streaming interruptions, etc., affecting consumers' viewing experience and potentially triggering consumer complaints. In addition, digital live streaming still faces challenges in content innovation. How to generate interesting and creative content to attract viewers and maintain their interest is an important issue.

5 OPTIMIZATION STRATEGIES FOR CROSS BORDER E-COMMERCE DIGITAL MARKETING OF HAIR BLOWERS

5.1. Optimization of Digital Human Live Streaming Strategy

Choose cross-border e-commerce platforms that support digital human technology for live streaming, such as Amazon Live, TikTok Shop, etc. Based on the market and brand of hair dryers, as well as the aesthetic preferences of consumers, customize a personalized anchor image to enhance brand recognition. Digital human anchors should have sufficient professional knowledge to provide detailed information on the performance, functions, and price of hair dryers.

It is also necessary to demonstrate the actual usage effect of the hair dryer. The product can be visually presented through 3D display and other methods, and interactive activities such as lucky draws and lucky bag lucky draws can be designed to retain customers and increase their willingness to purchase [18].

5.2 Optimization of Digital Marketing Strategy

Utilize big data to analyze audience behavior data, including viewing duration, interaction frequency, conversion rate, etc., and adjust live streaming strategies in real-time. Based on user profiles and purchasing preferences, carry out precise marketing push, such as targeted advertising, personalized recommendations, etc.

Regularly update live streaming content to avoid homogenization, such as inviting industry experts for live streaming explanations, hosting themed live streaming events, etc. Plan special live broadcasts based on hot topics and holiday events, such as "Hair Care Festival" and "Hair Dryer Purchase Guide".

Utilize various channels such as social media and short video platforms to preheat and promote digital live streaming, attracting more potential audiences. Collaborate with KOLs or internet celebrities for live streaming linkage to expand brand influence and audience base.

Optimize the settings and interactive elements of the live broadcast room to ensure that viewers can smoothly watch and participate in the live broadcast. Provide high-quality after-sales service and shopping experience, such as quick response to consumer inquiries, convenient return and exchange processes, etc.

5.3 Technical Support and Innovation

Continuously optimizing the image and motion techniques of digital human anchors to enhance realism and interactivity. Introduce more intelligent language synthesis and speech recognition technologies to enhance the language expression ability of digital human anchors.

In addition, explore the application of technologies such as virtual reality (VR) and augmented reality (AR) in live streaming, such as virtual hair dryers and immersive shopping experiences. Utilizing artificial intelligence algorithms for personalized recommendations and intelligent customer service to enhance user experience and conversion rates.

6 CONCLUSION

This article explores in depth the strategies and effects of utilizing digital live streaming as an innovative marketing tool in the hair dryer industry in the context of the digital age. Through systematic case studies, theoretical analysis, and data analysis, this study concludes that the digital live streaming marketing strategy for hair dryers has significant academic value and practical significance in enhancing brand influence, enhancing user interaction experience, promoting product sales, and expanding market scope.

Specifically, digital live streaming provides a new display platform for hair dryer products with its unique virtual image and highly realistic interactive approach. Through precise target market positioning and personalized content planning, digital live streaming can effectively attract the attention of target consumers, enhance brand awareness and reputation. At the same time, the real-time interaction and personalized recommendations of digital human anchors enhance users' sense of participation and experience, promoting the conversion of product sales. In addition, the implementation of digital live streaming marketing strategies for hair dryers also requires comprehensive consideration of multidimensional factors such as user experience, technology platforms, and data optimization. By deeply mining user data, accurately grasping consumer needs, continuously optimizing live streaming content and marketing strategies, and achieving maximum marketing effectiveness.

The implementation of this strategy will help hair dryer companies break through the limitations of traditional marketing models, expand market space, and enhance competitiveness. In the future, with the continuous development of digital technology and the expansion of application scenarios, the digital live streaming marketing strategy for hair dryers will show broader application prospects and practical value, injecting new vitality into the sustainable and healthy development of the hair dryer industry.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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AUTOMATIC PRICING AND REPLENISHMENT MODEL OF VEGETABLE PRODUCTS BASED ON MULTIPLE LINEAR REGRESSION

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Abstract: In fresh supermarkets, the shelf life of vegetable products is often relatively short, and the quality of the product always turns worse over time. In order to achieve the minimum loss and maximum profit, it is crucial for supermarkets to make reasonable replenishment and pricing decisions for the sold vegetable products.Traditional pricing and replenishment strategies are inefficient, making it difficult to accurately control costs and consuming a significant amount of manpower.This article comprehensively processes and analyzes the sales data of a supermarket, establishes a sales price relationship daily replenishment pricing model, and successfully predicts the daily replenishment volume and pricing of the target date. It is hoped to provide a systematic daily replenishment and pricing strategy for supermarket in the sales of fresh vegetables and vegetables, and help supermarket achieve maximum self-interest.
Keywords: Daily replenishment pricing model; Demand price theorem; Multiple regression; Binding item

1 INTRODUCTION

Fresh products are an indispensable necessity in daily life, and people have a great demand for them. Due to the difficulty in preserving fresh products, people tend to purchase them in small quantities multiple times, resulting in some fresh supermarkets that are close to home and at moderate prices being favored by people[1]. Among fresh products, vegetable products play a major role in product sales. The shelf life of vegetable products is generally short, and they often have an immediate nature during the sales process - most varieties cannot be sold the next day if they are not sold on the same day. In order to meet consumers' pursuit of product diversity, supermarkets often sell a wide variety of vegetables, and the purchase transaction time for vegetables is usually from 3:00 to 4:00 in the morning[2-3]. Therefore, merchants often need to make replenishment decisions for each vegetable category on the day without knowing the specific individual product and purchase price.

The traditional pricing method for vegetable products is a subjective cost plus pricing method based on factors such as the color, selling time, and quality of vegetable products by supermarket operators. This type of method not only consumes a lot of energy for supermarket operators, but also makes it difficult for supermarket operators to achieve precise cost control due to unclear purchase prices of goods[4]. The various types of vegetable items make precise pricing even more difficult, ultimately making it difficult for supermarket operators to maximize their own interests.

This article attempts to establish a daily replenishment pricing model based on a multiple linear regression model, taking into account multiple influencing factors such as purchase volume, loss rate, and product type. To help supermarket operators achieve precise pricing of fresh vegetables and vegetables while saving manpower and resources, and improve customer satisfaction; Helping consumers have a diverse selection of product types, obtain reasonable product prices, and ultimately support the high-quality development of fresh agricultural product sales terminals.

2 PROBLEM DESCRIPTION

This article establishes an appropriate mathematical model, under the assumption that supermarkets make replenishment plans based on categories, and first analyzes the relationship between the total sales volume of each vegetable category and cost plus pricing. Based on this, and with the goal of maximizing the revenue of supermarkets, the daily replenishment volume of each category of vegetables in the next week is given.

Using the processed data to analyze the trend of changes in individual product pricing and sales volume, it was determined that there is a linear relationship between pricing and sales. Therefore, a multiple linear regression model was used to solve the problem. We will use data from total sales volume and cost plus pricing to perform multiple linear fitting on the sales volume of various vegetable categories, with total sales volume as the dependent variable and cost and other related variables as independent variables. We will fit the model and predict the total sales volume for the next week,determining the total replenishment amount based on the relationship between total sales and replenishment amount (Total sales=(1-Loss rate) · Replenishment amount).And finally, determine the total replenishment amount and pricing strategy based on the cost plus pricing method.Considering the limited sales space of vegetable products, further development of replenishment plans for individual items is proposed.

3 MODEL ASSUMPTIONS

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Considering that the sales data of supermarkets are greatly influenced by external environmental factors, such as the impact of holidays on the customer flow of supermarkets; The behavior of supermarket operators themselves can also greatly affect sales data, such as supermarket promotional activities, etc; The behavior of different supermarket operators can also have a mutual impact on their sales data; There is also a mutual influence relationship between prices of different items and categories. To study the sales data of supermarkets for three years, due to the limited practical research scope of sales data, and to ensure the rigor and reliability of the model and final results, the following assumptions are made:

(1)The sales data provided by the supermarket for three years is accurate and complete, and there are no duplicate or incorrect records.

(2)The sales data of supermarket in the short term remains stable and will not be affected by certain unexpected factors such as natural disasters.

(3)Market conditions remain stable, the behavior of competitors in supermarkets remains stable, and their pricing strategies and sales plans will not experience significant fluctuations; Consumer preferences and purchasing power remain relatively stable.

(4)The historical sales data of the supermarket can predict the future sales of the supermarket, and the historical sales data can serve as a reference for predicting future sales data.

(5)The sales space of the supermarket will not undergo significant changes in a short period of time, and the sales space of the supermarket is constant for a certain period of time.

(6) Pricing will to some extent affect sales volume. Pricing based on market rules is negatively correlated with sales volume.

(7) Unless there is clear data showing correlation, the correlation between individual items and categories is not considered, and the sales volume of each item and category are treated as independent data.

4 SYMBOL DESCRIPTION

Symbols that used in the article are in the Table 1 below.

Table 1 Symbol Description

Symbol	Description
Q_{ij}	Predict the sales volume of category j on day i,or the sales volume of individual item j on day i.
h_{ij_1}, h_{ij_2}, h_{ij_3}, ..., h_{ij_m}	All independent variables related to category j, including pricing,time, correlation between categories, loss rate, etc.There are m independent variables in total.
b_{j_1}, b_{j_2}, b_{j_3}, ……, b_{j_m},	The model parameters of all independent variables related to i in category j, including pricing, time, correlation between categories, loss rate, etc., totaling m independent variables.
a_j	Model parameters independent of j variety and i
ϵ	Error term of the model
P_{ij}	Pricing of j categories/items on day i
c_{ij}	Cost of category/item j on day i
r_{ij}	Profit margin of category/item j on day i
R_{ij}	Profit of category/item j on day i
γ_j	j category/item loss rate
W_{ij}	Replenishment quantity for category/item j on day i
n	The total number of saleable items

5 ESTABLISHMENT OF A DAILY REPLENISHMENT PRICING MODEL FOR SALES PRICE RELATIONSHIP

5.1 The relationship between total sales volume and cost plus pricing

Before solving this problem, we first introduce the demand theorem in microeconomics. The demand theorem is one of the fundamental theorems in economics, which states that the demand for a commodity varies inversely with its price, while other conditions remain unchanged. Simply put, the higher the price of a product, the fewer people buy it; The

lower the price, the more people will buy. There is a certain correlation between sales volume and cost pricing. Therefore, here we choose the multiple regression prediction method to solve the problem [5-8].
The multiple regression prediction method is a statistical method used to determine the relationship between one or more independent variables and the dependent variable. The following is the form of the relationship:
Set the sales volume of the product as Qij. The basic form of the relationship is:

$$Q_{ij} = a_j + b_{j_1} h_{ij_1} + b_{j_2} h_{ij_2} + b_{j_3} h_{ij_3} \ldots\ldots + b_{j_m} h_{ij_m} + \epsilon \quad (1)$$

·Q_{ij} is the dependent variable (the sales volume we want to predict)

·h_{ij_1}, h_{ij_2}, h_{ij_3}, ..., h_{ij_m} are independent variables (influencing factors, including pricing, time, correlation between categories, loss rate, etc.)

·aj, b_{j_1}, b_{j_2}, b_{j_3}, ……, b_{j_m}, are parameters

·ϵ is error term

To facilitate the solution and avoid over fitting, the expression is simplified.

$$Q_{ij} = a_j + b_{ij} P_{ij} \quad (2)$$

Therefore, only the key value of sales volume Pij is selected for expression. Use the least squares method to determine the various parameters of the model.

5.2 Establishment and Solution of Optimization Model

Due to limitations in the sales space of supermarkets, it is necessary to choose the best sales combination in order to maximize profits. For optimization problems, choose to establish a sales price relationship daily replenishment pricing model for solving. The pricing strategy can be determined by the relationship between sales volume and cost pricing obtained in 5.1, so only sales volume prediction is needed here.
Considering that sales volume will be influenced by multiple factors such as time and wholesale price, a multivariate fitting model will be established using Python. Using the sales volume of vegetable categories as the dependent variable and wholesale prices as the independent variable.
The cost pricing method is based on the cost and profit of goods as support during the pricing process, therefore, it is set:Q_{ij} represents the sales volume of category j on day i, P_{ij} represents the pricing of category j on day i, c_{ij} represents the cost of category j on day i, r_{ij} represents the profit margin of category j on day i, and R_{ij} represents the profit margin of category j on day i. A_j and b_j are constants.

$$Q_{ij} = a_j + b_j P_{ij} \quad (3)$$

The pricing of category j on day i can be expressed as:

$$P_{ij} = (1 + r_{ij}) c_{ij} \quad (4)$$

The profit of category j on day i can be expressed as:

$$R_{ij} = Q_{ij} r_{ij} \quad (5)$$

The total profit of goods is expressed as:

$$R_{total} = \sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij} \quad (6)$$

For constraint conditions, the equation constraint is the equation relationship between sales volume and pricing; The inequality constraint is that all variables are non negative, and the sales volume should be within the range of the historical maximum and minimum, namely:

$$Q_{min} \leq Q \leq Q_{max} \quad (7)$$

In summary, the optimization model is:

$$max\ R_{total} = \sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij} \quad (8)$$

$$s.t.\begin{cases} P_{ij} = a_j + b_j Q_{ij} \\ P_{ij} = (1 + r_{ij}) c_{ij} \\ R_{ij} = Q_{ij} r_{ij} \\ P_{ij},\ Q_{ij},\ R_{ij} \geq 0 \\ R_{ij} \in R \\ \mathrm{i} = 1,\ 2,\ \ldots\ldots \mathrm{n} \\ \mathrm{j} = 1,2,\ldots\ldots \mathrm{m} \\ （\text{Representing different vegetable varieties}） \end{cases} \tag{9}$$

At the same time, provide the relationship between the loss rate and replenishment quantity, assuming the loss rate is γ j. If the replenishment quantity is W_{ij}, then:

$$Q_{ij} = \ （1 - \gamma_j）W_{ij} \tag{10}$$

5.3Establishment of a Model Considering Constrained Items

The revenue of supermarkets is influenced by various factors such as the type of replenishment items, the minimum display quantity of each item, and the amount of product replenishment. Therefore, it is necessary to determine the optimal replenishment quantity and pricing strategy for the optimal product combination under the constraint of the number of item types to maximize the revenue of supermarkets. For optimization problems with multiple influencing factors, multiple regression prediction methods are used, Establish a constrained single item sales price relationship daily replenishment pricing model to solve the problem. In order to establish an optimization model, R_j is measured by r_j and constrained to be within the [0,0.2] interval. The optimization model is used to solve and obtain the optimal solution of the final r_j. On the basis of the previous model, the corresponding functional relations and constraints can be obtained, and the final solution function is as follows:

(1) The relationship between sales volume Q_{ij} and pricing P_{ij} is:

$$Q_{ij} = a_j + b_j P_{ij} \tag{11}$$

(2) The corresponding relationship between pricing P_{ij},cost C_{ij}, and interest r_{ij} rate is:

$$P_{ij} = (1 + r_{ij}) C_{ij} \tag{12}$$

(3) The relationship between profit R_{ij},cost C_{ij}, price P_{ij} and sales Q_{ij} is：

$$R_{ij} = (P_{ij} - C_{ij}) Q_{ij} \tag{13}$$

(4) The corresponding relationship between salesQ_j,loss rateγ_j,and replenishmentW_j is：

$$Q_j = (1 - \gamma_j) W_j \tag{14}$$

(5) The newly added constraint is that the total number of items that can be sold should be between n1 and n2, and the display quantity of each item should be at least x kilograms, taking n as the total number of items.

$$\mathrm{n1} \leq \mathrm{n} \leq \mathrm{n2}$$
$$W_j \geq 2.5$$
$$R_{total} = max \sum_{i=1}^{j} R_j \tag{15}$$

$$s.t.\begin{cases} Q_j = a_j + b_j P_j \\ P_j = (1 + r_j) C_j \\ R_j = (P_j - C_j) Q_j \\ Q_j = (1 - \gamma_j) W_j \\ P_j, Q_j \geq 0 \\ W_j \geq x \\ R_j \in R \\ j = 1,2,3 \ldots\ldots n1 \leq n \leq n2 \end{cases} \tag{16}$$

6 ALGORITHM DESIGN

6.1 Algorithm Design of Total Sales and Cost Plus Pricing Model

(1) Merge sales data and wholesale price data: First, group the sales data by date and item code, and calculate the daily total sales volume.
(2) Check the column names of wholesale price data, redefine column names to match sales data, convert sales date columns to date format, and merge the data again.
(3) Define X (independent variable) and y (dependent variable).
(4) Divide the training and testing sets, fit the multiple linear regression model, and calculate the R ^ 2 value of the model to evaluate the degree of fit of the model.

6.2 Algorithm Design for Optimizing Models

(1) Group sales data by category and statistically describe the sales volume of vegetables in different categories. To make it more intuitive, draw a histogram of the distribution of sales volume.
(2) Draw a box diagram.
(3) Calculate the correlation coefficient between categories, and based on the statistical description of sales volume and the category correlation coefficient matrix, ultimately establish an optimization model for vegetable sales volume.

6.3 Establishment of a Model Considering Constrained Items

(1) Recalculate the slope and intercept of the linear regression model.
(2) Extracting Slope and Intercept from a Linear Model.
(3) Perform the optimization process again.
(4) Ensure that the display quantity of each item is at least x kilograms.
(5) Obtain the optimized cost profit margin and establish an optimization model that considers constrained individual products. Calculate the expected sales volume and pricing strategy for each product based on the optimized cost-profit margin.

7 MODEL ANALYSIS AND SOLUTION

7.1 Daily Replenishment Volume and Pricing Strategy for Each Category of Vegetables in the Next Week

This article establishes an appropriate mathematical model, under the assumption that supermarkets make replenishment plans based on categories, and first analyzes the relationship between the total sales volume of each vegetable category and cost plus pricing. Based on this, and with the goal of maximizing the revenue of supermarkets, the daily replenishment volume and pricing strategy for each category of vegetables in the next week, from July 1 to 7, 2023, are given.
Set the sales volume of the product as Q_{ij} and only select the key value of sales volume P_{ij} to represent it. Using the least squares method, calculate the various parameters of the model, and the results are shown in the table below. Table 2 to Table 7 represent the parameters of cauliflower, eggplant, mosaic, chili, edible fungi, and aquatic rhizomes, respectively.

Table 2 The Result of Cauliflower

	B	Standard Error
a_j	20.94	2.19
b_j	-15.68	3.47

Table 3 The Result of Eggplant

	B	Standard Error

a_j	13.27	0.96
b_j	-8.33	1.60

Table 4 The Result of Mosaic

	B	Standard Error
a_j	12.08	0.60
b_j	-0.59	0.69

Table 5 The Result of Chili

	B	Standard Error
a_j	9.51	0.91
bj	-3.62	1.91

Table 6 The Result of Edible Fungi

	B	Standard Error
a_j	10.00	1.02
b_j	-3.83	1.83

Table 7 The Result of Aquatic Rhizomes

	B	Standard Error
a_j	13.83	0.82
b_j	-10.99	1.72

Based on historical data, predict the sales volume and pricing strategy of each individual product from July 1st to July 7th, 2023. The pricing strategy can be obtained from the relationship between the sales volume and the cost pricing obtained from the previous model, so only the sales volume can be predicted here.

Considering that sales volume is influenced by multiple factors such as time and wholesale price, combined with existing data from the previous three years and the conclusion drawn from the first question, a multivariate fitting model is established using Python.

Using the sales volume of vegetable categories as the dependent variable and wholesale prices as the independent variable. Firstly, the aquatic rhizome category is selected as an example for the above analysis, and then the predicted sales results of the aquatic rhizome category in the next week are given, as shown in the Table 8 below.

Table 8 The predicted sales results of the aquatic rhizome category in the next week

Time	Sales volume（kg）
2023/7/1	18.95
2023/7/2	16.32
2023/7/3	17.17
2023/7/4	16.73
2023/7/5	18.61
2023/7/6	18.40
2023/7/7	18.49

The cost pricing method is supported by the cost and profit of the goods during the pricing process, and determines the pricing of the goods through this relationship. For constraint conditions, the equation constraint is the equation relationship between sales volume and pricing; The inequality constraint is that all variables are non negative, and the sales volume should be within the range of historical maximum and minimum quantities. Based on the established model, the daily replenishment volume and pricing strategy for each vegetable category in the next week are obtained, as shown in the Table 9 and Table 10 below.

Table 9 The Replenishment Volume and Pricing Strategy for each Vegetable Category

	Cauliflower		Mosaic		Chili	
Date	Total daily replenishment（kg）	Pricing strategy(%)	Total daily replenishment（kg）	Pricing strategy (%)	Total daily replenishment（kg）	Pricing strategy (%)
2023-07-01	53.35	50.06%	211.46	33.25%	75.14	75.14%
2023-07-02	20.12	25.25%	260.46	27.43%	108.96	108.95%
2023-07-03	41.15	50.15%	261.42	42.88%	109.55	109.55%
2023-07-04	39.27	87.36%	164.15	20.38%	43.09	43.09%
2023-07-05	50.92	41.12%	262.48	91.23%	110.03	110.02%
2023-07-06	31.45	39.27%	260.47	38.74%	108.93	108.92%
2023-07-07	29.18	52.17%	203.12	55.48%	70.09	70.08%

Table 10 The Replenishment Volume and Pricing Strategy for each Vegetable Category

	Eggplant		Edible fungi		Aquatic rhizomes	
Date	Total daily replenishment（kg）	Pricing strategy (%)	Total daily replenishment（kg）	Pricing strategy (%)	Total daily replenishment（kg）	Pricing strategy (%)
2023-07-01	9.79	96.00%	65.20	33.06%	18.95	84.08%
2023-07-02	8.73	41.80%	66.91	100.03%	16.32	44.21%
2023-07-03	5.62	64.84%	31.85	107.01%	17.17	88.24%
2023-07-04	10.84	105.51%	49.31	86.00%	16.73	32.74%
2023-07-05	3.30	95.34%	46.76	92.50%	18.61	52.91%
2023-07-06	6.62	109.11%	58.33	91.30%	18.40	33.92%
2023-07-07	6.15	84.10%	61.97	62.41%	18.49	38.11%

7.2 Replenishment and Pricing Strategy for Vegetable Items on July 1st

Considering the limited sales space of vegetable products, it is required to provide a further replenishment plan for each item. Specifically, this article requires a replenishment quantity and pricing strategy for each item on July 1 based on the available varieties from June 24 to 30, 2023, and provides conditional constraints. The constraints are as follows:

(1) Control the total number of items that could be sold between 27 and 33;
(2) The minimum order quantity for each item should meet the display quantity of 2.5kg;
(3) Try to meet the market's demand for various types of vegetable products;
(4) The supermarket has the highest revenue.

On the basis of the established model that considers the constraint of individual products, during the process of substituting data for solving, it was found that the data for June 2023 was partially missing. Considering the accuracy of the results, the data from May 2023 was used as a substitute. Based on expected profits, 30 items with the highest expected profits were selected and a model was established using Python. The final results are shown in the Table 11. below.

Table 11 Replenishment and Pricing Strategy for Vegetable Items on July 1st

Number	Replenishment	Price
01	226.00	3.95
02	150.00	3.39
03	149.00	3.32
04	133.00	1.85
05	99.60	3.70
06	93.00	4.56
07	87.90	11.43
08	79.00	3.77
09	79.00	2.15
10	76.30	4.88
11	73.00	5.47
12	70.00	4.10
13	62.50	3.52
14	62.00	2.45
15	49.00	3.78
16	49.00	2.99
17	47.90	7.85
18	45.00	3.01
19	42.20	8.05
20	41.50	5.25
21	34.30	3.54
22	32.40	18.58
23	31.50	5.44
24	29.50	9.08
25	28.20	21.15

8 CONCLUSION

(1) By solving the model, we found that compared from a category perspective: the total sales of flowers and leaves are the largest and significantly higher than other types; The total sales volume of eggplants is the smallest; The total sales volume of chili peppers and fungi used is relatively close; Finally, the total sales of cauliflower and aquatic rhizomes are basically the same. The pricing strategies of the same category on different dates often have significant fluctuations. Taking aquatic rhizome vegetables as an example, the standard deviation of the pricing strategy from July 1 to 7, 2023 is 23.38037, indicating that there is significant fluctuation in the pricing of aquatic rhizome vegetables within a week.

(2) This article analyzes sales data and establishes appropriate mathematical models to develop a daily replenishment plan and pricing strategy for the supermarket, in order to maximize the revenue of the supermarket and meet the

demand of consumers for various types of vegetables. Therefore, the purpose and significance of this article are from the perspectives of both enterprises and consumers.

(3) From the perspective of enterprises, developing a reasonable daily replenishment plan and pricing strategy can improve sales efficiency, better grasp the sales situation and market demand of vegetable products, timely replenish goods, avoid inventory backlog or shortage, control costs, and ultimately achieve benign pricing of products and improve profit margins. At the same time, better meet customer needs, ensure sufficient supply of goods and reasonable prices, and improve customer shopping experience and satisfaction.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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IMPACT OF FINANCIAL TECHNOLOGY ON ENTERPRISES' GREEN INNOVATION PERFORMANCE--BASED ON CHINESE A-SHARE LISTED COMPANIES

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Abstract: Based on the microdata of Chinese A-share listed companies from 2009 to 2023, this paper explores the impact of FinTech on the green innovation performance of enterprises and its mechanism of action. It is found that FinTech significantly enhances firms' green innovation performance, as evidenced by the increase in the number of green patent applications and patent citations, indicating that FinTech has a positive role in promoting both the quantity and quality of green innovation. Further analysis shows that the enhancement of financing constraints will weaken the positive impact of FinTech on green innovation performance. In contrast, enterprise green concern mediates between FinTech and green innovation performance. In addition, the promotional effect of FinTech on green innovation performance is more significant in SOEs, manufacturing industries, and the eastern region. The research in this paper provides empirical evidence for FinTech to promote green innovation and provides a reference for policymakers to optimize the institutional environment for FinTech to support green innovation.
Keywords: FinTech; Green innovation performance; Financing constraints; Green concern

1 INTRODUCTION

The rapid emergence and evolution of financial technology has become a vital factor in helping companies achieve sustainable development. Its impact on the innovation and performance of green businesses has been acknowledged by the public. At present, China's corporate green innovation is in the process of rapid development and significant change, from the traditional high energy consumption, high pollution production model to the green innovation-driven path of sustainable development, not only to deal with the external environmental regulations tightening and social pressure but also enterprises in the fierce market competition to achieve differentiated advantages, the inherent need to open new market space.

Achieving eco-friendly innovation faces numerous challenges, as the inherent features of elevated expenses and substantial uncertainties often discourage businesses from voluntarily engaging in sustainable development practices[1]. This is reflected in the long green investment research and development cycle and information asymmetry. The flourishing development of the new financial technology industry under the wave of digitalization, such as big data, AI and blockchain technology, provides an effective solution to break the multiple shackles of green innovation financing limitations, transformation pressure and risk loss[2].

The outcomes of corporate green innovation encompass the holistic results attained in terms of financial gains, ecological impact, and societal contributions through sustainable innovation initiatives[3]. Existing research indicates that assessing green innovation effectiveness requires a dual approach, incorporating both measurable metrics (such as the volume of eco-friendly patents filed and granted) and qualitative indicators (like the frequency of citations for green patents and related references). This combined framework provides a thorough representation of a company's achievements in sustainable innovation efforts[4].

The impact of FinTech on firms' green innovation performance is a complex and multidimensional research area. Existing literature has explored the facilitating effect of FinTech on green innovation and its potential constraints from both positive and negative aspects. FinTech can significantly contribute to the development of green finance by enhancing the efficiency of financial services, alleviating information asymmetry[5] and financing constraints[6], optimizing risk allocation, increasing the intensity of R&D investment and improving corporate ESG performance[7]. At the same time, existing research has also found that FinTech can increase operational costs and liquidity risks for firms, as well as using FinTech to "Greenwashing" the environment and neglect actual green innovation initiatives[8].

This study examines the influence of financial technology on green innovation outcomes by categorizing it into qualitative and quantitative dimensions, filling gaps in current research. It analyzes the mediating effect of funding limitations and the role of corporate environmental awareness, uncovering detailed mechanisms through which FinTech drives sustainable innovation. Additionally, analyzing heterogeneity across property rights, regions, and industries refines the differentiated impacts of FinTech, offering policy insights for FinTech development, "dual-carbon" goal implementation, and green business cultivation.

2 RESEARCH HYPOTHESES

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Enterprise green innovation activities usually require long-term investment, face high risks and are irreversible. These characteristics make green innovation activities particularly vulnerable to changes in enterprises' internal management capacity and the external environment[9,10]. FinTech promotes green innovation through various mechanisms, including reducing information asymmetries, easing financing constraints and increasing willingness to invest in innovation[11]. FinTech utilizes big data and artificial intelligence to accurately identify and assess the value and risk of green projects, helping financial institutions understand corporate environmental performance while making it less challenging to finance green innovations. In addition, FinTech enhances environmental management capabilities through digital monitoring and real-time data analysis, optimizing production processes to reduce waste and emissions[12]. It also stimulates green innovation by raising awareness of environmental responsibility and enables efficient access to external knowledge resources[13], promoting interdisciplinary exchange and collaborative innovation[6]. Consequently, this study puts forward the following hypothesis:

H1: Financial technology significantly enhances the green innovation outcomes of businesses.

Financing constraints significantly inhibit green innovation, especially in highly polluting industries. Green credit policies may exacerbate these constraints by increasing the cost of finance and credit thresholds, leading firms to prioritize traditional business over green innovation[14,15]. High financing constraints can undermine the effectiveness of FinTech in mitigating information asymmetries and reducing financing costs[16-18]. As a result, this study proposes the following hypothesis:

H2: The enhancement of financing constraints weakens the positive effect of firms' FinTech level on green innovation performance.

By increasing enterprises' green focus, FinTech promotes incorporating environmental responsibility into their strategic decision-making, thereby contributing to improving green innovation performance. The growing emphasis on environmental sustainability drives companies to allocate more resources toward eco-friendly technology R&D and sustainable operations, enhancing resource efficiency and fostering the creation of greener products with stronger market appeal[19]. At the same time, the increase in green concern helps enterprises obtain policy support, market opportunities, and brand image advantages, forming a positive cycle and ultimately realizing a win-win situation for both economic and environmental benefits[20]. Therefore, this paper proposes the following hypothesis:

H3: FinTech enhances green innovation performance by increasing firms' green focus.

3 RESEARCH DESIGN

3.1 Sample Selection and Data Sources

This study utilizes A-share listed firms from the Shanghai and Shenzhen stock exchanges as the sample, covering the period from 2009 to 2023. Due to the different listing times of each company, the panel data used is an unbalanced panel. The data on green invention patents of listed companies and citations are from the China Intellectual Property Website; the data on FinTech development are from the annual reports of each company's enterprise; and the data on enterprise-level control variables are from the data collated from CSMAR and Wind. According to the existing studies, this paper deals with the sample data as follows: firstly, the data of listed companies that have been delisted before listing are excluded; secondly, companies labeled as ST, ST*, or PT are removed from the sample; thirdly, firms with significant missing data for key variables are also excluded; and fourthly, logarithmic treatment and shrinking treatment are adopted for some indicators.

3.2 Variable Setting

Here, this study discusses the rationale behind the selection and construction of the explained variable, explanatory variable, and control variables. Firstly, this study uses green innovation performance (GreenInnovation) as an explained variable and measures it from both quantitative and qualitative dimensions. In the quantitative dimension, the number of green patent applications (PatentApply) is used as a proxy variable for green innovation performance, and this metric effectively captures the level of innovative output achieved by companies in their eco-friendly technology research and development efforts. In terms of quality dimension, it is measured by the logarithmic value of patent citations (Cite), which can reflect the technological influence and knowledge diffusion effect of green innovation achievements.

Secondly, the financial technology development level (FinTech) is used as an explanatory variable. This research adopts the machine learning approach proposed by Huang, Huang and Yang [21] to analyze the frequency of 124 FinTech-related terms in listed companies' annual reports, encompassing six areas such as artificial intelligence, blockchain, cloud computing, big data, and online/mobile technologies. The extracted data is then log-transformed to determine the annual FinTech development level of these firms.

The following variables were selected as the control variables: firm size, firm age, return on assets, Herfindahl index, gearing ratio, cash holdings, and percentage of independent directors based on other corporate green innovation performance studies.

3.3 Model Setting

In order to empirically test the effect of financial technology on the green innovation performance of enterprises, the following fixed effect model is specifically constructed, as shown in equation (1):

$$GreenInnovation = \alpha_0 + \alpha_1 F\,\text{int}\,ech + \alpha_2 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Where $Control_{i,t}$ is a control variable, μ_i is an individual fixed effect, λ_t is a time-fixed effect, and $\varepsilon_{i,t}$ is a random perturbation term incorporating the remaining unobservables in the model.

4 Empirical Analysis

4.1 Benchmark Regression

Table 1 displays the baseline regression outcomes examining FinTech's influence on corporate green innovation performance, incorporating firm and time-fixed effects with clustered standard errors. Columns (1) and (2) reveal that FinTech notably boosts the volume of green innovation (PatentApply) at the 1% significance level, with findings remaining consistent even after adding firm-level controls. Columns (3) and (4) substitute the dependent variable with green patent citations (Cite), demonstrating that FinTech also significantly improves the quality of green innovation at the 1% level, irrespective of control variables. These outcomes indicate that FinTech fosters green investment and R&D incentives by optimizing resource allocation and providing technical assistance, enhancing both the volume and quality of green innovation. In summary, the results support the conclusion that FinTech significantly enhances green innovation performance, confirming Hypothesis 1.

Table 1 Benchmark Regression

	(1) PatentApply	(2) PatentApply	(3) Cite	(4) Cite
FinTech	0.892***	0.437***	0.183***	0.030***
	(0.059)	(0.067)	(0.003)	(0.004)
Age		0.060***		0.028***
		(0.017)		(0.001)
HHI		-0.990*		-0.107***
		(0.406)		(0.025)
Debt		0.042		0.014***
		(0.047)		(0.003)
ROA		-0.057		-0.018***
		(0.056)		(0.004)
Cash		1.375**		-0.324***
		(0.428)		(0.027)
Size		0.453***		0.138***
		(0.090)		(0.006)
Indep		2.250**		1.042***
		(0.723)		(0.045)
_cons	-0.938***	-11.502***	-0.113***	-3.359***
	(0.183)	(1.803)	(0.008)	(0.113)
N	58336	46988	58330	46986

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

4.2 Endogeneity Analysis

Although the benchmark regression shows that FinTech significantly promotes corporate green innovation, endogeneity issues such as omitted variables or reverse causality may exist. The Durbin-Wu-Hausman test results (p = 0.0183) reject the exogeneity hypothesis, confirming the need for an instrumental variable (IV) approach. To address this, Internet penetration (Internet) is used as an IV for FinTech development, following Ding, Jin and Tian [22]. As Table 2 shows that the first-stage regression shows a significantly positive correlation between Internet penetration and FinTech ($p < 0.01$), with an F-statistic of 10406.73, ruling out weak instrument concerns. The second-stage results indicate that FinTech remains significantly positive ($p < 0.01$) for both green patent applications (PatentApply) and citations (Cite) after controlling for endogeneity. Overall, the IV approach robustly validates FinTech's positive impact on corporate green innovation.

Table 2 Endogeneity Analysis

	(1) FinTech	(2) PatentApply	(3) Cite

Internet	5.144***		
	(0.050)		
FinTech		0.579***	0.105***
		(0.140)	(0.007)
_cons	1.744***	0.181	3.810***
	(0.017)	(0.480)	(0.025)
Controls	Yes	Yes	Yes
N	44329	44329	42881

4.3 Robustness Analysis

(1) Replacement of explained variables. For the quantity dimension, the number of green patents obtained (PatentGet) replaces green patent applications (PatentApply); for the quality dimension, the number of patents cited by others (OtherCite) replaces the number of citations (Cite). Table 3 shows that FinTech's regression coefficients remain significantly positive ($p < 0.01$) for both PatentGet (columns 1-2) and OtherCite (columns 3-4), confirming FinTech's significant contribution to both the quantity and quality of green innovation. These results robustly support the benchmark findings.

(2) Replacement of explanatory variables. This paper replaces the FinTech measure with the Peking University Digital Financial Inclusion Index of China (PKU_DFIIC, Digitalization), which reflects regional FinTech development at the municipal level. Columns (5)-(8) of Table 3 show that Digitalization's regression coefficients are significantly positive ($p < 0.01$ or $p < 0.05$) for both green patent applications (PatentApply, columns 5-6) and citations (Cite, columns 7-8), confirming that regional FinTech development significantly enhances both the quantity and quality of green innovation. These findings further reinforce the reliability of FinTech's beneficial influence on green innovation outcomes.

Table 3 Robustness Analysis

	(1) PatentGet	(2) PatentGet	(3) OtherCite	(4) OtherCite	(5) PatentApply	(6) PatentApply	(7) Cite	(8) Cite
FinTech	0.484***	0.182***	0.184***	0.036***				
	(0.025)	(0.043)	(0.003)	(0.004)				
Digitalization					0.011***	0.004*	0.002***	0.004***
					(0.001)	(0.002)	(0.000)	(0.000)
_cons	-0.449***	-7.863***	-0.146***	-3.119***	-0.516	-12.559***	0.113***	-2.312***
	(0.078)	(1.159)	(0.008)	(0.110)	(0.264)	(2.791)	(0.010)	(0.159)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	58336	46988	58330	46986	40187	33593	40184	33592

(3) Principal Component Analysis. To further test robustness, this study employs principal component analysis (PCA) to create a composite green innovation performance metric (PC1) based on four variables: PatentApply, PatentGet, Cite and OtherCite. Table 4 shows that FinTech's regression coefficient is significantly positive ($p < 0.01$) for PC1, both with and without firm-level controls, confirming FinTech's significant contribution to green innovation performance. The PCA results further validate the robustness of the findings.

Table 4 Principal Component Analysis

	(1) PC1	(2) PC1
FinTech	0.195***	0.048***
	(0.005)	(0.007)
_cons	-0.640***	-5.517***
	(0.017)	(0.212)
Controls	No	Yes
N	46105	38884

5 FURTHER ANALYSIS

5.1 Moderating Effect

In this study, we aim to investigate the moderating effect of financing constraints (SA) between the level of FinTech development (FinTech) and the number of green patent applications (PatentApply), and the model is set up as shown in equation (2):

$$GreenInnovation = \alpha_0 + \alpha_1 F\text{int}ech + \alpha_2 F\text{int}ech \times SA + \alpha_3 SA + \alpha_4 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

Variables are centered to simplify interaction effects and reduce multicollinearity. Table 5 shows that the interaction term Fin_SA_center is significantly negative at the 5% level in column (2) and the 10% level in column (4), indicating that FinTech's positive impact on green patent applications and citations weakens under high financing constraints. This suggests that while FinTech enhances green innovation, its effect is dampened when firms face significant financial limitations, as constrained access to finance hinders their ability to translate FinTech advantages into actual innovations. H2 is supported.

Table 5 Moderating Effect

	(1) PatentApply	(2) PatentApply	(3) Cite	(4) Cite
FinTech	0.437***		0.030***	
	(0.067)		(0.004)	
FinTech_center		0.468***		0.030***
		(0.068)		(0.004)
SA_center		-12.247***		-0.668***
		(0.552)		(0.032)
Fin_SA_center		-0.450**		-0.015
		(0.143)		(0.008)
_cons	-11.502***	-18.856***	-3.359***	-3.951***
	(1.803)	(1.889)	(0.113)	(0.106)
Controls	Yes	Yes	Yes	Yes
N	46988	47027	46986	53530

5.2 Mediating Effect

Based on the analysis of the theoretical mechanism in the previous section, enterprises' green concerns are chosen as the mediating variable. The mediation effect model clarifies the role of financial technology development on enterprises' green innovation performance. Equations (3) and (4) show the specific model setting.

$$GreenAttention = \alpha_0 + \alpha_1 F\text{int}ech + \alpha_2 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

$$GreenInnovation = \alpha_0 + \alpha_1 F\text{int}ech + \alpha_2 GreenAttention + \alpha_3 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

Table 6 shows that corporate GreenAttention significantly mediates the relationship between FinTech development and green patent applications. Columns (2) and (5) reveal a strong positive correlation between FinTech development and GreenAttention. Columns (3) and (6) indicate that when both variables are included, FinTech's direct impact weakens, while GreenAttention plays a partial mediating role, suggesting FinTech indirectly promotes green innovation by increasing corporate green concern. A 500-time bootstrap test confirms the mediating effect's significance at the 5% level, supporting the hypotheses and highlighting the key role of GreenAttention in this process.

Table 6 Mediating Effect

	(1) PatentApply	(2) GreenAttention	(3) PatentApply	(4) Cite	(5) GreenAttention	(6) Cite
FinTech	0.437***	25.498***	0.380***	0.030***	25.498***	0.024***
	(0.067)	(0.656)	(0.068)	(0.004)	(0.656)	(0.004)
GreenAttention			0.002***			0.000***
			(0.000)			(0.000)
_cons	-11.502***	-623.083***	-10.108***	-3.359***	-623.083***	-3.204***
	(1.803)	(17.680)	(1.829)	(0.113)	(17.680)	(0.115)
Controls	Yes	Yes	Yes	Yes	Yes	Yes

N	46988	46988	46988	46986	46988	46986

5.3 Heterogeneity Analysis

To examine the heterogeneous impact of FinTech on green innovation performance, this paper analyzes differences by property rights, industry, and region.

(1) Property Rights Heterogeneity: In Table 7, columns (1) and (3) are non-state-owned enterprises, and columns (2) and (4) are state-owned enterprises. FinTech significantly promotes green innovation in both state-owned enterprises (SOEs) and non-SOEs, with SOEs showing a more substantial effect. This is attributed to SOEs' richer resources, stable financial support, and greater focus on long-term development and social responsibility, often backed by government policies.

(2) Industry Heterogeneity: In Table 7, columns (5) and (7) are non-manufacturing industries, and columns (6) and (8) are manufacturing industries. FinTech positively impacts green innovation in both manufacturing and non-manufacturing industries, with a more pronounced effect in manufacturing. Manufacturing firms face more tremendous environmental pressures and have more mature technological foundations, enabling them to integrate FinTech more effectively for green innovation, often supported by government policies.

Table 7 Property Rights and Industry Heterogeneity

	(1) PatentApply	(2) PatentApply	(3) Cite	(4) Cite	(5) PatentApply	(6) PatentApply	(7) Cite	(8) Cite
FinTech	0.403***	0.688***	0.099***	0.160***	0.335***	0.632***	0.076***	0.126***
	(0.027)	(0.085)	(0.004)	(0.007)	(0.054)	(0.041)	(0.005)	(0.004)
_cons	-30.935***	-34.958***	-4.389***	-5.220***	-15.084***	-57.454***	-3.262***	-6.966***
	(3.825)	(3.603)	(0.126)	(0.147)	(2.486)	(5.144)	(0.130)	(0.127)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	27059	17979	27058	17978	16454	30534	16454	30532

(4) Regional Heterogeneity: In Table 8, columns (1) and (4) are the central region, columns (2) and (5) are the western region and columns (3) and (6) are the eastern region. FinTech significantly enhances green innovation in eastern, central, and western regions, with the most potent effect in the eastern region. The eastern region benefits from more developed financial markets, better FinTech infrastructure, higher environmental standards, and incredible policy support and financial investment.

Table 8 Regional Heterogeneity

	(1) PatentApply	(2) PatentApply	(3) PatentApply	(4) Cite	(5) Cite	(6) Cite
FinTech	0.336***	0.433***	0.631***	0.101***	0.119***	0.113***
	(0.058)	(0.072)	(0.047)	(0.008)	(0.009)	(0.004)
_cons	-19.387***	-16.837***	-41.459***	-4.233***	-3.645***	-5.132***
	(2.460)	(2.655)	(3.876)	(0.192)	(0.215)	(0.114)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	7840	6177	32742	7840	6177	32740

6 CONCLUSION AND DISCUSSION

FinTech significantly enhances green innovation by improving financing efficiency, risk management, and resource allocation. Due to its resource advantages, technological maturity, and policy support, its impact is more pronounced in state-owned enterprises, manufacturing industries, and the eastern region.

To promote green innovation through FinTech, it is essential to increase investment in technologies like big data, AI, and blockchain to enhance financing efficiency and risk management for green projects, while encouraging financial institutions to develop tailored products. Additionally, optimizing the institutional environment by strengthening legal frameworks and fostering collaboration among financial institutions, tech firms, and green enterprises is crucial. Finally, creating a supportive policy environment through targeted FinTech policies for different enterprises, industries, and regions, and promoting industry-university-research collaboration, will further advance FinTech applications in green innovation.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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AN ECONOMIC ANALYSIS OF THE IMPACT OF DIGITAL ECONOMY DEVELOPMENT ON THE INHERITANCE OF JIAMA WOODBLOCK PRINTING

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Abstract: With the rapid development of the digital economy, the protection and transmission of intangible cultural heritage (ICH) have encountered both new opportunities and challenges. This paper focuses on Jiama woodblock printing, a traditional carrier of folk culture, and explores the impact mechanisms of digital economy development on its inheritance through a questionnaire-based empirical study. The research findings indicate: first, the development of the digital economy significantly promotes the inheritance of Jiama woodblock printing; second, such promotion occurs through enhancing the dissemination of Jiama art and expanding its audience base. Based on these findings, the paper proposes several strategies: deep integration of digital technologies with ICH, improved digital literacy training for inheritors, and the establishment of a government-led, multi-stakeholder support mechanism. These measures aim to achieve the dynamic inheritance and sustainable development of Jiama woodblock printing. This study expands the research perspective on the empowerment of ICH protection by the digital economy and provides both theoretical insights and practical references for addressing intergenerational transmission gaps and enhancing market competitiveness.
Keywords: Digital economy; Intangible cultural heritage; Jiama woodblock printing inheritance; Mediation effect

1 INTRODUCTION

1.1 Research Background

In recent years, China's digital economy has grown rapidly, permeating sectors such as finance, education, and cultural dissemination. Technologies like big data, cloud computing, and the Internet of Things have driven new industries and reshaped consumer behavior through livestream e-commerce and short video marketing[1]. This transformation offers new opportunities for the protection and inheritance of intangible cultural heritage (ICH). Jiama woodblock printing, as a vital bearer of traditional Chinese folk culture, stands to benefit from digital empowerment by overcoming traditional limitations and enabling broader, more innovative dissemination.

However, challenges remain. Traditional ICH transmission relies on oral and manual teaching, now threatened by aging inheritors and limited youth engagement. While digital tools have enhanced visibility, content often lacks depth and cultural authenticity. Most digital museums remain static and underutilize immersive technologies like VR and AI. Moreover, local governments often prioritize recognition over sustainable support, and insufficient marketization hinders innovation. The gap between ICH and modern urban life continues to widen, with public awareness and participation remaining low[2].

To address this, the paper constructs a framework linking digital economy development, Jiama dissemination, audience expansion, and heritage transmission, and proposes corresponding hypotheses. Compared to previous research, this study contributes in two key ways. First, it integrates the digital economy perspective into ICH studies, highlighting how digital tools enhance dissemination and audience engagement using Jiama as a case. Second, it proposes targeted strategies—such as IP-based development, cross-sector collaboration, and youth-oriented digital outreach—to address commercialization barriers and intergenerational transmission challenges[3].

1.2 Research Status

1.2.1 Research status of digital economy development

The digital economy plays a pivotal role in China's socialist modernization and represents a strategic choice to seize the opportunities presented by the new wave of technological revolution and industrial transformation. Li Sanxi (2021) [4]points out that China's digital economy has entered the global leading tier, as evidenced by the steady advancement of digital industrialization, the accelerated development of industrial digitalization, the significant progress in digital governance, and the ongoing improvement of the data factor market. In addition, the author summarizes several key factors behind China's success in developing its digital economy, including the decisive role of the market in resource allocation, the government's leading role in the construction of digital infrastructure, and a regulatory approach

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characterized by inclusiveness and prudence.

Although China has made remarkable achievements in digital development, its digital economy still faces several challenges, including the lack of core underlying technologies, insufficient integration of the digital and real economies, the need for further improvement in the development of a digital society and digital government, and the relatively early-stage construction of a digital ecosystem. As noted by Yang Zhaoxia[5], the current development of the digital economy is constrained by the absence of foundational core technologies, thereby limiting its potential to drive high-quality economic growth. Li Sanxi et al.[6]further emphasize that the digital economy continues to encounter problems such as weak integration between digital technologies and real industries, underdeveloped digital governance systems, and an immature digital ecosystem. Therefore, moving forward, it is essential to strengthen innovation in foundational technologies and enhance the construction of digital infrastructure to ensure the sustainable development of the digital economy.

1.2.2 Research status of Jiama Woodblock Printing

As an important component of Chinese folk woodblock printing, Jiama woodblock printing has long played a significant role in folk beliefs, religious rituals, and cultural transmission. Studies have shown that Jiama printing not only embodies a wealth of ethnic cultural symbols but also reflects regional variations in social beliefs and artistic styles. Wan Huiling[7] points out that Jiama printing and zhima art both belong to China's woodblock print heritage, integrating traditional beliefs and folk customs, and possess substantial cultural, educational, and aesthetic value. Li Jing[8] further analyzes the historical background of Jiama art in Yunnan, arguing that it gradually developed into a unique form of folk printmaking under the influence of Han culture from the Central Plains, while continuously evolving through intercultural exchanges among different ethnic groups. In addition, recent research has addressed the challenges and directions for the inheritance and innovation of Jiama printing in contemporary society, including issues such as intangible cultural heritage protection, market-oriented application, and digital dissemination. However, existing studies remain relatively fragmented, and further systematic and in-depth exploration is still needed.

1.2.3 Research status of the influence of digital economy development on intangible cultural heritage

Although digitization offers new pathways for the protection and dissemination of intangible cultural heritage (ICH), its practical implementation still faces multiple challenges. One of the foremost issues is the tension between technological application and cultural attributes. Song Junhua et al. (2023) [9]point out that current ICH digitization tends to emphasize technology over culture, neglecting the living and localized nature of heritage practices, which results in a loss of cultural meaning. Bai Jinxiang et al. (2023)[10], using traditional sports heritage as an example, reveal issues such as overly simplistic preservation methods and an imbalanced transmission system. While digitization has alleviated some of these problems, it has not fundamentally resolved them.

Secondly, the lack of institutional support restricts the long-term development of ICH digitization. Yi Ling et al. [11]emphasize that the digitization of intangible cultural heritage involves complex intellectual property issues, such as unclear ownership and the absence of effective transaction mechanisms, highlighting the urgent need for a tiered protection system and the development of dedicated trading platforms. At the same time, Gao Jiesong et al. [12]argue that although intelligent technologies have improved the construction of ICH databases, the limited participation and discourse power of heritage bearers in technological applications weakens the sustainability of the cultural ecosystem.

The rapid development of the digital economy has provided technical tools and innovative approaches for the preservation of intangible cultural heritage (ICH). However, the transmission of ICH remains constrained by technological alienation, institutional deficiencies, and regional disparities. Going forward, it is essential to promote the deep integration of technology and culture, improve mechanisms for rights protection, and address the digital divide in order to achieve the living transmission and value regeneration of ICH.

1.2.4 Literature review

Existing research indicates that the digital economy plays a significant role in driving industrial transformation and improving social governance. However, it still faces challenges such as deficiencies in key technologies and the underdevelopment of the digital ecosystem. Studies on Jiama Woodblock Printing have largely focused on its cultural value, historical evolution, and challenges in transmission, but the research remains fragmented and lacks systematic analysis. Moreover, while the digital economy offers new technological tools for the preservation of intangible cultural heritage (ICH), the digitization process often prioritizes technology over culture, weakening the living nature of ICH. At the same time, issues such as insufficient institutional safeguards and the diminished discourse power of inheritors remain unresolved. Overall, current research provides theoretical support for the role of the digital economy in ICH preservation, but there is still a need to deepen the integration of digital technologies with cultural transmission and to improve related policy frameworks to promote the sustainable development of ICH.

2 THEORETICAL MECHANISMS AND RESEARCH HYPOTHESES ON THE IMPACT OF DIGITAL ECONOMY DEVELOPMENT ON THE TRANSMISSION OF JIAMA WOODBLOCK PRINTING

2.1 The Influence of the Development of Digital Economy on the Inheritance of Jiama Woodblock Printing

In the context of the digital economy, the modes of intangible cultural heritage (ICH) production are shifting from traditional handicrafts to digitalized processes. The production of Jiama Woodblock Printing can leverage technologies

such as digital engraving, AI-assisted design, and 3D printing to enhance production efficiency, lower the barriers of manual craftsmanship, and ensure high-precision reproduction of techniques. These advances also strengthen the creative transformation and product upgrading capabilities of Jiama Woodblock Printing, thereby promoting its transmission. Based on this, the following hypothesis is proposed:
Hypothesis 1: The development of the digital economy significantly promotes the transmission of Jiama Woodblock Printing.

2.2 The Mediating Effect of the Spread of Jiama Woodblock Printing

Traditional modes of intangible cultural heritage (ICH) dissemination have largely relied on localized displays, making it difficult to reach a broader audience. In the digital economy era, platforms such as short videos, livestreaming, and e-commerce have created new opportunities for the promotion and transmission of Jiama Woodblock Printing. For instance, short video platforms can enhance public awareness of its cultural value by narrating the historical background and technical details of Jiama Woodblock Printing. In addition, online education and digital museums offer more accessible channels for the transmission of its craftsmanship. Based on this, the following hypothesis is proposed:
Hypothesis 2: The development of the digital economy facilitates the dissemination of Jiama Woodblock Printing and further promotes its transmission and preservation by enhancing public awareness and interest in learning.

2.3 The Mediating Effect of Expanding Audience Group

Driven by the digital economy, the dissemination and consumption channels of Jiama Woodblock Printing have continuously expanded, offering more people the opportunity to access and understand this form of intangible cultural heritage. Platforms such as short videos, social media, and e-commerce have lowered the threshold for information acquisition, enabling Jiama Woodblock Printing to reach a wider audience—including younger consumers and international markets. Furthermore, its integration with modern design and cultural and creative industries has aligned it more closely with contemporary aesthetic trends, enhancing public acceptance and cultural identification. Based on this, the following hypothesis is proposed:
Hypothesis 3: The development of the digital economy can effectively broaden the audience base for Jiama Woodblock Printing, thereby further promoting its transmission and development.
The theoretical framework illustrating the impact of digital development on the transmission of Jiama Woodblock Printing is shown in the Figure 1 below:

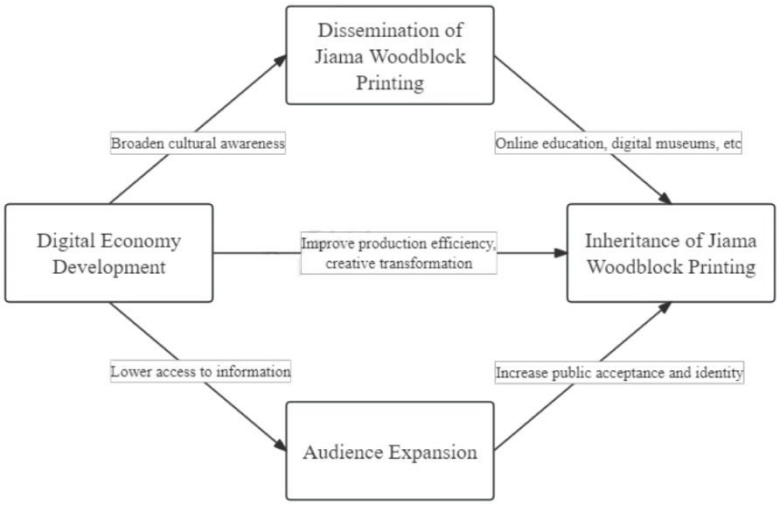

Figure 1 Theoretical Mechanism Diagram

3 AN EMPIRICAL ANALYSIS OF THE IMPACT OF DIGITAL ECONOMY DEVELOPMENT ON THE INHERITANCE OF JIAMA WOODBLOCK PRINTING

3.1 Basic Information of the Questionnaire

This study employed a random sampling method to conduct a nationwide survey through online questionnaires. After excluding responses with more than one-third of the items left blank, evident patterned answers, and significant missing basic information, a total of 203 valid questionnaires were retained.
Descriptive statistical analysis was used to validate the collected data, including frequencies and corresponding proportions. The overall characteristics of the sample were analyzed based on the respondents' gender, age, educational background, and occupation.
As shown in Table 1, male respondents accounted for 51.72%, while female respondents accounted for 48.28%,

indicating a relatively balanced gender distribution. The respondents represented a wide range of age groups, with the largest proportion aged 26–35 (33.50%), followed by those aged 36–45 (23.65%). Respondents under 18 and over 60 were relatively few, accounting for 11.33% and 9.85% respectively. A high proportion of respondents held a bachelor's degree or higher, with undergraduates comprising 36.45% and those with a master's degree or above accounting for 17.73%. The respondents' occupations were diverse. The largest group was general employees (27.09%), followed by business managers (11.82%) and commercial/service workers (6.90%). Students also accounted for a significant share, at 17.24%.

This survey covered respondents of different genders, ages, educational levels, and occupational backgrounds, providing comprehensive data support for studying the inheritance and development of Jiama Woodblock Printing in the context of the Digital Economy.

Table 1 Basic Information of the Questionnaire

Variable	Category	Frequency	Percentage	Cumulative Percentage
Gender	Male	105	51.72%	51.72%
	Female	98	48.28%	100%
Age	Under 18	23	11.33%	11.33%
	18–25 years	12	5.91%	17.24%
	26–35 years	68	33.50%	50.74%
	36–45 years	48	23.65%	74.39%
	46–60 years	32	15.76%	90.15%
	Over 60	20	9.85%	100%
Educational Background	Junior high school or below	17	8.37%	8.37%
	High school	29	14.29%	22.66%
	Associate degree	47	23.15%	45.81%
	Bachelor's degree	74	36.45%	82.26%
	Master's degree or above	36	17.73%	99.99%
Occupation	Student	35	17.24%	17.24%
	Government/Agency Official/Public Servant	13	6.40%	23.64%
	Business Manager	24	11.82%	35.46%
	General Employee	55	27.09%	62.55%
	Professional Technician	9	4.43%	66.98%
	Commercial/Service Industry Worker	14	6.90%	73.88%
	General Worker	9	4.43%	78.31%
	Agriculture/Forestry/Animal Husbandry/Fishery Worker	7	3.45%	81.76%
	Freelancer	15	7.39%	89.15%
	Unemployed	5	2.46%	91.61%
	Other Occupation	17	8.37%	99.98%

3.2 Questionnaire Reliability and Validity Test

3.2.1 Reliability test results

Table 2 Reliability Test

Cronbach's alpha	**Normalized** Cronbach's alpha	Number of terms
0.890	0.793	13

This study conducted a reliability test on the questionnaire, and the results are shown in Table 2. The overall Cronbach's Alpha coefficient was 0.890, indicating a high level of internal consistency reliability. Additionally, the standardized item Cronbach's Alpha was 0.793, further confirming the reliability of the questionnaire. The measurement items demonstrated good consistency within the overall structure, and the data exhibited high stability, making it suitable for subsequent statistical analysis.

3.2.2 Validity test results

The Kaiser-Meyer-Olkin (KMO) test is used to measure the adequacy of the correlation among variables for further analysis. The KMO value ranges from 0 to 1, and it is generally considered that KMO ≥ 0.6 indicates a reasonable data

structure. Bartlett's test of sphericity is used to examine whether the correlations among variables are significant; if $p < 0.05$, it suggests strong correlations among variables, indicating a reasonable questionnaire structure suitable for further analysis.

As shown in Table 3, In this study, the KMO measure of sampling adequacy was 0.699, which is close to 0.7, indicating good internal consistency and a well-designed questionnaire. The approximate chi-square value of Bartlett's test of sphericity was 192.223, with 6 degrees of freedom and a significance level of $p < 0.001$, suggesting significant correlations among variables and supporting the validity analysis of the questionnaire. Therefore, the questionnaire demonstrates good validity and is appropriate for subsequent research analysis.

Table 3 Validity Test

KMO		0.699
Bartlett's Test of Sphericity	Approximate chi-square	192.223
	Degree of freedom	6
	Significance	0.000

3.3 Regression Analysis

This study employs a regression analysis method, taking Digital Economy Development as the independent variable and the Inheritance of Jiama Woodblock Printing as the dependent variable, to empirically examine the relationship between them. The regression results Table 4 show that Digital Economy Development has a significant positive impact on the Inheritance of Jiama Woodblock Printing, with a regression coefficient of 7.035 and passing the 1% significance level ($p < 0.01$). This suggests that the development of the digital economy can effectively promote the inheritance of Jiama Woodblock Printing. The model's R^2 is 0.239, indicating that it explains 23.9% of the variation in inheritance, and the adjusted R^2 is 0.235, showing a relatively stable model fit. The F-value is 63.09 with a significance level of 0.000, further proving the model's overall statistical significance. Thus, it can be concluded that Digital Economy Development plays a positive role in advancing the Inheritance of Jiama Woodblock Printing.

Table 4 Regression Analysis Table

VARIABLES	Inheritance of Jiama Woodblock Printing
Digital Economy Development	7.035***
	(7.94)
Constant	68.065***
	(13.25)
Observations	203
R-squared	0.239
F test	0
r2_a	0.235
F	63.09

The regression equation model is as follows:

$$y = 7.035x + 68.065 \quad (1)$$

3.4 Intermediate Effect Test

To further explore the mechanism through which Digital Economy Development influences the Inheritance of Jiama Woodblock Printing, this study takes Digital Economy Development as the independent variable and the Inheritance of Jiama Woodblock Printing as the dependent variable. The Bootstrap method is employed to test the mediating paths, focusing on the mediating effects of Dissemination of Jiama Woodblock Printing and Audience Expansion.

Table 5 Results of Mediation Effect Test

Bootstrap test						
		coefficient	Standard error	z	Statistical level	95% confidence interval
Dissemination of Jiama Woodblock Printing	Indirect effect	0.177	0.048	3.68	1%	[0.082748, 0.271612]
Audience Expansion	Indirect effect	0.281	0.038	7.47	1%	[0.20747, 0.3551386]
Sobel test						
Dissemination of Jiama Woodblock Printing	Indirect effect			0.119755		
	Direct effect			0.17718		
	Total effect			0.296935		
Audience Expansion	Indirect effect			0.015631		

Direct effect	0.281304
Total effect	0.296935

As shown in Table 5, the indirect effect coefficient of the Dissemination of Jiama Woodblock Printing is 0.177, with a standard error of 0.048, a z-value of 3.68, and a 95% confidence interval of [0.082748, 0.271612]. The total effect coefficient is 0.296935. This indicates that Digital Economy Development significantly promotes the Dissemination of Jiama Woodblock Printing, and that dissemination, as a mediating variable, has a significant impact on the dependent variable—Inheritance of Jiama Woodblock Printing. The indirect effect coefficient of Audience Expansion is 0.281, with a standard error of 0.038, a z-value of 7.47, and a 95% confidence interval of [0.20747, 0.3551386]. The total effect coefficient is also 0.296935. This indicates that Digital Economy Development significantly promotes Audience Expansion, and that audience expansion, as a mediating variable, also has a significant impact on the Inheritance of Jiama Woodblock Printing.

In the process of promoting the Inheritance of Jiama Woodblock Printing, both the Dissemination of Jiama Woodblock Printing and Audience Expansion play important mediating roles. Therefore, future efforts should focus more on the dissemination effect of digital platforms and social media to further enhance the influence of Jiama Woodblock Printing.

4 CONCLUSION AND DISCUSSION

This article is based on questionnaire surveys and literature analysis, systematically sorting and in-depth discussing the current situation and future development path of the inheritance of Jiama Woodblock Printing under the background of the digital economy. The research finds that with the widespread application of digital technologies and the rapid development of the digital economy, the transmission and inheritance methods of traditional intangible cultural heritage are undergoing profound changes. Jiama Woodblock Printing, as a traditional craft with deep national cultural connotations and religious belief backgrounds, is also facing new opportunities and challenges in the digital age.

The survey shows that the digital economy has expanded the transmission channels of Jiama Woodblock Printing through online education, digital museums, and other platforms, lowering the barriers to information access, broadening the audience, and increasing public attention and market influence, providing new opportunities for commercialization. However, currently, the integration of digital technology and Jiama art is not deep enough, and there is a lack of a systematic re-creation mechanism. The digital literacy of inheritors is relatively low, making it difficult for them to actively participate in transmission. In addition, relevant policy support is still inadequate, and there is a lack of a protection mechanism for the digitalization of intangible cultural heritage, which affects the depth and sustainability of its inheritance.

In response to the above conclusions, this article proposes the following three recommendations:

First, promote the deep integration of digital technology and intangible cultural heritage, enhancing the transmission and influence of Jiama Woodblock Printing. This involves digitizing the image styles, craft processes, and cultural connotations of Jiama Woodblock Printing, and re-creating them to increase their attractiveness and expressiveness.

Second, strengthen the digital literacy training for inheritors to improve their initiative and ability to participate in digital transformation. Help inheritors acquire basic information technology skills and enhance their awareness of transmission on new media platforms, as well as their content creation abilities.

Third, improve the policy support system for the digital protection and development of intangible cultural heritage. Establish a transmission mechanism guided by the government, with social participation and multi-party collaboration, creating a positive ecosystem where diverse participants work together to promote the inheritance of cultural heritage.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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