

provided opportunities for those excluded from the traditional financial system. Innovative financial instruments such as peer-to-peer lending and mobile financial services give SMEs direct access to capital, thereby reducing costs and time delays associated with intermediation.

This emerging financing model provides SMEs with a more flexible source of capital, driving their innovation and growth, and alleviating the bias and rigid restrictions of the traditional credit system to some extent. However, the success of this model depends on an appropriate regulatory and legal framework to protect consumers and maintain market stability.

4. Bank credit and SME financing constraints

SMEs play a vital role in economic development, but they face significant obstacles in accessing bank credit. Most SMEs rely on commercial banks as the main source of external capital, but the operations and growth potential of these enterprises are often limited due to credit constraints. Survey data show that about half of formal SMEs lack access to formal credit, forcing them to rely on internal funds or informal sources of financing, such as family and friends, to stay afloat.

For banks, SME loans are one of their important sources of income. Banks make profits by providing loans to SMEs, but because of the relatively high risk of SMEs, banks face no small challenge in lending money. Therefore, the lending business targeting SMEs requires particularly prudent risk assessment and due diligence to ensure the repayment of loans and the bank's income stability.

Empirical studies have shown that financing constraints have a significant negative impact on the growth and sustainable development of SMEs. Studies in several countries have found that although they face similar economic backgrounds, the financing environment and credit constraints of SMEs vary from country to country, which directly affects the innovation ability and market competitiveness of SMEs. There is a two-way relationship between the supply of bank credit and the financing constraints of SMEs. On the one hand, the supply of bank credit determines the ability of SMEs to obtain funds; On the other hand, the financing constraints of SMEs will also affect their performance in bank lending.

Different types of banks also have different effects on SME credit ^[8]. Research shows that regional banks and credit unions are more willing to lend to local SMEs because they have a deeper understanding of the local market and are able to offer more flexible lending terms. In contrast, large banks are generally more cautious about lending to SMEs due to their centralized management and strict risk control policies. However, with the popularity of digital financial instruments, banks are likely to adjust their credit strategies to better meet the financing needs of SMEs, thus easing the challenges posed by financing constraints.

Financing constraints for SMEs mainly stem from the gap between the demand side and the supply side of credit. Many SMEs have difficulty obtaining loans from traditional banks due to lack of adequate financial transparency and collateral. At the same time, banks tend to be conservative in their credit assessments of SMEs due to asymmetric information, further exacerbating financing difficulties. At this point, digital financial inclusion, as an innovative solution, can effectively ease the financing constraints faced by SMEs.

Digital financial inclusion provides SMEs with more flexible and low-threshold financing channels through convenient digital lending, online financing, and crowdfunding platforms. The digital platform leverages big data and artificial intelligence to conduct in-depth risk assessments and help financial institutions better understand the repayment ability of SMEs, thereby reducing risks brought about by information asymmetry. In addition, digital

finance has also promoted the availability of credit, with financial institutions able to process loan applications more quickly through big data analysis, greatly improving the approval efficiency. Small and medium-sized enterprises can connect directly with investors through online platforms, further broadening financing channels^[9].

The spread of digital financial inclusion has also reduced information asymmetries. Increased transparency has enabled financial institutions to obtain more information and assess the credit standing of SMEs more effectively, easing the financing barriers caused by information asymmetry.

5. Policy implications and suggestions

In order to better ease the financing constraints of SMEs and promote their sustainable development, this paper puts forward the following four policy recommendations, aiming to optimize the financing environment of SMEs through multi-party collaboration and innovation, so as to enhance their growth and competitiveness.

5.1. Strengthening policy synergies

Governments, financial institutions, and SMEs should work together to develop and implement more effective financing policies^[10]. First, the government can provide loan guarantees, interest rate subsidies, tax incentives, and other policy measures. Second, financial institutions should actively research and develop more financial products that meet the needs of SMEs, such as flexible loan programs for start-ups or high-growth enterprises, supply chain finance products, etc., to meet the capital needs of enterprises of different sizes and stages of development^[11]. At the same time, a more complete financial management system and credit evaluation system should be established, so as to enhance trust in cooperation with financial institutions and enhance the availability of financing.

5.2. Increasing regulatory innovation

In the context of the rapid development of digital finance, regulators need to flexibly adjust relevant policies and regulatory frameworks to adapt to changes in the digital financial environment, while ensuring that consumers' rights and interests are effectively protected. In addition, regulators should relax some excessive regulations on innovative products on the premise of ensuring financial security, and support fintech companies to conduct business without affecting market stability and consumers' rights and interests, so as to promote technological progress and diversification of financial services across the industry.

5.3. Boosting financial education

To enable SMEs to take better advantage of digital financial products and improve their financing capacity, universal access to financial education is essential. Governments, financial institutions, and relevant industry organizations should enhance financial literacy training for small and medium-sized business owners and managers. At the same time, customized training and consulting services should be launched to address the financing difficulties unique to small and medium-sized enterprises, so as to help enterprises optimize financial management and financing decisions and improve their ability to obtain capital. In the long run, this will boost SMEs' self-adaptation and financing ability in the capital market, further promoting their healthy development.

5.4. Promoting technological innovation

In the current digital age, promoting financial technology innovation is of great significance for SME financing. Financial institutions should encourage and actively adopt advanced technologies such as big data analysis,

artificial intelligence (AI), and blockchain to improve the accuracy of risk assessment and the efficiency of credit approval ^[12]. Big data and AI technologies can provide banks and financial institutions with a more comprehensive credit assessment by analyzing a company's financial status, business model, and industry background, and reduce the risks caused by information asymmetry, thus enabling more SMEs to access financing ^[13, 14].

Through the implementation of the above policy recommendations, benign interaction and cooperation between the government, financial institutions, and SMEs can be formed, and the optimization of the financing environment of SMEs can be promoted ^[15]. This multi-party cooperation will provide strong support for the sustainable development of SMEs and promote the overall growth and innovation of the economy.

6. Conclusion

This paper looks at how digital inclusive finance helps ease financing difficulties for small and medium-sized enterprises (SMEs), and the role bank credit plays in that process. The study finds that digital finance clearly reduces financing constraints for SMEs. It also shows that banks play a key role by using digital tools to improve access to credit and reduce information gaps, which leads to more loans for SMEs.

This means that developing digital inclusive finance not only helps expand financial services but also offers a practical way to solve the problems of “difficult and expensive financing” for SMEs. To support this, policies should continue to build digital finance infrastructure, improve regulations, and promote cooperation between banks and digital platforms to help SMEs grow sustainably.

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China-Europe Independent Station Electronics Integrator

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Abstract: Cross-border e-commerce usually involves multiple links such as online shopping platforms, payment systems, logistics services, customs clearance, and cross-border sales. From 2015 to 2023, China-Europe cross-border e-commerce has experienced rapid growth. Demand among Chinese consumers for European products has increased significantly, while European interest in Chinese goods has also steadily risen. Many small and medium-sized enterprises and cross-border e-commerce platforms have begun to enter this market. This article explores how independent e-commerce integrator platforms can leverage efficient, cost-effective supply chain services and brand advantages to attract Chinese and German SMEs. By doing so, these platforms can strengthen their market presence, reduce operational costs for SMEs, expand transaction volume, and ultimately create a win-win situation for all stakeholders.

Keywords: Service supply chains; Cross-border e-commerce; Independent station

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1. Cross-border E-commerce

1.1. China E-commerce

In recent years, cross-border e-commerce has become an important engine to support “external circulation”, and various parts of China have also attached great importance to the development of cross-border e-commerce. Based on **Figure 1**, China’s cross-border e-commerce market will reach 15.7 trillion yuan in 2022, a year-on-year growth of 10.56%^[1].

In China’s cross-border e-commerce transaction model in 2022, cross-border e-commerce B2B transactions accounted for 75.6%, and cross-border e-commerce B2C transactions accounted for 24.4% (**Figure 2**).

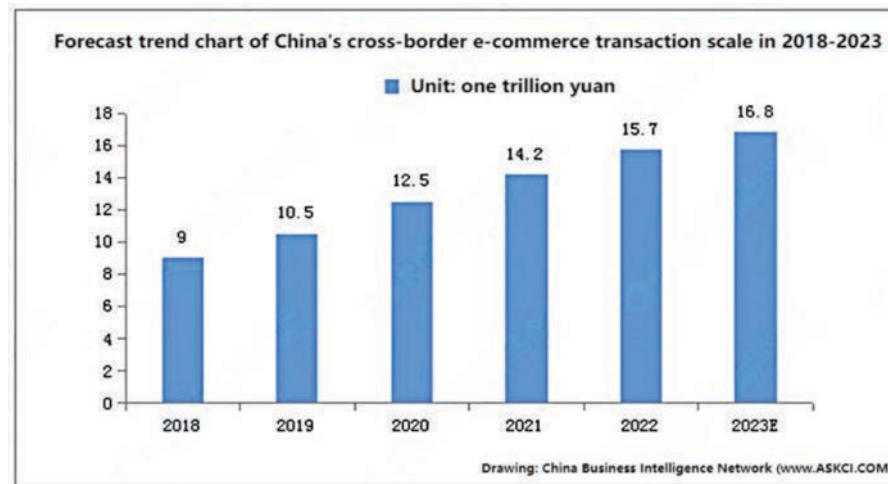


Figure 1. Forecast trend chart of China's cross-border e-commerce transaction scale in 2018–2023

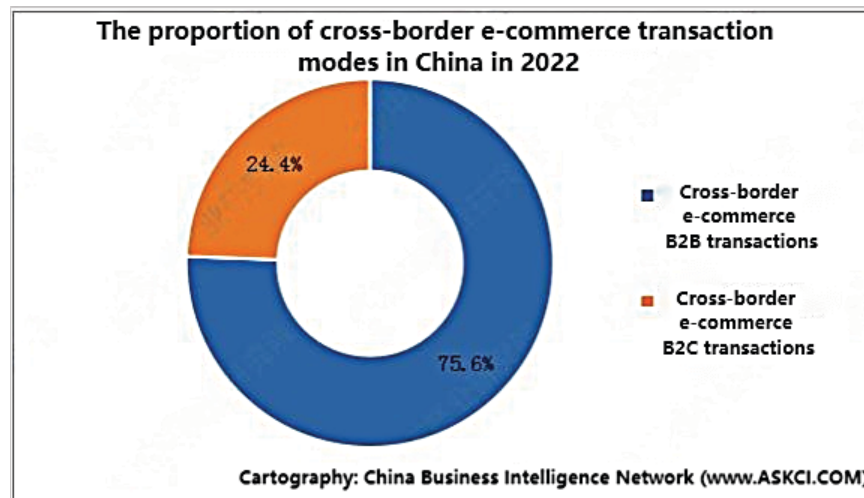


Figure 2. The proportion of cross-border e-commerce transaction modes in China in 2022

1.2. European cross-border e-commerce

In 2019, the cross-border B2C e-commerce growth rate of 16 countries in Northern, Western, and Southern Europe (14 EU countries, Switzerland, and Norway) was 14%, as shown in **Figure 3**. Excluding cross-border tourism, the market size was 108.8 billion euros. This accounts for almost 23.5% of the 462 billion euros in e-commerce sales (excluding tourism) in the 16 countries mentioned above. By 2022, the European cross-border e-commerce market will reach 179 billion euros, with a growth of 65.74% in three years^[2].

Based on **Figure 4**, in Germany, cross-border business-to-consumer (B2C) e-commerce is becoming increasingly important in the online retail sector. In 2019, foreign e-commerce websites accounted for 21.4% of the entire e-commerce revenue. Three years later, the cross-border e-commerce market share increased to 26%^[3].

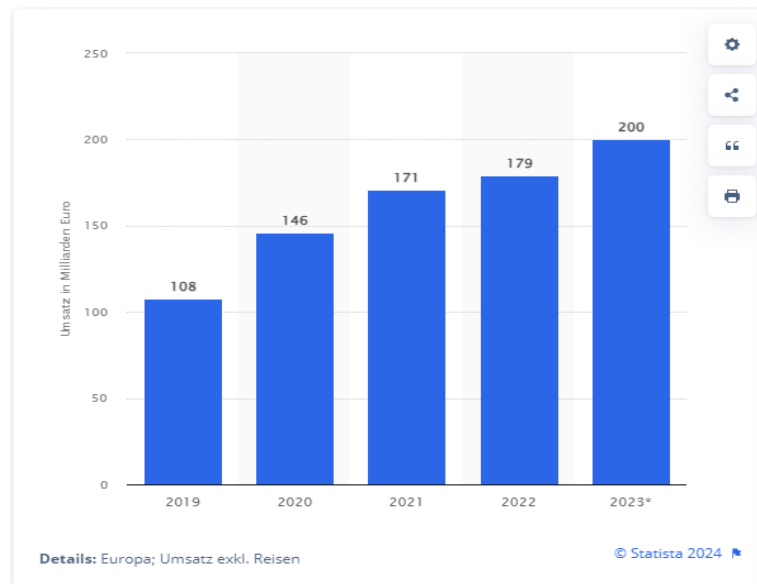


Figure 3. European cross-border e-commerce sales from 2019 to 2022 and forecast for 2023

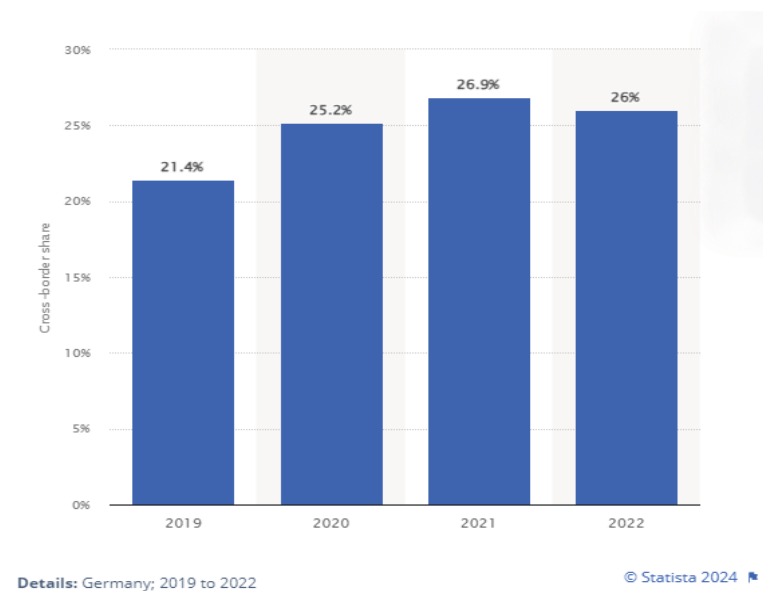


Figure 4. Share of cross-border B2C e-commerce out of total e-commerce revenue in Germany from 2019 to 2022

2. Current status and difficulties of cross-border e-commerce

Between 2017 and 2022, the scale of China's cross-border export e-commerce industry continued to maintain a year-on-year growth rate of more than 20%, superimposed by the epidemic's accelerating effect on the online consumption of countries around the world. In 2022, due to the combined impact of supply chain pressure caused by partial lockdowns and changes in the international situation, the marginal growth rate of the cross-border export e-commerce industry was set back, but the year-on-year positive growth of 9.4% was still achieved throughout the year.

After the epidemic is over, the number of new companies entering the China-Europe transnational e-commerce market continues to increase, and small enterprises have also become medium-sized enterprises over time and the market has recovered. However, compared with large capital enterprises Amazon, Alibaba, and JD.com, small and medium-sized enterprises in the China-Europe transnational e-commerce market etc. are still vulnerable groups.

Complex laws and regulations, high logistics and distribution costs, brand building and marketing, language and cultural barriers, market access barriers, consumer brand loyalty, cross-border electronic payments, and customs clearance are all what new companies need to face when entering the market. series of difficulties. Small and medium-sized enterprises that have achieved certain results in the market still have long-term difficulties to face on these issues.

2.1. Cross-border e-commerce logistics

One of the key areas of cross-border e-commerce is international logistics and transportation, which can be boiled down to the following processes: customs clearance of domestic goods to go overseas, customs transportation to overseas warehouses for storage and management of goods, delivery of goods to customers, and returns. Efficient logistics not only attracts new customers (different delivery methods and low-cost transportation) but also retains existing customers who have already placed orders (through timeliness, compliance with orders, lack of damage, etc.)^[4].

2.2. Consumer brand loyalty

Multiple consumer market surveys have shown that consumers are unable to make rational decisions and cannot understand their true motivations and attitudes in making purchasing decisions. The external characteristics of a product, such as packaging design, branding, price, content, and nutritional information, play a central role in consumers' purchasing decisions^[5].

Brand loyalty leads to certain marketing advantages such as reduced marketing costs, more new customers, and greater trade leverage^[6]. According to research, consumers' trust in product brands and the proposed trust dimensions directly affect consumer loyalty^[7].

On the other hand, brand awareness plays a role in consumer loyalty. Brand awareness (BA) refers to the way consumers connect with the products they want. This kind of recognition is not only about consumers' perception of the product, but also reflects their overall understanding and recognition of the brand. In communication and interaction, consumers' level of brand awareness directly shapes their attitude towards the brand and purchasing tendency. Therefore, improving brand awareness can not only increase product exposure and sales but also help strengthen brand loyalty and influence^[8]. There are also some obstacles to improving brand awareness, such as fierce market competition, poor effects, and a lack of sustainability.

3. Cross-border e-commerce supply chain

Cross-border e-commerce supply chains face several challenges, including international logistics, customs clearance, payment and currency exchange, language and cultural differences, and product quality control.

A supply chain includes all products, services, funds, and the flow of information between suppliers and customers, from the original supplier to the final buyer^[9]. In e-commerce, supply chain management mainly involves handling information, logistics, and financial processes.

For example, managing shipping, tracking payments in different currencies, and ensuring smooth communication across countries are all key parts of running an effective cross-border e-commerce supply chain.

4. Independent station electronics integrator

Numerous authors consider that the design of a quality website is a key aspect of e-business strategy since this is the principal medium of communication to interact with current and potential customers. Thus, success in the virtual market requires firms to correctly manage technology and the information provided on its website ^[10].

It is difficult for small and medium-sized enterprises to gain an advantage in the capital market if they work alone. In the capital market, it is often difficult for small and medium-sized enterprises to gain competitive advantages on their own. Therefore, this article aims to propose a new concept, that is, the concept of independent station cross-border electronics integrator. The concept aims to create a unique brand image by establishing an independent e-commerce platform and trademark in Europe. By inviting many small and medium-sized enterprises to join, they become part of the brand, and all products are sold using a unified trademark, thereby rapidly growing the brand's scale. By leveraging brand influence, strong supply chain capabilities, and high-quality after-sales service, a larger share of the cross-border e-commerce market can be captured.

One of the characteristics of an independent website is the integration of its brand influence and trademark. Through effective brand building, independent websites can create a unique brand image and enhance the brand's influence by providing high-quality products and services, establishing good customer relationships, and brand community social spaces.

5. Independent station integrators provide service capability

Independent site Integrators can, to a certain extent, enhance consumers' brand recognition and purchase intent by strengthening brand communities, optimizing logistics and supply chain management, and providing efficient payment and tax solutions. They can also support the growth of SMEs in the global marketplace by enhancing customer satisfaction and market comparison through effective after-sales service and traffic marketing strategies.

5.1. Provide brand benefits and consumer brand loyalty

Research findings indicate that in the general market, consumers who interact with social media brand communities tend to exhibit a probable positive attitude towards the brand, such as trust and loyalty. Consumer brand recognition may serve as the foundation for transforming interactions within consumer brand communities into consumer brand identification. This suggests that when consumers can accurately identify and understand a brand's characteristics and values, they are more likely to form emotional connections with the brand, thereby developing loyalty and a sense of identification. This brand identification extends beyond mere purchasing behavior; it also includes alignment with the brand's philosophy and culture, which in turn encourages consumer participation in brand communities and active engagement within these communities ^[11].

Interactions between members, as well as between members and brands, significantly shape consumers' relationships with the brand and their attitudes toward it (**Figure 5**) ^[12]. This approach actively cultivates emotional bonds with the network subject, crucial for strengthening customer loyalty. Grounded in the understanding that emotional engagement is vital for retention and satisfaction, it enhances the perceived value and stability of customer relationships ^[13].

Brand identity refers to the unique set of characteristics that not only shape the distinct image of a brand but also enable consumers to clearly distinguish it from competitors in the market ^[14]. This concept encompasses the brand's visual elements, linguistic style, values, and the unique experiences it offers, which are crucial for establishing brand loyalty and a sense of identity in a fiercely competitive market. Through consistent and focused communication of the brand message, businesses can ensure the stability and authenticity of the brand image, thereby creating a clear and lasting brand perception in the minds of consumers.

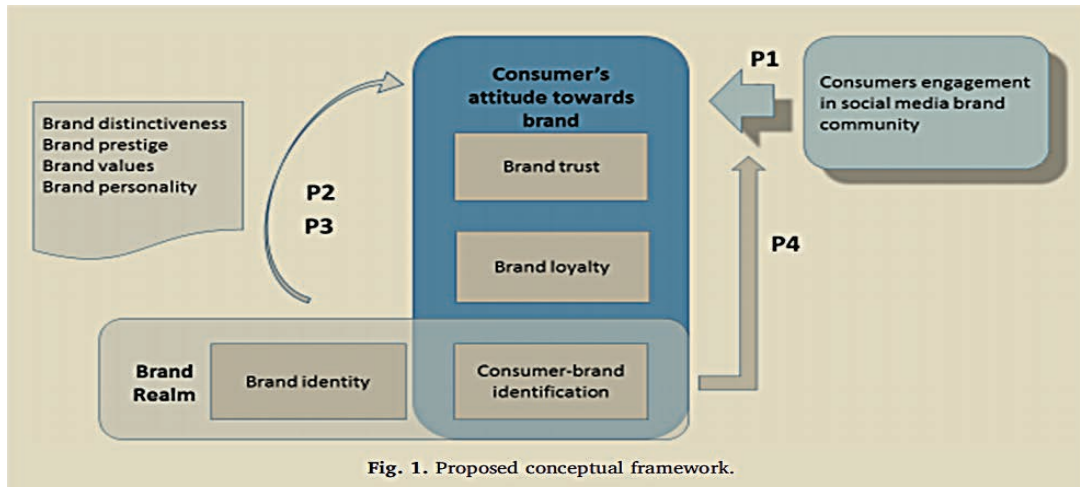


Figure 5. Proposed conceptual framework

Brand communities help companies attract individual customers and strengthen relationships with these customers, thereby building long-term relationships ^[15]. These lasting relationships with customers make the company more competitive, thereby greatly improving its marketing effectiveness ^[16]. Brand communities built by independent site e-commerce integrators enable direct interaction with potential customers, allowing companies to showcase their unique characteristics, core values, and product advantages, ultimately enhancing brand awareness and image.

5.2. Efficient logistics and warehousing

A prominent feature of cross-border e-commerce is the increased costs associated with logistics. International transport of goods inherently results in higher logistics expenses compared to local deliveries. This not only raises the operational expenses for companies but can also deter consumer purchases, particularly for low-value products. Research indicates that higher shipping fees directly influence consumer buying behavior, as consumers are particularly sensitive to elevated shipping costs ^[17].

The intricacies inherent in cross-border logistics have been demonstrated to result in prolonged delivery times and heightened quality uncertainty. Multi-node transportation and customs clearance processes have been identified as factors that exacerbate the risks and delays associated with international shipping. In this context, delivery efficiency and accuracy have emerged as critical indicators of e-commerce platform competitiveness.

Conversely, the intricacies and expenses associated with international returns have the potential to impede consumer experience and impose a substantial burden on merchants. To address these challenges, it is imperative for e-commerce platforms to optimize their returns processes, maintain cost control, and offer flexible options, thereby enhancing customer satisfaction and strengthening their competitive position in the market.

According to data collected from offline interviews, the charges for storage in overseas warehouses are based on either volume or weight, with a daily rate of 0.99 euros (including a 28-day free storage period). Furthermore, the charges for storage exceeding 180 days are merely 1.5 euros per day. Incoming and shelving costs are waived, and the fee for drop-shipping is only 0.6 euros per SKU.

Partnering with logistics service providers enables independent stations to integrate all logistics links from suppliers to consumers, facilitating bulk processing and shipment of parcels. This integration allows stations to take advantage of economies of scale, thereby reducing costs. Supply chain optimization has also been demonstrated to reduce delivery times and enhance the precision and dependability of distribution.

5.3. Management and after-sales cost reduction

When cross-border e-commerce expands the international market, it needs to invest a lot of resources in brand promotion, advertising, online and offline promotion, and other activities. However, these initiatives are not always successful and may sometimes bring greater risks and uncertainties.

In the context of cross-border e-commerce, language differences often serve as a substantial impediment to effective communication. E-commerce platforms and sellers must therefore provide multilingual support to ensure effective communication and the provision of clear product information and customer service. This includes specialized language translation functions online, which are necessary to manage events such as returns and exchanges and to address customer queries.

A lack of adequate language support may lead to misinterpretations of product details, elevating the risk of disputes and negatively impacting customer loyalty and satisfaction. Independent site integrators address these challenges by providing comprehensive multilingual support, including localized website content, product descriptions, customer service, and technical support in multiple languages.

5.4. Payments, finance, and tax

Cross-border e-commerce is characterized by numerous challenges related to payment and currency settlement. Initially, cross-border transactions are subject to compliance with relevant European currency trading regulations and financial system requirements, thereby increasing the complexity of the payment process. Secondly, exchange rate regulatory measures have led to heightened uncertainty and cost risk in transactions. In terms of taxation, the independent tax policies of European countries necessitate that enterprises possess an in-depth understanding of and strictly comply with these policies to ensure tax compliance. Consequently, cross-border e-commerce companies operating within the European market must meticulously assess the constraints imposed by legal and regulatory frameworks to ensure compliance and facilitate sustainable growth.

Professional tax advisors within independent site integrators play a crucial role in ensuring compliance with European tax regulations. They possess a thorough understanding of both national tax laws across European countries and broader EU tax directives, as well as international tax treaties. Their expertise helps businesses operate in full compliance, avoid tax-related risks, optimize tax structures, and minimize tax costs. As a result, partners benefit not only from reduced tax and financial labor costs but also from improved financial and tax outcomes.

5.5. Brands influence purchase intentions

Core brand image and brand attitude have a positive effect on customers' purchase intention^[18]. Shwu-Ing *et al.* portrayed research on a larger scale, suggesting the major components of core-brand image are awareness of

the brand and preference for the brand. The two components of core brand image, awareness of the brand and preference for the brand, have an impact on core brand image and are positively associated with the attitude of the core brand ^[19].

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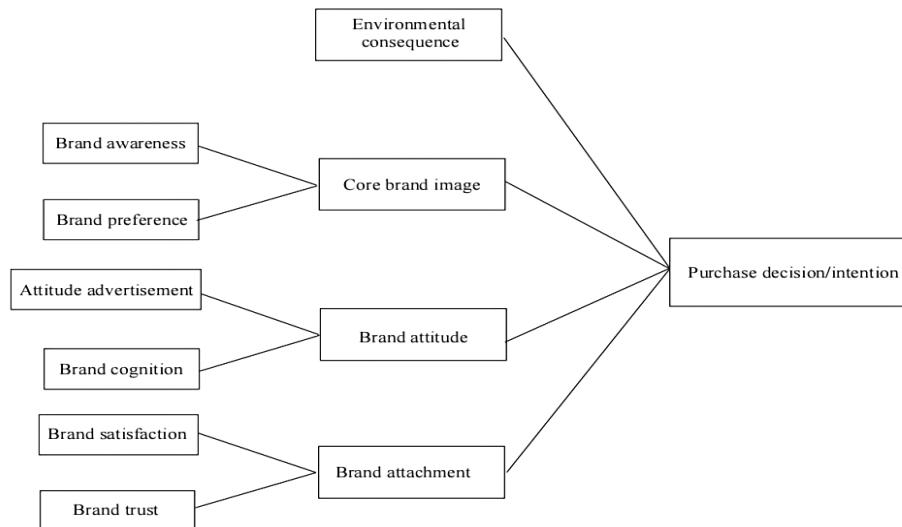


Figure 6. Model of factors influencing purchase decision/intention through brand image, attitude, and attachment

5.5.1. Brand attachment

Aspects of public interactions include emotional responses and sensations toward others. Trust, in particular, emerges as a critical outcome of these interactions. Previous research in both psychology and marketing has consistently identified trust as a vital component of close interpersonal and consumer-brand relationships. Brand trust is impact-based, meaning it stems from emotional impressions formed through public interactions associated with the brand. These interactions create a lasting psychological connection, reinforcing the consumer's attachment to the brand ^[20].

5.6. Traffic marketing

Larger social media campaigns tend to result in significantly higher number of orders and sale income. The results of the research also reveal that the effectiveness of social media marketing varies across products depending on their complexity, cost, and brand status ^[21].

Social media has indeed transformed the way people exchange opinions and experiences about brands (**Figure 7** and **Figure 8**). Positive interactions and endorsements have the potential to rapidly spread across vast geographical regions, reaching a large audience. Conversely, negative comments can also propagate just as swiftly, emphasizing the importance of maintaining a positive brand image and promptly addressing any issues. The visual and interactive features of social media endow it with a profound ability to enhance brand reputation. Users can easily engage with and share content, thereby enhancing the brand's visibility and credibility.

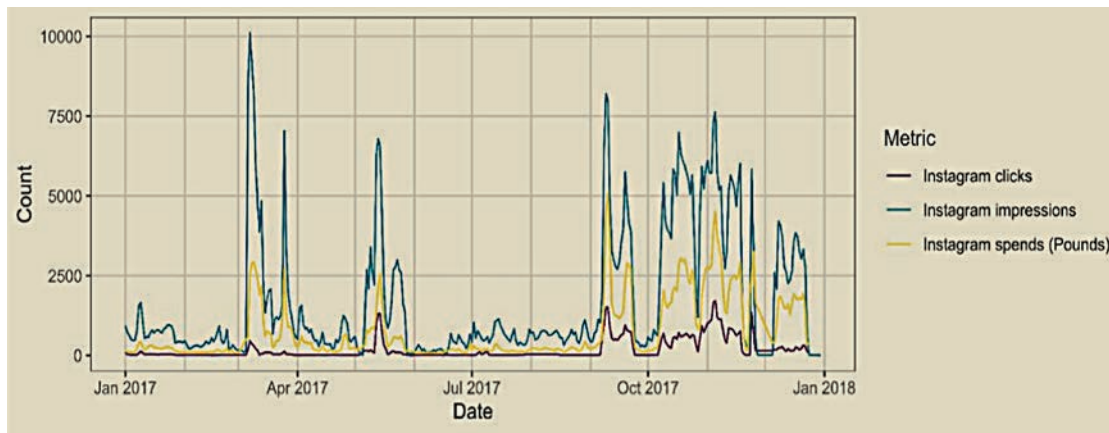


Figure 7. Trends in Instagram clicks, impressions, and advertising spend (Jan 2017 – Jan 2018)

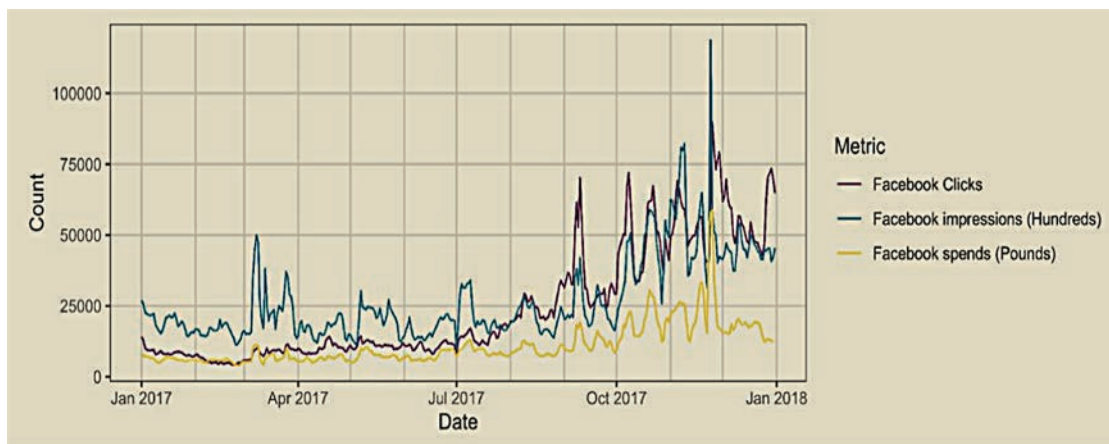


Figure 8. Trends in Facebook clicks, impressions, and advertising spend (Jan 2017 – Jan 2018)

As can be seen from the chart, the click-through rate and the degree of impression left on consumers are directly proportional to the marketing investment in social media. In other words, achieving good marketing results in e-commerce marketing is often accompanied by high advertising costs. But it's unclear whether this will maximize positive transaction volume from consumers. This is a high cost for small and medium-sized cross-border e-commerce companies. While it can increase awareness and make more consumers aware of their product, it cannot clearly define return on investment. In the model of an independent station cross-border electronics integrator, this portion of the work is handled by the integrator. As a result, small and medium-sized cross-border e-commerce businesses can eliminate these associated costs and instead allocate their resources to other critical areas such as product design, quality improvement, and innovation.

6. Conclusion

This article explores the rapid growth of China-Europe cross-border e-commerce and the challenges it faces. It also provides a detailed analysis of how independent electronics integrators can effectively leverage their supply chain service capabilities and brand strengths to attract small and medium-sized enterprises, thereby increasing transaction volume and achieving mutually beneficial outcomes. Independent website integrators offer a range

of valuable services to small and medium-sized cross-border e-commerce businesses, including support in building brand loyalty, streamlining logistics, reducing management and after-sales costs, and providing solutions for payments, finance, and taxation. Research indicates that by strengthening brand communities, optimizing supply chain operations, and delivering efficient payment and tax services, these integrators can significantly boost consumer brand awareness and purchase intent. Additionally, through targeted service offerings and traffic marketing strategies, they enhance customer satisfaction and competitiveness, ultimately supporting the sustainable growth of SMEs in the global marketplace.

Disclosure statement

The author declares no conflict of interest.

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Evaluation of Resilient Suppliers Based on the Improved Z-number - ORESTE Method

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Abstract: *Objective:* Existing research mainly relies on quantitative indicators. However, the subjectivity of qualitative indicators and the problem of their difficulty in quantification limit the comprehensiveness of evaluation. Therefore, a resilience supplier evaluation method based on the improved Z-number-ORESTE is proposed. *Methods:* Through the construction of a multi-tiered evaluation index system incorporating supplier capabilities, resources, strategic aspects, and resilience, Z-numbers are harnessed to signify qualitative indicators. An advanced Z-number distance metric is implemented, meticulously considering the impact exerted by the reliability portion of Z-numbers on information risk. The refined ORESTE ranking algorithm introduces the concepts of strong and weak orderings and capitalizes on the Borda assignment function. This approach facilitates a more precise appraisal of the performance of alternative solutions. By amalgamating the improved Z-number distance measurement approach with the ORESTE ranking methodology for multi-attribute decision-making, it becomes feasible to more efficiently assess the recovery capacities and adaptability of suppliers in the face of unforeseen incidents and risks. *Results:* Through the analysis of the comprehensive performance of the existing suppliers of a certain electronics enterprise, the results regarding the suppliers' recovery capabilities and adaptability when facing unexpected events and risks are obtained. Eventually, the suppliers that are in line with the long-term development strategy of the enterprise are selected. *Conclusion:* This evaluation system has verified its feasibility and effectiveness. Moreover, the system is capable of effectively identifying and selecting resilient suppliers, providing more reliable decision-making support for the enterprise's supply chain management.

Keywords: Z-number distance measure; Oreste ranking method; Multi-criteria decision-making; Evaluation of resilience in suppliers

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1. Introduction

In the complex and changing business environment, manufacturing companies face severe challenges in supply chain management, and suppliers, as the core link, are selected and evaluated to directly affect cost, quality, and

customer satisfaction. For example, Nazari-Shirkouhi *et al.* included supplier resilience into consideration to cope with globalized competition and contingency shocks, and Gökler *et al.* considered suppliers' environmental, social, and governance (ESG) performance under the concept of sustainable development ^[1, 2]. However, as the risk of supply chain disruption increases, resilient supplier evaluation is becoming a hot research topic. Resilience specifically refers to a supplier's ability to quickly resume operations in the time of risk, and has become a key metric for improving supply chain resilience.

Existing resilient supplier evaluation studies have primarily relied on quantitative metrics, such as product cost, pre-prepared inventory levels, and lead time variability, as seen in the works of Davoudabadi *et al.*, Mahmudul Hassan *et al.*, Fallahpour *et al.*, and Abedian *et al.* ^[3–6]. However, there is a growing shift toward incorporating qualitative metrics, including product reliability, agility, traceability, and resilience. However, the evaluation of qualitative indicators is susceptible to subjective factors and difficult to quantify, and scholars mostly use Triangular Fuzzy Number (TFN), Intuitionistic Fuzzy Number (Interval-valued Intuitionistic Fuzzy (IVIF)), and so on to quantify. However, since the decision-making process of indicator evaluation requires the design decision-maker to have multidisciplinary knowledge, the experts involved in the decision-making process often need to consider its reliability due to the limitations of their own knowledge structure and other constraints. In contrast, the Z-number characterizes the certainty and uncertainty information through the probability and intensity parameters synchronously, which can effectively reduce the subjective bias, and its intuition is more acceptable to the decision makers. Although scholars such as Wang *et al.*, Aliev *et al.*, Yaakob *et al.*, and Dong *et al.* convert Z-numbers to classical fuzzy numbers for distance measurement, such methods suffer from information loss defects ^[7–10]. Shen *et al.*, Das *et al.*, Cheng *et al.*, and Hu *et al.* propose a novel measurement based on potential probability distribution methods, but still do not fully consider the impact of decision makers' risk preferences on information risk ^[11–14]. Although improved methods have been proposed by Shen *et al.* and Chen *et al.* to improve the measurement accuracy and reliability, they are still insufficient ^[15, 16]. In this paper, the Z-number distance measure will be further improved by combining the preferred distance measure of Shen *et al.* ^[15].

Existing studies have used multi-attribute decision-making methods to evaluate suppliers. For example, Halдар *et al.* and Sahu *et al.* applied the TOPSIS method to evaluate strategic suppliers in disaster scenarios, where they used fuzzy numbers to assess supplier performance on general selection criteria (e.g., product quality) and resilience attributes (e.g., responsiveness) ^[17, 18]. Sahu *et al.* used the VIKOR method for ranking suppliers in a fuzzy environment to identify the most desirable toughness suppliers ^[18]. However, these methods rely on the setting of the ideal solution and are susceptible to the interference of subjective factors, which affects the reliability of the results. The ORESTE method, on the other hand, achieves the ranking through the calculation of the distance between the solutions, which avoids the problem of the ideal solution pre-setting and avoids the interference of subjective factors, and its calculation process is relatively simple and easy to operate. In addition, the ORESTE method introduces adjustable parameters, which can be flexibly adapted to the decision-making preference, and at the same time, through the combination of weak and strong ranking mechanisms, it can more accurately reflect the relationship between the advantages and disadvantages of the solutions, which can significantly improve the evaluation strength.

The resilient supplier evaluation system constructed in this paper aims to assess the resilience and adaptability of suppliers in the face of unexpected events and risks. The system contains four first-level indicators: supplier capability, supplier resources, supplier strategy, and supplier resilience, and is underpinned by a number of second-level indicators. To address the ambiguity and uncertainty of the qualitative indicators, this paper adopts the

Z-number characterization of the assessment information, and combines the improved Z-number distance measure and the ORESTE ranking method for multi-attribute decision making. The improved Z-number distance measure considers the impact of its reliability component on the information risk, while the improved ORESTE ranking method introduces strong and weak ranking, using the Borda assignment function, so as to more accurately assess the performance of the program. The method can effectively assess supplier resilience and provide more reliable decision support for supply chain management.

2. Vendor evaluation system that takes resilience into account

In supply chain management, supplier selection has a direct impact on cost, quality, delivery and service. Assessing supplier resilience requires a combination of multi-dimensional indicators: traditional indicators are usually statistically analyzed through questionnaire interviews; green indicators focus on environmental competitiveness and pollution control, etc.; and resilience indicators cover key dimensions such as robustness, responsiveness, cooperation and agility, in order to cope with the risk of supply chain disruption.

There are more evaluation indicators for suppliers of resilience, and in this paper, based on the literature, we have established the first-level indicators and their second-level indicators as shown below ^[3–6]:

- (1) Supplier capabilities (C1): production capacity (C11, daily/monthly/yearly production), technological innovation capacity (C12, R&D investment/number of patents), quality control capacity (C13, quality incident rate/customer complaint rate).
- (2) Supplier resources (C2): financial strength (C21, total assets/business revenue), human resources (C22, number/quality/stability of employees), logistics resources (C23, warehouse size/transport network).
- (3) Supplier strategy (C3): risk management capability (C31, risk identification/response/risk resilience), flexible supply chain management capability (C32, inventory strategy/market response), sustainability strategy (C33, environmental protection measures/energy management).
- (4) Supplier resilience (C4): robustness (C41, supply chain network structure/contingency planning), responsiveness (C42, response time/flexibility), co-operation (C43, willingness to co-operate/effectiveness), agility (C44, production adjustment time), visibility (C45, transparency of information), risk mitigation (C46, early warning systems), excess inventory (C47, inventory turnover), Resilience (C48, speed of recovery/effectiveness).

3. Multi-attribute decision-making method based on Z-number-ORESTE

The multi-attribute decision-making method based on Z-number-ORESTE consists of two parts: the first part adopts the Z-number to process the toughness supplier evaluation information, proposes the improved Z-number distance measure to supplement the application of the distance measure to consider the effect of the reliability part of the Z-number on the risk of the information, and reduces the loss of the information by calculating the preference distance between the suppliers, which more accurately reflects the strengths and risks of the information, and at the same time, introduces the improved Z-number distance measure to better consider the risk preferences of decision makers. In the second part, by applying the improved Z-number distance measure, the ORESTE ranking method is used to rank the options.

3.1. Z-number and its improved distance measure

3.1.1. Z-number

Z-number, consists of two parts: A and B . A denotes the range of possible values of the uncertain variable X , and B denotes the reliability of A . Z-number represents the superiority of the information by taking into account the randomness of the uncertain variable X and the reliability of the information. z-number is expressed as:

$$X_{is}(A,B) \quad (1)$$

3.1.2. Improved Z-number distance measures

Z-number can effectively express the uncertainty of information and is widely used in multi-objective decision-making problems. In this paper, combined with the preferred distance measure proposed by Shen *et al.*, an improved Z-number distance measure is proposed ^[15]. The specific steps include:

(1) Suppose two Z-numbers $Z_1=(A_1,B_1)$ and $Z_2=(A_2,B_2)$. Calculation of affiliation degree

$$\mu A\alpha(x)=\alpha\mu A(x) \quad (2)$$

where $\mu A(x)$ is the affiliation function of the Z-number A and α is the exact value of the reliability part B of the Z-number. Using the value of the affiliation function of $Z\alpha$, the degree of affiliation of each $Z\alpha$ at different values of x is calculated.

(2) Define the improved Z-number distance measure $Z_1=(A_1,B_1)$ and $Z_2=(A_2,B_2)$ correspond to the potential probability expectation intervals $EZ_1=[a_1,b_1]$ and $EZ_2=[a_2,b_2]$, respectively.

(3) The improved Z-number distance measure $D=(Z_1,Z_2)$ is calculated as follows:

$$D(Z_1,Z_2)=d_1+d_2+d_3 \quad (3)$$

$$d_1=\frac{|a_1-a_2|+|b_1-b_2|}{2} \quad (4)$$

$$d_2=\int [0,1] |\mu Z\alpha_1(x)-\mu Z\alpha_2(x)| dx \quad (5)$$

$$d_3=\frac{|\mu Z\alpha_1(c_1)-c_2|+|\mu Z\alpha_2(c_2)-c_1|}{2} \quad (6)$$

$$c_1=\frac{a_1+b_1}{2} \quad (7)$$

$$c_2=\frac{a_2+b_2}{2} \quad (8)$$

where d_1 is the average distance between two Z-number expectation intervals; d_2 is the integral distance of its affiliation function on the domain $[0,1]$, and the affiliation functions of $Z\alpha_1$ and $Z\alpha_2$ are $\mu Z\alpha_1$ and $\mu Z\alpha_2$; d_3 is the union distance of the affiliation functions, and c_1 and c_2 are the centroids of EZ_1 and EZ_2 , respectively.

3.2. Z-number-ORESTE ordering

The ORESTE sequencing method is an effective multi-attribute decision-making method that achieves an

accurate sequencing of solutions through a combination of weak and strong sequencing. The improved ORESTE sorting method involves several structured steps for handling multi-attribute decision-making problems ^[19]. First, a decision problem is defined, consisting of m scenarios (objects) denoted as $(A_i (1 < i \leq m))$, and n evaluation attributes. Experts are then invited to provide evaluation information for each scenario under each attribute using Z-numbers, which account for both the estimated performance and the confidence in that estimation. Based on the evaluation data, an improved Z-number distance measure is employed to calculate the distances between Z-numbers across different scenarios under the same attribute. These distance values reveal the differences in performance and provide critical input for subsequent stages, such as determining the weak ranking, constructing the Preference Intensity Relation (PIR) structure, and establishing the strong ranking. The distance of each scenario from the optimal one under the same attribute is also calculated to support this analysis. Following this, weak ranking is determined by assigning preference score values to each scenario, where a lower score indicates a higher rank. To further analyze preference relationships, the PIR structure is constructed by calculating the preference intensity between each pair of scenarios. This allows for an intuitive understanding of the relative advantages among alternatives. To align with human cognitive behavior in decision-making, non-differentiation and non-comparability thresholds are introduced. These thresholds ensure that scenarios perceived as indistinct or incomparable due to minor or ambiguous differences are treated accordingly in the model. The detailed formulas and calculation steps involved in this process are applied in sequence to achieve a structured, accurate, and human-centered decision analysis.

The calculation steps and formulas are as follows:

(1) Calculate the preference intensity, average preference intensity, and net preference intensity of a program (object) relative to another program(object) under the attributes.

$$\Delta T(Z_i, Z_j) \quad (9)$$

$$\overline{\Delta T(Z_i, Z_j)} = \frac{\sum_{k=1}^n \Delta T(Z_i, Z_j)_k}{n} \quad (10)$$

$$\Delta T_{net}(Z_i, Z_j) = \overline{\Delta T(Z_i, Z_j)} - \overline{\Delta T(Z_j, Z_i)} \quad (11)$$

where $\Delta T(Z_i, Z_j)$ denotes the preference strength of scheme Z_i with respect to scheme Z_j under a certain attribute; n is the total number of attributes; $\overline{\Delta T(Z_i, Z_j)}$ is the average preference strength of scheme Z_i with respect to scheme Z_j ; $\Delta T(Z_i, Z_j)_k$ denotes the preference strength of scheme Z_i with respect to Z_j under the k_{th} attribute. $\Delta T_{net}(Z_i, Z_j)$ denotes the net preference intensity of scheme Z_i with respect to scheme Z_j .

(2) Determine the undifferentiated threshold.

$$\delta = \sqrt{\frac{\alpha(s_2) - \alpha(s_1)}{2}} \quad (12)$$

where $\alpha(s)$ is the score function. The no-difference threshold is used to determine the circumstances under which the programs(objects) are undifferentiated, and the programs(objects) are considered to be undifferentiated from each other when the absolute value of their net preference intensity is less than the no-different threshold.

(3) The incomparable threshold is obtained and calculated as follows:

$$\mu = \delta \quad (13)$$

$$\sigma = \frac{\Delta + \mu}{2} \quad (14)$$

where Δ is a variable related to the strength of net preference. The non-comparable threshold is used to determine the circumstances under which a program(object) is non-comparable.

(4) Preference thresholds are obtained and the program is determined by Equation (11):

$$\begin{cases} \Delta_{x_i, x_j} > \sigma & X_i \text{ has a clear preference for } X_j, \\ |\Delta_{x_i, x_j}| \leq \delta & \text{No difference between } X_i \text{ and } X_j, \\ \delta < |\Delta_{x_i, x_j}| \leq \sigma & X_i \text{ is not comparable to } X_j, \end{cases} \quad (15)$$

(5) Based on the preference thresholds and the non-comparable thresholds, the PIR relationships between the programs are established, i.e., the three relationships of preference, non-comparable and undifferentiated.

(6) Determine strong ordering. Based on the PIR relationship of the scheme (object), strong ordering is performed and the strong ordering result is obtained.

(7) Precise sorting. According to the PIR relationship, the scheme (object) is sorted, and the Borda assignment function is used to accurately sort the results of the strong sorting to get the final sorting value, the higher the Borda value, the more the scheme (object) is sorted forward.

$$g_{ij} = \begin{cases} 1 & X_i \text{ has a clear preference for } X_j, \\ 0 & \text{No difference between } X_i \text{ and } X_j, \\ -1 & X_i \text{ is not comparable to } X_j, \end{cases} \quad (16)$$

$$Borda(X_i) = \sum_{j=1}^m g_{ij} \quad (17)$$

4. Case study

An electronic enterprise mainly engaged in the production of smartphones, in the face of fierce competition in the market, fast product iteration, technical pressure, and other challenges, the need to choose from the supplier A_1, A_2, A_3 in the best 1-2 suppliers for long-term co-operation. Supplier A_1 is a large supplier, strong capacity, technological innovation and quality control excellence, resource-rich and high toughness, strong willingness to cooperate; supplier A_2 is a medium-sized enterprises, capacity, innovation, quality control, resources and toughness are at a medium level, medium willingness to co-operate; supplier A_3 is small in scale, capacity, innovation, quality control are weak, limited resources, toughness is weak, the willingness to co-operate in general. Specific steps are as follows:

(1) **Table 1** shows the raw data of the enterprise's evaluation of suppliers A_1, A_2 , and A_3 .

Table 1. Data from expert surveys

Norm	A ₁	A ₂	A ₃
C11	(500,600,700)	(400,600,600)	(300,400,500)
C12	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.4,0.5,0.6)
C13	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.6,0.7,0.8)
C21	(1000,1200,1400)	(800,1000,1200)	(600,800,1000)
C22	(200,220,240)	(150,170,190)	(100,120,140)
C23	(10,12,14)	(8,10,12)	(6,8,10)
C31	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.5,0.6,0.7)
C32	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.4,0.5,0.6)
C33	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.6,0.7,0.8)
C41	(0.5,0.6,0.7)	(0.7,0.8,0.9)	(0.6,0.7,0.8)
C42	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.4,0.5,0.6)
C43	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.6,0.7,0.8)
C44	(0.5,0.6,0.7)	(0.4,0.5,0.6)	(0.3,0.4,0.5)
C45	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.4,0.5,0.6)
C46	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.5,0.6,0.7)
C47	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.6,0.7,0.8)
C48	(0.9,1.0,1.0)	(0.8,0.9,1.0)	0.8,0.9)

(2) **Table 2** shows the data and Z-number construction after standardization of suppliers A₁, A₂ and A₃.

Table 2. Construction of standardized data and Z-numbers

Norm	A ₁	A ₂	A ₃
C11	(0,0.33,0.67,0.9)	(0,0.33,0.67,0.85)	(0,0.33,0.67,0.8)
C12	(0.25,0.29,0.33,0.8)	(0,0.17,0.33,0.8)	(0,0.17,0.33,0.75)
C13	(0.33,0.37,0.42,0.95)	(0.25,0.33,0.42,0.9)	(0.25,0.33,0.42,0.85)
C21	(0.25,0.29,0.33,0.85)	(0,0.17,0.33,0.75)	(0.25,0.33,0.42,0.8)
C22	(0,0.33,0.67,0.9)	(0,0.33,0.67,0.85)	(0,0.33,0.67,0.85)
C23	(0,0.33,0.67,0.8)	(0,0.33,0.67,0.8)	(0,0.33,0.67,0.8)
C31	(0.25,0.29,0.33,0.85)	(0,0.17,0.33,0.8)	(0,0.17,0.33,0.75)
C32	(0.25,0.29,0.33,0.8)	(0,0.17,0.33,0.75)	(0,0.17,0.33,0.7)
C33	(0.33,0.37,0.42,0.95)	(0.25,0.33,0.42,0.9)	(0.25,0.33,0.42,0.85)
C41	(0,0.33,0.67,0.9)	(0,0.17,0.33,0.85)	(0,0.17,0.33,0.8)
C42	(0.25,0.29,0.33,0.85)	(0,0.17,0.33,0.8)	(0,0.17,0.33,0.75)
C43	(0.33,0.37,0.42,0.95)	(0.25,0.33,0.42,0.9)	(0.25,0.33,0.42,0.85)
C44	(0,0.33,0.67,0.9)	(0,0.33,0.67,0.85)	(0,0.33,0.67,0.8)
C45	(0.25,0.29,0.33,0.85)	(0,0.17,0.33,0.8)	(0,0.17,0.33,0.75)
C46	(0.25,0.29,0.33,0.8)	(0,0.17,0.33,0.75)	(0,0.17,0.33,0.7)
C47	(0.33,0.37,0.42,0.95)	(0.25,0.33,0.42,0.9)	(0.25,0.33,0.42,0.85)
C48	(0.33,0.37,0.42,0.95)	(0.25,0.33,0.42,0.9)	(0.25,0.33,0.42,0.85)

(3) **Table 3** shows the results of the combined evaluation of suppliers A_1 , A_2 , and A_3 . A comprehensive evaluation of suppliers A_1 , A_2 , and A_3 is performed through Equation (2).

Table 3. Comprehensive evaluation results

Object	Potential probability expectation interval	Combined fuzzy number	Degree of affiliation (math.)
A_1	0.75875	(0.74875,0.75875,0.76875)	0.75875
A_2	0.67875	(0.67875,0.68875,0.69875)	0.68875
A_3	0.63875	(0.63875,0.64875,0.65875)	0.64875

(4) **Table 4** shows the comparative distances of suppliers A_1 , A_2 , and A_3 . Comparative distances of suppliers A_1 , A_2 , and A_3 are calculated by Equations (3)–(8).

Table 4. Results of the distance comparison among suppliers

Norm	$D(A_1, A_2)$	$D(A_1, A_3)$	$D(A_2, A_3)$
C11	0.2585	0.32	0.305
C12	0.22	0.28	0.265
C13	0.205	0.26	0.245
C21	0.23	0.29	0.275
C22	0.245	0.305	0.29
C23	0.26	0.32	0.305
C31	0.22	0.28	0.265
C32	0.235	0.30	0.285
C33	0.205	0.26	0.245
C41	0.24	0.30	0.285
C42	0.235	0.30	0.285
C43	0.205	0.26	0.245
C44	0.25	0.31	0.295
C45	0.235	0.30	0.285
C46	0.22	0.28	0.265
C47	0.205	0.26	0.245
C48	0.21	0.27	0.255

(5) The distance between supplier A_1 and other suppliers on most indicators is relatively small, yielding: supplier $A_1 >$ supplier $A_2 >$ supplier A_3 .

(6) The PIR structure of suppliers A_1 , A_2 , and A_3 is obtained through Equation (9)–(11). **Table 5** shows the preference intensity of suppliers A_1 , A_2 , and A_3 , and **Table 6** shows the average preference intensity and net preference intensity of suppliers A_1 , A_2 , and A_3 .

Table 5. Preference intensity

Norm	A ₁ &A ₂	A ₁ &A ₃	A ₂ &A ₃
C11	0.05	0.1	0.05
C12	0.04	0.08	0.04
C13	0.03	0.06	0.03
C21	0.04	0.08	0.04
C22	0.05	0.1	0.05
C23	0.06	0.12	0.06
C31	0.04	0.08	0.04
C32	0.05	0.1	0.05
C33	0.03	0.06	0.03
C41	0.04	0.08	0.04
C42	0.05	0.1	0.05
C43	0.03	0.06	0.03
C44	0.06	0.12	0.06
C45	0.05	0.1	0.05
C46	0.04	0.08	0.04
C47	0.03	0.06	0.03
C48	0.03	0.06	0.03

Table 6. Average preference intensity and net preference intensity

	Z ₁	Z ₂	Z ₃
$\Delta T(Z_1, Z_i)$	0	-0.133	-0.6
$\Delta T(Z_2, Z_i)$	0.133	0	-0.533
$\Delta T(Z_3, Z_i)$	0.6	0.533	0
Z ₁	0	0.133	0.2
Z ₂	0.133	0	0.133
Z ₃	0.2	0.133	0

(7) The score functions $\alpha(0)=0$, $\alpha(1)=1$, $\Delta=0.6$ are known and the undifferentiated threshold $\delta = \frac{\sqrt{2}}{2} \approx 0.707$ is obtained through Equation (12).

(8) Using Equations (13)–(15), preference threshold $\mu=5$, incomparable threshold $\sigma = \frac{0.6+1}{2} = 0.8$, and PNR structure of suppliers A₁, A₂, and A₃, **Table 7** shows the conclusions of the PNR relationships.

Table 7. The PIR relationship

Object	Net preference intensity	Judgment of relationship to threshold	PNR relationship conclusion
A1&A2	0.133	$0.133 < 0.707$ $0.133 < 0.8$	No difference
A1&A3	0.6	$0.6 < 0.707$ $0.6 < 0.8$	No difference
A2&A3	0.533	$0.533 < 0.707$ $0.533 < 0.8$	No difference

(9) The strong ordering of suppliers A_1 , A_2 , and A_3 is obtained through Equation (16): supplier $A_1 >$ supplier A_2 (undifferentiated relationship, can be juxtaposed), supplier $A_1 >$ supplier A_3 , and supplier $A_2 >$ supplier A_3 (undifferentiated, can be juxtaposed). At the same time, through Equation (17), the above results are sorted using the Borda assignment function to obtain: the Borda value of Supplier A_1 is 1.5, the Borda value of Supplier A_2 is 1, and the Borda value of Supplier A_3 is 0.5, which gives the final sorting result: Supplier $A_1 >$ Supplier $A_2 >$ Supplier A_3 .

(10) Based on the above results, the ranking results of suppliers are: Supplier $A_1 >$ Supplier $A_2 >$ Supplier A_3 . As a result, it is obtained that Supplier A_1 is selected as the best partner for the following reasons:

- (a) Supplier A_1 has the highest overall affiliation (0.75875), indicating the best overall performance.
- (b) Supplier A_1 's net preference intensity relative to A_2 and A_3 are positive (0.133 and 0.6, respectively), and compared to the distance is smaller, the indicator advantage is outstanding.
- (c) Supplier A_1 has obvious advantages in toughness dimensions (e.g., robustness, etc.) and can effectively guarantee supply chain stability.
- (d) All evaluation systems (e.g., PIR relationship, net preference intensity, etc.) verify that Supplier A_1 is leading in production capacity, technological innovation, quality control, resources, strategic management, and resilience, which significantly reduces the risk of supply chain disruption.

In summary, Supplier A_1 is the best choice to provide high-quality products and services to the enterprise, while enhancing the resilience and competitiveness of the supply chain. The final result is obtained: Supplier A_1 is the best choice, supplier A_2 is the next best, and supplier A_3 is the last.

5. Conclusion

This paper proposes a resilient supplier evaluation method based on improved Z-number-ORESTE, which aims to effectively assess the resilience and adaptability of suppliers in the face of unexpected events and risks. The method evaluates the program(object) more accurately by constructing a multi-level evaluation index system containing supplier capabilities, resources, strategies, and resilience, and combining the improved Z-number distance measure and ORESTE ranking method for multi-attribute decision-making. Through case studies, this paper verifies the feasibility and effectiveness of the method. The results show that the method can effectively identify and select resilient suppliers and provide more reliable decision support for enterprise supply chain management. However, the method has some shortcomings, such as the strong dependence on experts in the ORESTE ranking method, as well as the fact that it is mainly applicable to decision-making problems with more qualitative indicators. Future research directions could include reducing the dependence on experts, integrating the method with other multi-attribute decision-making methods, and applying it to other fields to expand its

application scope. It is believed that as the research continues, the resilient supplier evaluation method based on improved Z-number-ORESTE will be further improved and play a greater role in the field of supply chain management.

Disclosure statement

The authors declare no conflict of interest.

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Visual Analysis of Smart Supply Chain Based on CiteSpace

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Abstract: Under the trend of economic globalization, the importance of supply chains has gradually become prominent, especially with the transformation and upgrading of China's industrial chains in recent years. Supply chain transformation has emerged as a significant focus of current academic research, and the construction of smart supply chains represents an inevitable development trend. This paper utilizes 1,051 research articles on smart supply chains published in core journals on China National Knowledge Infrastructure (CNKI) from 2014 to 2024 as the data source. It analyzes the literature data using CiteSpace software, visually exploring and revealing the frontiers and hotspots of domestic research on smart supply chains. The data analysis reveals that academic research in this field is at a stage of steady and healthy development. Domestic research trends include the cooperative mechanisms of smart supply chains in manufacturing, the operational mechanisms of smart supply chains in agriculture, and systematic research on influencing factors of smart supply chains.

Keywords: Bibliometrics; CiteSpace; Smart supply chain; Visual analysis

Online publication: July 15, 2025

1. Introduction

China's logistics market has gradually expanded in recent years and has now become the largest logistics market globally. The "Guiding Opinions on Actively Promoting Innovation and Application of Supply Chains" issued by the General Office of the State Council in October 2017 points out that it is necessary to center on improving development quality and efficiency, achieve deep integration among supply chains, the Internet, and the Internet of Things, effectively integrate various resources and elements, and build a smart supply chain system supported by big data, featuring networked sharing, and intelligent collaboration. Against this backdrop, strengthening logistics construction and building an independent and complete supply chain system are of great significance for establishing a new development phase, implementing new development concepts, constructing a new development paradigm, and promoting high-quality development. With the support of national policies and the continuous advancement of reforms, smart supply chain research has garnered significant attention from scholars. To better sort out the research context of smart supply chains, this study employs the CiteSpace analysis tool to conduct a visual analysis of related research on smart supply chains in the CNKI (China National Knowledge Infrastructure)

core database. By synthesizing keyword co-occurrence and clustering, this study analyzes the hotspots and development trends of domestic smart supply chain research.

2. Data sources and research tools

2.1. Data sources

For this study, core journals included in CNKI (such as CSSCI, CSSCD, etc.) were used as the data source, with a search time range set from 2014 to 2024. The search was conducted using precise keywords such as “smart supply chain” or “big data.” A total of 1,188 research articles related to smart supply chains were retrieved. After manually excluding irrelevant documents such as conference announcements, authorless documents, interview reports, etc., 1,051 document data were obtained. These data were finally exported and saved in CNKI’s Refworks format ^[1].

2.2. Research Tools

CiteSpace is a data visualization analysis tool dedicated to academic literature analysis, capable of detecting hot topics and their evolutionary characteristics within a discipline or field ^[2]. The specific steps for analyzing smart supply chain research data using CiteSpace software are as follows: Firstly, the full records and cited references of the 1,051 articles were exported in plain text format, converted, and saved. After importing the saved text data, the panel operation parameters were selected, with “Time Slicing” set to “2014 JAN - 2024 DEC” and “Years Per Slice” set to “1.” Through the above analysis, the current research status in the field of smart supply chains was summarized. By selecting “Keyword” under “Node Types,” the obtained knowledge map could display the research hotspots in the analyzed field, providing a basis for grasping valuable development directions and research trends.

3. Temporal and spatial knowledge map and analysis of smart supply chain research

3.1. Temporal distribution map of smart supply chain themes

The annual number of publications in a particular field can reflect, to a certain extent, the academic research level and overall development trend of that field. Furthermore, statistical analysis of the annual number of publications in a field helps to objectively understand and predict the research hotspots and development trends in that field ^[3]. To delve deeper into the knowledge output in the domestic field of smart supply chain research, this study conducted a statistical analysis of research articles related to smart supply chains published in core journals of CNKI from 2014 to 2024. The resulting trend chart of the annual number of publications in the field of smart supply chain research is shown in **Figure 1**.

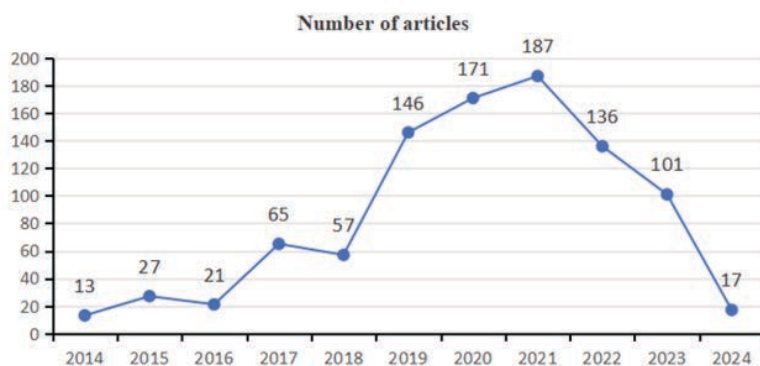


Figure 1. Statistics of annual literature on smart supply chain.

As can be seen from **Figure 1**, research on smart supply chains is currently in a rapid development phase, with a significant focus on big data, artificial intelligence, and smart logistics, among other areas ^[4]. Based on a growth model, the development of smart supply chain research can be divided into two stages: from 2014 to 2018 was the exploratory phase of smart supply chain research, with an average annual publication volume of less than 100 articles domestically and internationally before 2019. From 2019 to 2024 is the rapid growth phase, during which the domestic publication volume has increased, averaging more than 100 articles per year. Overall, the number of publications on smart supply chain research over the years has shown a steady upward trend. Even though the COVID-19 pandemic has affected recent years, there has been no decrease in the number of publications; instead, there has been a significant increase. This indicates that more scholars hold a high level of enthusiasm for research and have begun to prioritize the smartening of supply chains. Therefore, there is a strong possibility of continued growth in related fields in the future.

3.2. Spatial distribution map of disciplines in smart supply chain research

To understand the current high-productivity academic groups and institutions in the field of smart supply chain research, this study counted the number of papers published by various research institutions in this field. The top five institutions with the highest number of papers are Tianjin University, Renmin University of China, Jiangsu University, Jiangxi University of Science and Technology, and China Federation of Logistics and Purchasing. This indicates that these five institutions possess greater research depth and potential in the field of smart supply chain research. Among them, Tianjin University, Nankai University, Northeastern University, Hunan Business University, and the National Natural Science Foundation of China have formed small-scale cooperative research groups ^[5]. The top 15 research institutions have all published more than 5 papers, demonstrating that smart supply chain research has received widespread attention from academic groups and institutions in recent years and has achieved certain research results.

Research institutions are the main force in discipline research and undertake many scientific research tasks. In recent years, a large number of research institutions focused on smart supply chains have emerged. To understand the cooperation between different research institutions, CiteSpace software was used, and “institution” (research institution) was selected as the keyword in the node type box to generate a map of institutions involved in smart supply chain research. The nodes represent institution names, the size of the nodes indicates the number of published papers, the font size of the labels represents the level of centrality, and line segments connect cooperating institutions ^[6]. The cooperation network diagram of smart supply chain research institutions contains 358 nodes and 106 lines, with a network structure compactness of 0.0016. This indicates that the academic groups engaged in smart supply chain research are relatively dispersed, with limited cooperation and strong cohesion among different research institutions. A cohesive research institution network has yet to be formed.

4. Analysis of hot topics and trends in smart supply chain

4.1. Analysis of research hotspots in smart supply chain

4.1.1. Keyword-based analysis of research hotspots

High-frequency and high-centrality keywords serve as the focal points and essence of articles, reflecting to some extent the hot topics that experts and scholars in the field have concerned over a period of time. By conducting a keyword analysis using CiteSpace, the top 23 high-frequency keywords is obtained, along with a co-occurrence knowledge graph of these keywords, to explore the research hotspots in the field of smart supply chain. Apart from the most central keyword “smart supply chain,” terms such as “smart logistics,” “Internet of Things (IoT),”

“big data,” “smart agriculture,” and “blockchain” are located at the center of the graph and closely related to other keywords, indicating their tight integration with supply chain management, logistics, and big data construction.

These keywords represent the popular topics in smart supply chain research. In the co-occurrence network of keywords related to smart supply chain, there are 275 nodes and 149 connections, with a network density of 0.0111. Compared to the knowledge graph of institutional collaborations, it can be observed that the structural compactness of the keyword co-occurrence network has significantly improved, but it remains relatively loose overall. In future scientific research, besides maintaining close cooperation among academic groups, it is also necessary to maintain focus and conduct in-depth research on these topics [7].

Based on the **Table 1** analysis, “smart logistics” is the keyword with the highest frequency of occurrence in smart supply chain literature, primarily because “smart logistics” constitutes a major domain of the subject searched for in this research literature [8]. In addition, other high-frequency keywords mainly include “supply chain,” “Internet of Things (IoT),” “big data,” “smart agriculture,” “new retail,” “blockchain,” and “Internet Plus.” The high-frequency keywords in smart supply chain research topics tend to change over time, reflecting to some extent the shifts in research focus during the in-depth promotion and development of this field. Among all high-frequency keywords, the selected 23 keywords account for 31% of all keywords in smart supply chain research topics, indicating that these selected high-frequency keywords can effectively capture the hot topics in smart supply chain research.

Table 1. Keyword distribution in the research field of smart supply chain (Part)

Rank	Centrality	Word frequency	Key words
1	0.36	106	Smart Logistics
2	0.38	78	Supply Chain
3	0.09	28	Internet of Things
4	0.08	24	Big data
5	0.02	14	Smart agriculture
6	0.03	14	New retail
7	0.02	13	Blockchain
8	0.07	13	Agricultural products
9	0.01	13	Internet+
10	0.04	12	Smart tourism

4.2. Analysis of research hotspots based on keyword clustering

The keyword clustering function of CiteSpace can identify hot topics and development trends in a particular research field [4]. The keyword clustering analysis of the literature data was conducted using CiteSpace software. The clustering analysis yielded a Q-value (modularity value) of 0.5857 and an S-value (average silhouette value) of 0.6949, indicating that the cluster structure divided by clustering is sufficiently significant and the clustering results are convincing. However, the keywords cover a wide range of research fields, making it difficult for them to naturally cluster into tightly connected groups. This diversity may lead to less cohesive clustering results, consequently lowering the Q-value and resulting in a moderate level of significance. A total of 13 clusters were obtained through clustering analysis in the field of smart supply chain research. The clustering analysis revealed that each cluster contains 2 nodes, i.e., 2 keywords. The specific clustering results are shown in **Table 2**.

Table 2. Keyword clustering results

Serial number	Clustering results	Cluster keywords
1	Clustering#1	New retail, smart logistics
2	Clustering#2	Supply chain, big data
3	Clustering#3	Artificial intelligence, smart tourism
4	Clustering#4	Smart agriculture, Internet of Things
5	Clustering#5	Digitization, blockchain
6	Clustering#6	Agricultural products, Internet+
7	Clustering#7	Supply chain visualization, ai prediction
8	Clustering#8	Automated storage, chain finance
9	Clustering#9	Sensor Technology, analytics hub
10	Clustering#10	Data-driven, predictive analytics
11	Clustering#11	Blockchain tracing, green logistics
12	Clustering#12	Data analysis, supply chain resilience
13	Clustering#13	Supply chain networks, supply chain innovation

4.3. Analysis of research frontiers in teacher education disciplines

4.3.1. Analysis of research frontiers based on emerging keywords

Research frontiers refer to a series of emerging dynamic concepts and potential research questions, while emerging vocabulary denotes terms that are frequently cited or appear in relevant literature within a short period ^[9]. Over a certain timeframe, the scientific issues or themes discussed in a group of literature based on emerging vocabulary can serve as one of the criteria for identifying and predicting research frontiers. In this study, the CiteSpace tool is utilized to analyze and explore sample data related to the field of smart supply chain research, and 13 emerging keywords are identified, as shown in **Table 3**.

Table 3. Emerging keywords in the research field of smart supply chain

Key words	Emergent strength	Start year	End year
Smart logistics	5.85	2014	2018
Internet of Things	3.2	2014	2016
Logistics management	1.28	2014	2015
Smart port	1.5	2015	2018
Mode innovation	1.02	2016	2017
Collaborative Development	1.77	2017	2019
JD.com	1.77	2017	2019
Countermeasures	1.14	2017	2018
Information technology	1.14	2017	2018
Smart manufacturing	1.05	2018	2019
Pandemic	1.7	2020	2021
Smart supply chain	1.54	2020	2021
Development pathway	1.17	2022	2024

5. Conclusion

There are valuable research opportunities in smart supply chain research, and future studies can be conducted from the following three aspects. Firstly, identifying the obstacles to the operation of smart supply chains. Taking corporate smart supply chains as the research object, it is necessary to address the obstacles in the operation of smart supply chains across different industry sectors^[10]. Breakthroughs can be sought in areas such as the standardization of data and processes, intellectual property protection, and the cultivation of digital human resources. Secondly, optimizing smart supply chains in specific industries. In addition to smart supply chains in the circulation industry, further efforts should be made to enhance the optimization of smart supply chains in manufacturing, agriculture, and new retail, thereby improving the performance of smart supply chains. Thirdly, studying the evolution of smart supply chain ecosystems. Smart supply chains constitute an ecosystem comprising smart procurement, smart logistics, smart warehousing, and smart distribution. A key driving force within this ecosystem is data resources. Digital twins can enable innovation and integration within smart supply chains. In the context of digital twins, future research will focus on smart supply chain modeling, real-time optimization of smart supply chains, data utilization in smart supply chain collaboration, and the evolution of smart supply chain ecosystems.

Disclosure statement

The authors declare no conflict of interest.

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Research on the Impact of Digital Finance Development on Bank Credit

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Abstract: The rapid development of digital finance is profoundly changing the structure and management mode of bank credit. Through mobile banking, artificial intelligence, big data, cloud computing, and online lending platforms, banks are able to optimize credit services, increase efficiency, and improve access to credit ^[1]. This evolution began in the late 20th century and accelerated after the 2008 global financial crisis. Through automated approval, precise risk assessment, and real-time monitoring, digital finance has improved credit efficiency, reduced costs, promoted financial inclusion, and enabled groups not covered by traditional financial services to gain support. However, the popularity of digital finance has also brought new challenges, such as consumer protection, cybersecurity, and fraud risks, and there is an urgent need to update the regulatory framework to address these issues. Nonetheless, the technological spillover effects of digital finance have promoted bank credit innovation and improved market competitiveness. This paper analyzes the role of digital finance in credit efficiency, cost, risk management, and financial inclusion, and puts forward policy recommendations to deal with potential risks and ensure the stability and sustainable development of the financial system.

Keywords: Digital finance; Bank credit; Research

Online publication: July 15, 2025

1. Introduction

The integration of digital finance has significantly promoted the growth of bank credit, and the growth rate of personal loans in particular has exceeded that of traditional credit loans. Digital technology not only helps banks optimize their credit structure and reduce the risks of traditional lending models, but also improves operational efficiency and service quality. However, this transformation has also brought new challenges, such as consumer protection issues, cybersecurity threats, and increased risk of fraud. These issues have led to ongoing discussions on whether the existing regulatory framework is adequate to safeguard consumer rights and financial stability.

Overall, the interaction between the development of digital finance and bank credit illustrates a dynamic and rapidly changing financial environment. While digital finance offers important opportunities to improve the

availability of credit and increase the efficiency of banks, it is also important to be alert to potential risks to ensure the long-term stability of the financial system. As a result, the continued evolution of digital finance has become a central concern for researchers, regulators, and financial practitioners around the world.

2. The development of digital finance

The rapid evolution of digital finance is profoundly changing the banking industry, especially in the field of bank credit. Since the end of the 20th century, digital technology has been gradually integrated into the banking sector with technological advances and shifts in consumer behavior, bringing a revolution to financial services. This transformation process accelerated after the 2008 global financial crisis, with regulatory reforms driving the introduction of more stringent regulations to safeguard the stability of the financial system and enhance consumer protection.

Since the 1980s, the advent of the banking data era has marked significant advances in banking data management and reporting practices. The regulatory environment has evolved in response, notably with the implementation of the Dodd-Frank Act in the United States, which after the financial crisis aimed to address vulnerabilities in the financial system, strengthen capital requirements, and improve banks' risk management practices. At the same time, these regulations have driven innovation in banks' data practices and the adoption of digital financial solutions, increasing transparency and accountability among financial institutions.

The rise of digital finance has significantly changed the banking and financial services landscape, redefining how financial activities are performed and delivered. The following technologies are being applied to bring greater convenience, efficiency, and accessibility to consumers and businesses.

2.1. Mobile banking

Mobile banking has become an important part of digital finance, allowing users to manage financial accounts from their smartphones anytime, anywhere, for operations such as balance inquiries, fund transfers, bill payments, and loan applications. With biometric authentication and encryption protection, users are able to securely access their accounts and enjoy a convenient banking experience. In addition, features such as mobile check deposit further reduce the need for customers to travel to bank branches, greatly improving user convenience.

2.2. Artificial Intelligence (AI)

Artificial intelligence is revolutionizing bank operations by optimizing processes and enhancing the customer experience. AI-powered chatbots provide 24/7 service, significantly reducing customer wait times and increasing customer satisfaction. AI algorithms are able to analyze massive amounts of data, identify unusual patterns, and enhance fraud detection and risk management capabilities. At the same time, AI technology can also provide customers with personalized financial advice to enhance user engagement and loyalty.

2.3. Big Data and cloud computing

The combination of big data and cloud computing enables banks to analyze customer behavior and preferences more precisely, thereby improving credit assessment and risk prediction. The application of these technologies has accelerated the updating of financial products and services, increased customer satisfaction, and improved the overall quality of services.

2.4. Online lending platforms

Online lending platforms have subverted the credit structure of traditional banks and provided alternative financing solutions ^[2]. For example, platforms such as Ant Huabei and JD Baitiao enable customers to obtain loans quickly and easily, providing financial institutions with diversified sources of income and reducing reliance on traditional credit card businesses. This shift to digital lending has increased financial inclusion, especially in regions where traditional banking services are less widely available.

2.5. Digital payment solutions

Digital payment platforms, such as Alipay and WeChat Pay, have dramatically changed the way consumers pay, reducing the reliance on cash transactions. By providing instant fund transfer and payment processing functions, these platforms have simplified financial transactions and boosted users' convenience and transaction efficiency, becoming an integral part of today's financial ecosystem.

In conclusion, advances in digital finance have not only improved the efficiency and accessibility of bank credit, but also provided a strong impetus for the popularization and innovation of financial services worldwide. However, as technology continues to evolve, the relevant regulatory framework and risk management mechanisms need to be updated with it to ensure the stability and sustainability of the financial system.

3. The impact of digital finance on bank credit

The integration of digital finance has significantly increased the scale of bank credit, especially the growth of personal loans. By adopting digital financial technologies, banks are able to optimize their credit structure and reduce the risk burden in traditional lending practices. However, while the advantages of digital finance in improving credit access and operational efficiency are clear, issues such as consumer protection and the risk of fraud remain. As the financial sector responds to these changes, it remains critical to balance innovation with a strong regulatory framework to protect consumers and ensure the long-term stability of the banking system ^[3].

Digital finance has significantly changed the landscape of bank credit, affecting the structure of credit products and the associated risks. The integration of digital financial technology has not only expanded the scale of bank credit, but also prompted a significant change in the ratio of personal loans to credit loans, thus easing some of the risk burden that banks usually face. With the continuous development of digital finance, banks need to adjust their credit structure, which further affects their risk exposure and overall stability ^[4].

3.1. Data privacy and security

Data privacy is another major concern when Large Language models (LLMs) are deployed in the financial industry. The risk of exposing personally identifiable information (PII) during data analysis necessitated strong privacy regulations and strict data processing protocols. In addition, financial institutions must prioritize transparency in their methods of data collection and processing in order to maintain customer trust. Ensuring diversity and representation in data sets is critical to preventing discriminatory outcomes, as biased or incomplete data can lead to unfair treatment of individuals in financial decisions.

The impact of digital finance on bank credit is far-reaching and multifaceted, and with the rapid development of financial technology (FinTech), significant changes have taken place in areas such as bank credit models, credit processes, and risk management ^[5]. The following are the main impacts of digital finance on bank credit:

(1) Improve credit efficiency

The traditional credit approval process is often cumbersome and time-consuming, requiring banks to manually review numerous applications, collect data, and conduct credit analyses. However, automation and artificial intelligence (AI) are streamlining these tasks, improving efficiency, and accuracy. While digital finance has made credit approval automatic by introducing technologies such as artificial intelligence, big data analysis, and machine learning, which has greatly improved efficiency ^[6].

(2) Reduce credit costs

Traditional bank credit approval usually requires a lot of manual participation, and every link from customer application, data review to credit issuance may involve high labor and administrative costs. Through automation, process optimization, and technical support, digital finance helps banks reduce manual intervention in these links, reducing the operating costs of credit services ^[7].

(3) Broaden the target group for credit

Small and medium-sized enterprises (SMEs) have long been a weak link in traditional bank credit services, mainly because they lack adequate credit history, asset guarantees, or financial transparency, leading to greater risks in lending.

(4) Improve credit risk management capabilities

Traditional bank credit risk assessment mainly relies on static information such as financial statements and credit history provided by borrowers, which may be difficult to fully understand the actual repayment ability of borrowers. Digital finance, through technologies such as big data and artificial intelligence, can make a comprehensive assessment from more dimensions and dynamic information, such as transaction data, behavioral data, social data, etc., thus improving the accuracy of risk identification ^[8].

(5) Financial inclusion and market penetration

The popularity of digital finance has enabled banks to extend credit services to groups not covered by traditional financial services, especially low-income people, young people, and customers in remote areas. These groups often find it difficult to obtain loan support in the traditional banking system, but digital finance can effectively reach these potential customers through its low threshold, fast approval, and flexible repayment features.

(6) Enhance competition in the financial market

The rise of digital finance has seen many financial technology companies (FinTech) start to enter the bank credit space, and these companies often rely on more flexible technologies and innovative business models to attract customers, reduce costs, and optimize services ^[9]. These companies innovate faster in products and services, bringing greater competitive pressure to traditional banks, forcing them to speed up their digital transformation and improve their own credit service capabilities and efficiency ^[10].

4. Suggestions

First, take advantage of technology spillover effect to optimize credit risk management. At present, the impact of digital finance on the credit risk of commercial banks has passed the inflection point, the competition effect has weakened, and the technology spillover effect has gradually increased. Banks should actively absorb the technology spillover effects brought about by digital finance, and combine technologies such as big data, cloud computing, and artificial intelligence to optimize credit risk management, reduce costs, and improve efficiency, so

as to lay a solid foundation for strengthening credit risk management ^[11].

Second, expand deposit channels and reduce the cost of liabilities. In the face of fierce deposit competition, banks should not over-rely on financing channels such as interbank liabilities. Technologies such as big data, cloud computing, blockchain, and artificial intelligence should be used to broaden deposit channels, increase low-cost customer deposits, and reduce the cost of interest-bearing liabilities. At the same time, it should actively expand medium - and long-term deposits, optimize the debt structure, and reduce reliance on short-term wholesale financing ^[12].

Additionally, promote digital transformation in a differentiated manner. Different types of banks should adopt differentiated digital transformation strategies for credit risk management according to their own development conditions ^[13]. Large banks can accelerate the transformation process by establishing their own technology subsidiaries or cooperating with Internet companies, Small and medium-sized banks should pay attention to the impact of digital finance on deposit business, reduce their reliance on high-cost liabilities, optimize their debt structure, and steadily improve their credit risk management capabilities through cooperation and sharing of technology and risks ^[14].

Furthermore, introduce complex IT talents to improve risk management ability. Both large banks and small and medium-sized banks should actively introduce high-level IT talents to build a complex team that understands both financial risk management and information technology. Big data technology supports credit risk management and credit rating, establishes a sound monitoring and early warning model, provides technical support, and prevents and defuses potential credit risks ^[15].

5. Conclusion

The rapid development of digital finance is profoundly transforming the structure and management models of bank lending. Leveraging technologies such as mobile banking, artificial intelligence, big data, cloud computing, and online lending platforms, banks have not only improved the efficiency of credit services but also expanded the coverage of financial services, effectively promoting financial inclusion. Through automated approval processes, precise risk control, and real-time monitoring, digital finance has reduced lending costs and improved the efficiency of resource allocation, offering new financing channels for groups previously underserved by the traditional financial system.

However, the widespread adoption of digital finance has also introduced a range of new challenges, such as consumer protection, cybersecurity, and fraud risk, necessitating improvements to the regulatory framework. Despite these risks, the technological spillover effects of digital finance have significantly driven innovation in bank lending and enhanced the overall competitiveness of the financial market.

This paper conducts a systematic analysis of the role of digital finance in credit efficiency, cost control, risk management, and financial inclusion, and puts forward corresponding policy recommendations to address potential risks and ensure the stability and sustainable development of the financial system.

Disclosure statement

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Analysis and Governance of the Phenomenon of Consumption Alienation in the Context of E-commerce Festival Creation

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Abstract: In modern society, influenced by mass culture and internal alienation, people experience alienation in the consumption field. The impulsive and excessive consumption of consumers not only reflects the changes in consumption culture but is also the result of the combined action of market, technological, and psychological factors. The shopping spree in the context of e-commerce festival creation is due to the hard control of science and technology and the soft penetration of mass culture, which fully invade individuals' work and life, evoke false and excessive demands, and thus generate consumption. The practical path to get rid of consumption alienation and return to rational consumption can start from three aspects: aesthetic awakening, concept guidance, and environmental regulation.

Keywords: Consumption alienation; Symbolic consumption; Consumption culture; Internet celebrity economy

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1. Introduction

In modern society, which is based on modern technical means and mass communication media, people's alienation is all-pervasive. Influenced by mass culture, digital technology, and internal alienation, people experience alienation in the consumption field. They become alienated from their consumer goods and themselves^[1]. Consumption, divorced from its creators, becomes a dominant force, comprehensively controlling people's time, aesthetics, and psychology. Modern people gradually lose their subject status in self-satisfying consumption and ultimately become people who lose their critical spirit and identify with the existing consumption order and social reality.

2. Why it happens: The triple-driver of market, technology, and psychological mechanisms

From the spontaneous bazaars of ancient traditional festivals to the centralized promotions during the Industrial

Revolution, and then to today's e-commerce festival creation, consumption has undergone tremendous changes in social development and transformation. Online shopping, taking advantage of technological progress and relying on the sales atmosphere of "festivals equal consumption" created by anchors, has always maintained its appeal to consumers. The impulsive and excessive consumption of consumers not only reflects the changes in consumption culture but also embodies the generation logic of consumption alienation. Behind this is the joint action of market, technological, and psychological factors.

2.1. The market cycle stimulates high-consumption in society

In modern market economy, the pursuit of profit is the driving force for the survival and development of enterprises. The desire for wealth possession prompts enterprises to actively hire labor and expand production. Improving efficiency and expanding scale mean an increase in output. Enterprises must find a matching consumer market to ensure that products can be sold smoothly, so as to maintain the cycle of enterprise funds. Therefore, creating various demands to stimulate consumption has become a "business strategy". People's consumption not only satisfies their own desires but also meets the profit goals of enterprises.

The evolution of contemporary shopping festivals is an example of stimulating consumption. The time limit of shopping festivals has expanded from one day to one month, the product categories have covered from home appliances to all fields, and the promotional methods have ranged from pop-up ads to TV galas, with a wide variety of forms. This process confirms the efforts made by enterprises to ensure social consumption. Through event planning, preferential plans, and brand marketing, they convert the purchasing power of customers into enterprise profits.

2.2. Digital technology expands the possibilities of intelligent consumption

"The problem of technical rationality is the core problem of modernity"^[2]. The deep-level variation of alienated labor and the cultural oppression of modern people are closely related to science and technology, which is also an important cause of consumption alienation.

Firstly, the rise of digital technology provides strong hardware support for the operation of e-commerce platforms. During shopping festivals, merchants push promotional information and cross-platform preferential activities through the platform. A large number of consumers browse products at the same time, and frequent user payments and buying-selling interactions require extremely high network stability of the platform. Secondly, the integration of artificial intelligence and big data provides accurate data sources for inducing consumption. Artificial intelligence, driven by computing power, captures effective elements from a vast number of products by grabbing people's consumption records and browsing history. According to the user portraits fed back by the data, it sends personalized product recommendations, inducing unnecessary consumption under the temptation of a series of calculation formulas. Finally, the addition of new media marketing provides reliable pain points for impulsive consumption. The cultural life of modern people is occupied by various social media. New media placement has become a new B2C marketing model^[3]. E-commerce enterprises take advantage of the information asymmetry between buyers and sellers to spread product information on different channels. In the all-round and three-dimensional marketing advertisements, they inadvertently induce the impulsive consumption of browsers. In essence, the scale and appeal of e-commerce festival creation not only benefit from its overwhelming marketing on social media but also from the recognition of consumption culture in an alienated society.

2.3. Escape psychology generates the initiative of individual consumption

Marx revealed four forms of labor alienation in “Economic and Philosophic Manuscripts of 1844”^[4]. By the 20th century, alienation had penetrated into all aspects of society and became “the inevitable and direct reality of all people living in capitalist society”^[5]. Consumption is a compensatory way for people who suffer from the pain of alienated labor.

Firstly, alienation triggers an escape-from-reality psychology. Technical rationality brings the confirmation of self-power. While transcending nature, people also lose the shelter of nature. This separation, along with individual growth and group development, evolves into the pursuit of competitiveness, dreams, and wealth, turning into a survival pressure. Modern people feel a sense of powerlessness in both work and life. To escape the uneasiness and burden brought by technical freedom, people begin to consciously seek substitutes for nature (here, nature refers to the original nature that can provide natural shelter and is constantly transcended by human practice), “to overcome the feeling of loneliness and powerlessness”^[6]. Secondly, the escape psychology leads to the recognition of consumption value. Under the influence of the escape psychology, people become more and more dependent on any individual or institution other than themselves. People’s self-identification needs to be obtained from the confirmation of the power of others. Catalyzed invisibly by mass culture and online marketing, individuals in self-doubt increasingly identify with the values advertised. Finally, the recognition leads to compensatory consumption. In an industrial society, people have no way to escape. They have to choose a way to relieve fatigue after a busy day. Under the constraints of the cultural industry, consumption becomes the best way to escape. “Modern workers are happy to drive a new car or have a relaxing night out after a tiring day at work”^[7]. Only in consumption can people feel stress-free happiness.

3. How it continues: The dual manipulation of science and technology and mass culture

The operation logic of e-commerce festival creation is that it can continuously stimulate consumption and ensure the smooth flow of the economic cycle. The key to this stimulation lies in the hard control of science and technology and the soft penetration of mass culture, which fully invade individuals’ work and life, evoke false and excessive demands, and thus generate consumption.

3.1. Alienation

In modern society, science and technology and their development have a dual nature. On the one hand, the progress of science and technology has greatly improved production efficiency and changed the lifestyle and living standards of human beings. On the other hand, science and technology have changed from an auxiliary tool to a dominant position, and the degree of people’s alienation has become more serious, making them fall into a cultural and consumption whirlpool.

Firstly, it continuously enriches individual consumption methods. From the two-sided nature of science and technology, it can be seen that Internet technology has brought new business models and consumption mechanisms. First, installment payments and credit-based shopping constantly encourage consumers to over-consume. Second, the trade-in shopping policy constantly creates new consumption demands. Third, time-limited flash sales and pre-sale marketing induce consumers to make impulsive choices. As a result, consumers begin to ignore their internal needs and make impulsive purchases under the influence of hunger marketing.

On the other hand, science and technology break the time-space limitations of traditional consumption

and promote the diversification of consumption channels. Consumers can open product live-streams, exclusive links, and social vertical accounts for consumption at any time and place. In addition, community group-buying, through the “social + consumption” model, indirectly stimulates consumption in the social-interaction link by taking advantage of the herd mentality. Eventually, the controlling power of technology goes to the extreme. Consumption behavior no longer reflects the labor exchange between people. Consumers continuously pursue material consumption in the emotionally fabricated “warm bed” of technology and finally forget their true emotions and values.

Secondly, it comprehensively controls individuals’ free time. Industrial culture penetrates into consumers’ minds through mass media such as advertisements. Consumers are even influenced by advertisements when choosing the color of a product. On the one hand, the commercialization of cultural products makes people violate their own personalities when consuming them, turning them into target users selected by enterprises and passive recipients of the cultural industry. On the other hand, people’s vision, hearing, and touch in their free time are almost occupied by mass-produced art products. Their consumption orientation is guided by industrial culture, and they gradually identify with consumption culture in the process of being influenced, ultimately eliminating people’s self-awareness and “critical and negative ability and political consciousness”^[8].

3.2. Cultural manipulation makes the consumption subject lose its subjectivity

Advanced technical means, with the help of mass media, infiltrate consumption culture, making people willingly accept the existing social order and consumption logic. Therefore, it is necessary to reveal the essence of the cultural manipulation of e-commerce festival creation, so that people can deeply understand the prevalence of cultural and consumption alienation in modern society, and promote the awakening of people’s subjectivity, “to return consumption to its true nature”^[9].

Firstly, it standardizes people’s consumption aesthetics. Before the development of science and technology and mass media, art products were people’s expressions of transcendence over freedom and reality. Nowadays, art products have become commodities and are no longer expressions of true personalities. Consumption aesthetics tend to be unified. It is no longer the manifestation of true will but an artificially-shaped shopping standard. The art products that people can choose independently are essentially screened commodities. The more people are faced with the same cultural commodities, the more they will fall into the identification of consumption values, and the more difficult it is for their aesthetics to break out of the consumption range defined by capital.

The “Internet celebrity economy” benefits from its standardization of consumers’ aesthetics. Internet celebrities use their influence to guide aesthetics and use the herd mentality to standardize consumers’ aesthetics to be consistent with industrially-produced commodities. At the same time, they win emotional trust. In this trust, consumers lose their thinking ability and the essence of transcendence, and the “Internet celebrity economy” continues to establish its dominance by taking advantage of mass culture.

Secondly, it creates people’s false needs. In the one-dimensional theory, Marcuse distinguished between “true needs” and “false needs”^[10]. True needs are those based on people’s instincts, while false needs are imposed on people by society. False needs are not people’s true inner desires. The weak critical consciousness of individuals and the erosion of social culture jointly obscure people’s ability to distinguish needs, leading to continuous consumption.

On the one hand, the real needs of people in real life are always limited, and enterprises need to create false needs to stimulate consumption. On the other hand, the production system constantly magnifies the pain of modern

people at work, which will inevitably lead to people's reflection on the status quo. Therefore, the consumer society must guide people to transform their pursuit of freedom and liberation into sensory satisfaction, use the satisfaction of false needs to eliminate people's doubts about false needs, and then fill people's free time with mass culture, stifle people's transcendental consciousness of the existing situation, and thus defuse the rebellious emotions of modern people.

Finally, it caters to people's consumption psychology. Modern people regard the number of commodities they own as a measure of success, forming a production mode that emphasizes possession and a psychological tendency to rely on authority. This character structure makes modern people unconsciously cater to the consumption world.

Rational spirit makes people believe that they can conquer nature and achieve material and spiritual freedom through scientific and technological progress. In reality, the promise of industrial rationality has not been fulfilled. The pursuit of wealth freedom has evolved into the "possession is happiness" psychology of modern people. People regard the possession of property as an inalienable right^[11]. The purpose of people's possession is not hoarding but consumption. The things they have consumed represent their existence. People lose their essential nature in labor and have to seek proof of their existence through continuous consumption. The more prevalent the alienation phenomenon is, the more consumption is separated from people's needs and becomes symbolic consumption.

4. How to regulate: The tripartite force of aesthetic awakening, concept guidance, and environmental regulation

Modern society, based on the principle of rationality, frantically expands production, resulting in a hedonistic tendency among modern people who rely on high consumption to obtain "spiritual comfort". Sensory enjoyment makes people fall into the abyss of over-consumption. The use value of goods is ignored, and luxury products with brand premiums are favored instead. Things are no longer valued for their practicality but for their "face value". To change the society of high production and high consumption, it is necessary to call for the return of rational consumption, which can start from three aspects: aesthetic awakening, concept guidance, and environmental regulation.

4.1. Awakening aesthetics in daily life

Mass culture is closely related to people's daily lives. To avoid the alienation of mass culture, it is necessary to highlight people's creative position in culture, enhance people's ability to distinguish and appreciate popular culture, and explore the compatibility between mass culture and traditional culture.

Firstly, awaken people's aesthetics in daily life. Encourage people's free expression in art creation, respect originality, and protect art creators. Restore the essence of freedom and transcendence contained in art products, and create a social atmosphere that can accommodate diverse aesthetics. Secondly, enhance people's discrimination ability in the consumer market. Advertising culture is deceptive and inductive. With the rise of short-video platforms, new business forms such as live-streaming e-commerce and digital marketing have emerged, making product promotion more covert. It is necessary to strengthen the popular science education of consumers, improve their ability to distinguish true and false needs, and reduce the possibility of impulsive consumption. Finally, strengthen the connection between traditional culture and the times. Chinese culture has a long history and left behind many cultural traditions. The compatibility between popular culture and traditional Chinese culture needs

to be explored, organically combine the two, and use well-known mass culture to spread the profound heritage of traditional culture.

4.2. Guiding the return of the subject status

Although the 21st century has achieved digital intelligence in technology, people's alienation has not disappeared. Instead, people have lost their subject status in consumption and willingly cater to the technological and consumption worlds ^[11]. Therefore, it is necessary to start from people's inner selves, promote a fundamental change in consumption concepts, focus on restoring people's transcendental and critical spirits, and thus re-establish people's dominant position in consumption.

Firstly, guide the consumption concepts of teenagers. Teenagers are the main group in the future consumer market, and their consumption concepts will have a significant impact on China's domestic-demand market. It is necessary to do a good job in school education and family education to help them establish correct consumption concepts. Secondly, create a "practical is better" consumption atmosphere. As young consumers gradually become the main force driving consumption, they are willing to spend a large amount of money on global travel for the pursuit of "poetry and distance" and are also willing to compare prices through multiple channels during shopping festivals ^[12]. It is both possible and necessary to create a "practical is better" consumption atmosphere. Finally, promote the value concept that "people are consumption subjects with a critical spirit". In an alienated society, consumption cannot be a tool for people to escape the hardships of work. Instead, it will trap people in new shackles. The full play of individuality and potential is the real way to improve the alienated situation. Modern people should realize that they are the masters of their lives and actively stimulate their inner strength to transcend themselves, becoming modern people with a critical spirit.

4.3. Regulating the order of the consumer society

In the contemporary era, where online shopping has become the mainstream consumption method, chaos such as false propaganda and price fraud has spread from offline to online. Therefore, it is necessary to strengthen the order of the consumer society, create a market of honest producers, and build a fair and reasonable shopping environment.

Firstly, improve laws and regulations, standardize the sales behavior of operators, and ensure the rights and interests of consumers. Secondly, social media platforms should strengthen background monitoring and use multiple means to ensure the implementation of e-commerce management systems, creating a rational-consumption online shopping platform. Standardize the market order of shopping festivals with high traffic and frequent transactions, such as "Double Eleven" and "New Year Shopping Festival", and monitor the "lowest price in the whole network" fabricated by live-streaming rooms or Internet celebrities across the platform to ensure clear and reasonable prices.

In addition, advocating rational consumption is also in line with the proposition of "Ecological Marxism" ^[13]. The capitalist system with expanding production and consumption is the root cause of the ecological crisis. Compared with the high-consumption society of capitalism, ecological rationality advocates "consume less, live better", emphasizing rationality in the consumption process, and choosing more durable and practical products, so as to reduce unnecessary product production and workers' labor and ultimately reduce the use of natural resources and achieve harmonious coexistence between man and nature ^[14].

5. Conclusion

In the context of e-commerce festival creation, consumption alienation has become an increasingly pervasive phenomenon driven by the intertwined forces of market logic, technological advancement, and psychological manipulation. The modern consumer is no longer an autonomous subject but a passive participant shaped by symbolic consumption and mass cultural influence. The dual manipulation of digital technology and mass media has obscured authentic needs, standardized aesthetic values, and distorted the purpose of consumption into a means of existential validation. To counter this, a multi-dimensional governance strategy is necessary—one that awakens aesthetic consciousness, reclaims individual subjectivity, and enforces environmental and regulatory standards. Only by promoting rational consumption, restoring critical thinking, and reestablishing the consumer as a self-aware subject can society break free from the cycle of overconsumption and move toward a more sustainable and human-centered economic order.

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Research on the Application of Artificial Intelligence Technology in Supply Chain Management

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Abstract: With the global economic digital transformation advancing quickly, the supply chain management issues facing the world are increased variability in customer demand, greater complexity within the supply chain processes, and chronic inefficiency bottlenecks. The rapid maturation of artificial intelligence provides a new pathway for optimizing supply chain performance, fundamentally transforming the traditional management paradigm through data-driven and intelligent algorithms. From demand forecasting to resource scheduling and risk early-warning to dynamic decision-making, artificial intelligence obtains significant improvements in response speed and accuracy for the supply chain and accelerated breakthroughs in end-to-end collaborative capabilities. There are still significant challenges during technology implementation, such as data silos, lack of transparency and interpretation in algorithms, and barriers to cross-organizational collaboration that limits its potential. Finding a balance between the incentivization of technology and management innovation has become an avenue within the academic community and industry to explore.

Keywords: Artificial intelligence technology; Supply chain management; Applied research

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1. Introduction

The focus of supply chain management is the flow of materials, information, and money in the most effective manner possible. The advent of artificial intelligence is disrupting the conventional wisdom in this area. Machine learning and natural language processing technologies are able to examine large amounts of unstructured data and offer real-time understanding around supplier selection, production scheduling, and logistics routes. In addition, deep learning models permit enterprises to anticipate and respond to shifts in market conditions in real time through the simulation of predictive events. Therefore, technology can not only shorten the decision-making chain but also provide a foundation for new models such as smart contracts and automated warehousing. While the transformational value of technology is clear, it does not come without its own risks. The reliance on digital models create concerns over data silos, biases embedded within algorithms, and dependency on technology, while enterprises must reorganize all functions to accommodate AI. In many respects, this challenge stands in the middle

of an opportunity to empower the enterprise with technology while demanding the wisdom of management to respond ^[1].

2. Applications of artificial intelligence technology in various links of supply chain management

2.1. Applications in the procurement link

Technological developments in artificial intelligence (AI) can assist the procurement process in two main ways. Through intelligent algorithms, AI technology analyzes historical procurement data and market conditions to design a supplier evaluation model that will help enterprises filter and identify highly suitable procurement partners. This technology will improve the procurement process and increase supplier evaluation efficiency. Using a data integration platform that employs natural language processing could extract real-time information about supplier qualifications and industry public opinion. The platform's usability can dynamically reconfigure the evaluation criteria, addressing the delays and subjective bias of traditional manual reviews. Secondly, an automated contract management system with semantic recognition technology can monitor the performance terms and risk points of procurement contracts and activate early warning mechanisms to prevent conflicts. All of which points to the procurement process that is trending toward a closed-loop succession due to technology development, which may have beneficial effects on the underlying stability and transparency of the upstream supply chain.

2.2. Applications in the production link

In the production stage, machine learning models utilize the real-time working condition data sampled by the sensors on the production line to dynamically adjust the operation parameters of the equipment and the rhythm of its material feeding, striking a balance between production capacity and energy consumption levels. The visual inspection mechanism captures the texture on the product surface and the details of assembly by means of high-definition cameras, which then compares these with the characteristic thresholds within the pre-determined quality standard library to identify minor flaws and initiate a sorting instruction. The predictive maintenance utilities employ the historical operation logs of the equipment and the environmental variables to simulate the wear curves of the components and the corresponding probabilities of failure, thereby generating a maintenance prioritization to deviate from the fixed-cycle maintenance routine. With the introduction of technology, the production process is starting to shatter the decisional inertia of traditional experience, transforming tacit knowledge into iterable algorithmic regulations and injecting an underlying driving force for continuous optimization into the manufacturing process ^[2].

2.3. Applications in the logistics link

The logistics process employs the route optimization algorithm, which combines real-time traffic flow data and weather change parameters to create dynamic delivery route plans to maximize timeliness and minimize fuel consumption. The warehousing management system automates the Task of storage location assignment and picking routes, using an order prediction model and the inventory turnover rate, which cuts down the time loss caused by manual searching of locations. The load sensor and electronic fence technology together monitor the load status of transportation tools and their geographical fence deviations while issuing adaptive scheduling instructions to accommodate sudden road condition anomalies. The blockchain-driven traceability platform encrypts and uploads logistics node information to the blockchain, facilitating non-tampering of handover

documents and goods status, and simplification of multi-party reconciliation protocol. The technology-enabled logistics network is gradually breaking down silos of information, building a full-link digital mirror continuously, from warehousing to terminal delivery, and enabling transformation for flexible operations in the middle reaches of the supply chain.

2.4. Applications in the sales link

In the sales process, customer behavior analysis tools combine the records of social media interactions and historical transaction data to analyze consumption preferences and the expected change in demand, which serves as the basis for the personalized recommendation engine's decision-making. The dynamic pricing engine relates inventory levels to the price changes of competitors, and combines historical reviews of promotional effort effectiveness to establish a price elasticity model in order to maximize profit. The intelligent customer service system analyzes the semantic focus of customer inquiries based on natural language understanding technology, matches solution templates in the knowledge base, and updates frequently asked questions to improve response accuracy in unison. Data-driven sales strategies are beginning to replace empiricism, transforming scattered market signals into quantifiable, actionable guidelines and creating clear reach channels for downstream value transfer in the supply chain ^[3].

3. Challenges of artificial intelligence in supply chain management

3.1. Data quality and security issues

At the data quality level, the heterogeneous data generated at each node of the supply chain, due to differences in collection standards and storage formats, leads to field misalignment or semantic conflicts during cross-system integration, directly affecting the training accuracy and prediction reliability of machine learning models. The deviations in timestamp alignment and unit conversion between the enterprise's internal order records and external logistics tracking information often obscure the real business rules, forcing the algorithm to consume additional computing power to clean the noisy data. Security risks are mainly concentrated on the potential leakage during the cross-platform data flow. The permission management loopholes in the interfaces of third-party service providers may expose sensitive information such as suppliers' pricing strategies or customers' transaction habits to the public network environment. The compliance pressure of privacy protection continues to intensify as the analysis of consumer behavior data deepens. There is still a technical possibility of restoring individual identities through cross-validation in the anonymized dataset, which may lead to legal accountability and brand trust crises. When the technical team balances the demand for data open sharing and the boundary of permission control, it often faces the trade-off between the complexity of encryption algorithms and the system response speed. Excessive protective measures may hinder the efficiency improvement of real-time collaborative decision-making. The fragmented storage status of data assets exacerbates the difficulty of information traceability. Some historical archives form breakpoints due to outdated formats or damaged media, affecting the vertical deduction ability of the supply chain risk model ^[4].

3.2. Cost and difficulty of technology application

At first, the cost of technology application is reflected in the hardware and software practice costs needed for enterprises to configure intelligent infrastructure. The use of high-performance computing clusters and edge computing devices frequently surpasses the yearly technology budget of small and medium-sized enterprises. The

adaptability problems experienced by the technical team in the localization transformation of algorithm models require a significant amount of resources to undertake secondary development against open-source frameworks to coordinate with specific business processes, which extend the conversion time of the testing phase to commercial use. The protocol compatibility issue for traditional warehousing equipment with new-type Internet of Things sensing devices mandates the ability of enterprises to maintain two parallel operating systems to preserve and maintain basic operating procedures during the transition period, which indirectly expands the worker and labour maintenance and energy costs. The requirement of continuous data annotation and feature engineering for algorithm iteration diverts a lot of working hours. The phenomenon of rework due to misunderstanding of requirements between the business and technical departments only serves to marginally dilute the usefulness or depth of technology use. The uneven technical standards within the supplier ecosystem lead to frequent data packet loss or field parsing errors during the API interface docking process. Enterprises have to additionally purchase middleware for protocol conversion to ensure the stability of communication between systems. The over-fitting tendency exposed during the model training phase forces the technical team to repeatedly adjust the hyperparameter combinations and validation set division strategies, exacerbating the vicious cycle of trial-and-error costs and time losses under the condition of limited computing resources.

3.3. Resistance to organizational culture and management change

The deeply ingrained empiricist thinking mode in organizational culture creates a cognitive conflict with the data-driven decision-making mechanism. Some management teams hold an overly cautious attitude towards the demand forecasting results output by algorithms and prefer to rely on subjective judgments based on accumulated manual experience. The resistance of front-line employees to automated processes stems from the role ambiguity after the transfer of operational permissions. The concurrent use of traditional manual ledgers and intelligent systems intensifies the sense of workflow fragmentation, resulting in the phenomenon of selective compliance with rules at the implementation level. After the introduction of technology, the cross-departmental collaboration mechanism reveals the rigidity of the original division of powers and responsibilities. When the procurement department and the production department adjust the material preparation plan based on algorithmic suggestions, they often have divergent goals because the assessment indicators are not updated synchronously. The misjudgment of the technology iteration speed by the decision-making layer leads to an imbalance in resource allocation. Some enterprises equate the local efficiency fluctuations during the short-term trial-and-error period with long-term strategic failure and prematurely reduce resource support, causing the technology implementation process to be interrupted ^[5]. There is a compatibility gap between the standardized solutions provided by technology suppliers and the enterprise's unique business processes. The implicit resistance from business units due to changes in operating habits at the initial stage of system switching is often misinterpreted as functional defects of the technology itself.

3.4. Legal, regulatory, and ethical issues

Multinational enterprises face the superimposed pressure of multi-jurisdiction compliance reviews when deploying intelligent algorithms. The strict restrictions on the use of consumer profiles under the EU's General Data Protection Regulation contrast sharply with the lenient provisions of digital trade agreements in the Asia-Pacific region, forcing legal departments to expend a great deal of effort in formulating regional compliance strategies. The legal boundaries of dynamic pricing algorithms within the framework of antitrust laws are not yet clear.

The gap between the collection of technical evidence for price coordination effects and the legal burden of proof leaves corporate legal teams lacking effective defense bases when responding to regulatory inquiries. Labor rights disputes triggered by automated decision-making are gradually emerging. The optimization logic of working-hour allocation by intelligent scheduling systems conflicts with the flexible clauses stipulated in collective labor contracts, often putting human resources departments in a dilemma of balancing efficiency improvement and labor protection. The absence of an algorithm bias detection mechanism in the supply-chain finance scenario may lead to the unconscious amplification of regional or industry-based discrimination in the credit scoring models of small and medium-sized enterprises, triggering the risk of inquiries from fair-trade review agencies ^[6].

4. Countermeasure suggestions for promoting effective application of artificial intelligence technology in supply chain management

4.1. Strengthening data management and security

The enterprise can create a cross-departmental data governance committee to collaboratively establish field naming conventions and metadata standards, and semantically align the supplier rating data residing in the procurement system with the inventory turnover data in the warehouse management system. The technology team implements a data masking module in the data lake architecture that automatically maps the field's visibility guidelines according to the level of employee and business context. Data exposure is tailored to achieve the sales department's need to view the geographic distribution of customers while restricting core business metrics exposure. The third-party audit body routinely performs integrity checks on the data lineage graph and implements an automatic repair process for timestamp breakpoints on logistics tracking information and financial settlement documents to allow the traceability chain to be reproducible in compliance with requirements. The application of blockchain technology in the supplier collaboration platform also covers the qualification document deposit link. An immutable hash value will be produced once the ISO certification certificates and quality inspection reports uploaded by each node have all been verified by the smart contracts ^[7]. The homomorphic encryption transmission channel established in the multi-cloud environment enables the production planning department to call the real-time inventory data of outsourced warehouses without decrypting the original information, effectively balancing the requirements of business collaboration efficiency and business secret protection. The data quality dashboard is integrated into the daily morning meeting system, allowing the person-in-charge of the transportation department to intuitively track abnormal GPS positioning update frequencies of in-transit supplies and promptly initiate the data supplementary collection process to avoid distortion of the prediction model.

4.2. Reducing the cost and difficulty of technology application

The hardware resource sharing platform organized by industry associations can link together the idle computing power resources of member firms and automatically schedule the prediction model training tasks during peak hours time periods to be executed at data centers in low-load zones. Its dedicated algorithm library for the supply chain, maintained by the open-source community, accumulates lightweight versions of transportation route optimization and inventory classification models on an ongoing basis. The technology team that calls these models only needs to change a small set of feature parameters to fit each enterprise's specific business scenarios. The plug-and-play edge computing boxes launched by equipment manufacturers are also pre-installed with mainstream Internet of Things protocol conversion modules. On-site engineers can directly connect to the existing management system in the warehouse deployment, skipping the complicated network configuration stage. The

regional digital transformation promotion center will regularly organize rotational exchanges between algorithm engineers and procurement supervisors so that the intuitive understanding of the business pain points helps prevent the architecture redundancy problem originating from an excessive pursuit of optimization prediction accuracy during the technical solution design stage. The automatic feature engineering tool developed by cloud service providers can identify seasonal fluctuation patterns in historical order data, replacing the high-cost operation mode of traditional manual construction of derived variables. The AI training sandbox environment subsidized by government departments allows small and medium-sized enterprises to test intelligent replenishment algorithms after desensitizing real data, avoiding the trial-and-error cost of directly purchasing commercial software that may overdraw the annual technology budget ^[8].

4.3. Promoting organizational culture and management change

Management regularly participates in wargaming activities of intelligent systems. Through interactions in simulating out-of-stock warnings and allocation decisions, they correct cognitive biases regarding the limitations of algorithms and gradually build a trust foundation for data-assisted decision-making. Cross-functional workshops invite production supervisors and algorithm engineers to jointly analyze cases of abnormal fluctuations in historical orders, transforming implicit experience in business scenarios into codifiable rule constraints and forming a standard operating manual for human-machine collaboration. The digital leadership assessment system designed by the human resources department includes the coverage rate of algorithm tool usage and the quality of problem feedback in department-level KPIs as assessment indicators for the promotion of middle-level cadres, forcing the management echelon to actively adapt to the transformation of the decision-making mode. The “process traversal” project planned by the change management office organizes financial staff to physically track the entire chain from the generation of purchase requests to the write-off of accounts payable in the intelligent replenishment system, eliminating the anxiety caused by information asymmetry in cross-departmental collaboration. The algorithm transparency section on the knowledge management platform allows purchasers to view the weight distribution of key variables in the demand forecasting model, enabling them to accurately locate problems with data source quality or parameter settings when raising questions. The intelligent improvement special channel added to the employee proposal system sets up a rapid verification process for the optimization suggestions of sorting path algorithms put forward by warehouse administrators, making the mechanism of using front-line experience to feed back into technological iteration operate regularly ^[9].

4.3. Improving laws, regulations, and ethics

The legislative body collaborates with the industrial circle to establish a dynamic algorithm filing list system, requiring enterprises to include the adjustment range of core parameters of the intelligent replenishment system and the logic of feature engineering of the demand forecasting model in the annual compliance audit report for future reference. The guidelines for ethical review of supply-chain algorithms formulated under the leadership of industry organizations clearly state that inventory optimization models shall not set discriminatory safety-stock thresholds based on regional economic differences, and the ethics committee is involved in the review process at the project initiation stage. The algorithm transparency monitoring toolkit developed by the judicial department can automatically identify the hidden regional-bias parameters in logistics route planning and generate a visual report for regulatory agencies to check whether enterprises fulfill their disclosure obligations. The updated data rights confirmation and certification system of the standardization organization refines the ownership of road-

condition information collected by Internet-of-Things devices during transportation into the revenue-sharing ratios among data generators, processors, and users. The provisions on the legal validity of smart contracts added to cross-border trade agreements require that the rules for handling quality disputes stipulated in the blockchain traceability system be compatible with local product-liability laws to avoid conflicts. The algorithm impact assessment template developed by law firms helps enterprises check whether the scorecards for supplier selection have implicit technical barriers that indirectly exclude small and micro-enterprises from eligibility^[10].

5. Conclusion

The integration of artificial intelligence and supply chain management marks a paradigm shift from experience-driven to data-driven approaches. The technology has demonstrated disruptive value in scenarios such as procurement sourcing, flexible production, and intelligent logistics, but its in-depth application is still restricted by the level of data governance and the ability of organizational change. Future competition will focus on how enterprises build an agile “human-machine collaboration” system, which not only uses algorithms to improve efficiency but also retains human judgment on complex risks. Policy-makers need to accelerate filling the legal and ethical vacuums, while enterprises need to strike a balance between technology investment and sustainable development. This transformation is not just an upgrade of tools but a reshaping of the resilience and innovation genes of the supply chain ecosystem.

Disclosure statement

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The Development of Green Finance and the Financing Constraints of Small and Medium-sized Enterprises

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Abstract: As an important tool to achieve sustainable economic and environmental development, green finance can effectively alleviate the financing constraints of small and medium-sized enterprises (SMEs), especially in promoting green transformation plays a key role. SMEs play an important role in economic growth, innovation, and job creation, but due to a lack of collateral, imperfect credit history, and opaque financial information, they face great obstacles in the financing process, especially in the early capital investment required for green transformation. Green finance, through innovative financial instruments such as green credit and green bonds, provides new financing channels for SMEs, helping them reduce financing costs, optimize financing structure, and promote their green transformation and sustainable development. This paper analyzes the current situation and root causes of SMEs' financing dilemma from the perspective of green finance, and probes into the influence of green finance policies on financing behavior.

Keywords: Green finance; Small and medium-sized enterprises; Financing constraints

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1. Introduction

Small and medium-sized enterprises (SMEs) face significant financing challenges, which hamper their growth and sustainability, especially in the context of green finance. Lack of adequate collateral and credit history is a widespread problem that exists in both developed and developing countries. As the global economic landscape changes and the risk of recession persists, financing pressures for SMEs are intensifying. To mitigate these challenges, governments around the world have established a variety of financing guarantee schemes. The development of green finance can optimize the economic structure of enterprises, thereby alleviating the financing problems of enterprises ^[1-2].

2. Current financing situation of SMEs

The financing of small and medium-sized enterprises (SMEs) has always been a key problem in economic development. Small and medium-sized enterprises (SMEs) occupy an important position in China's economy, providing a large number of job opportunities and innovation impetus. However, due to their small size, imperfect credit history, and insufficient collateral, SMEs face greater financing difficulties. The following are several major aspects of the financing situation of SMEs in China.

2.1. Limited financing channels

SMEs are highly dependent on bank loans. Traditionally, SMEs mainly rely on bank loans, but because SMEs generally lack sufficient asset collateral and credit history, banks are stricter in their loan approval and have a high financing threshold. In addition to the complementary role of non-bank financial institutions, some SMEs try to obtain funds through private financing, guarantee companies, financial leasing, equity financing, and other channels, but these methods are also subject to greater restrictions and high costs. It is difficult to rely on bonds and equity financing. SMEs lack sufficient market scale and credit ratings, making it difficult for them to raise funds by issuing bonds or going public. Even if they are able to issue corporate bonds, they usually face high costs and difficulty in accessing the market.

2.2. Financing costs are high

First of all, the credit risk of SMEs is high, and the credit of SMEs is not transparent enough. Many enterprises do not have enough financial statements, or it is difficult to provide accurate credit evaluation, which makes the lending institutions or investors face greater risks. Secondly, the lack of collateral, many small and medium-sized enterprises, due to limited assets, cannot provide banks or other financial institutions required collateral, resulting in higher financing costs or even being refused financing. Finally, there is a single financing channel. At present, bank loans are still the most important financing method for SMEs, but the interest rate of bank loans for small and micro enterprises is usually high, especially in the case of no guarantee or mortgage.

2.3. Information asymmetry

Small and medium-sized enterprises have poor information transparency, imperfect financial statements, tax records, credit history, and other aspects, which makes it difficult for financial institutions to effectively assess corporate risks and affect financing decisions. At the same time, the guarantee and collateral of SMEs are insufficient, and SMEs often lack effective collateral and collateral, especially for scientific and technological innovation and service enterprises. The evaluation standards of intangible assets, such as intellectual property and technology, are not clear, resulting in great difficulty in financing. Financing channels have strong limitations. Although technology finance and Internet finance provide more financing channels for SMEs, these channels still have problems, such as a low degree of marketization and imperfect supervision.

3. The impact of the development of green finance on SME financing

In recent years, China's economy has achieved remarkable results, becoming the second-largest economy in the world. However, long-term reliance on the extensive economic development model has also led to serious problems of environmental pollution and waste of resources. With the environmental situation becoming increasingly severe, the traditional model of sacrificing the environment for economic growth is no longer

sustainable. How to balance the contradiction between economic development and environmental protection has become a realistic problem to be solved urgently. As a financial tool to promote the coordinated development of the economy and environment, green finance is being widely used. The report to the 19th CPC National Congress made it clear that a market-oriented green technology innovation system should be built, and green finance should be developed ^[3]. In March 2021, the National People's Congress further stressed in the 14th Five-Year Plan that people should adhere to the development concept of "clear waters and lush mountains are gold and silver mountains", accelerate the development of green finance, and support green technology innovation. Obviously, the development of green finance has become an important measure to promote green technology innovation and sustainable development ^[4].

In the process of promoting green economic development, green finance has played a key role. Existing research focuses on the impact of green credit policies and green bond policies. By adjusting the allocation of bank loans, green credit policies promote the green transformation of enterprises, while forming financing constraints on high-polluting enterprises; Green credit policies help to optimize the economic structure and achieve a win-win situation for both the economy and the environment; The issuance of green bonds can improve the market liquidity of enterprises, enhance their environmental performance and get positive feedback from the market ^[5].

The impact of green finance on the financing of SMEs is increasingly emerging, especially in the context of promoting environmentally friendly industries and sustainable development. Green finance not only provides SMEs with new financing opportunities but also enhances their market competitiveness and social responsibility. Specifically, green finance impacts SME financing in the following ways ^[6].

3.1. Providing new financing channels

With the rapid development of green finance, more and more banks and financial institutions have launched financing instruments such as green loans and green bonds to specifically support projects such as environmental protection and clean energy.

In recent years, the number of green investment funds has gradually increased, focusing on areas such as environmental protection, energy transition, and climate change. SMEs will be able to attract investment from green funds if they meet green criteria. These funds not only provide financial support but may also bring technical guidance and market expansion opportunities.

Supply chain finance and carbon trading markets: Green finance also provides more flexible ways for SMEs to raise finance. For example, through supply chain finance, some SMEs can access financial support through green partnerships.

3.2. Reducing financing costs

As SMEs generally face higher financing costs, green certification can help companies demonstrate their commitment to environmental protection and sustainable development, resulting in lower financing costs. Financial institutions believe that green projects have higher long-term returns and stability, so they tend to offer more competitive lending rates or other favorable terms ^[7].

The Chinese government provides subsidies, loan guarantees, and preferential tax policies for green projects, effectively reducing financing costs for small and medium-sized enterprises. The government's financial support and guarantee policies for green enterprises have helped banks reduce the risks of lending to SMEs, thus enabling banks to provide loans at lower interest rates ^[8].

3.3. Enhancing market competitiveness

As consumers become more concerned about environmental protection and sustainability, green finance provides an opportunity for SMEs to highlight their environmental image. Through green certification or access to green finance support, companies can not only enhance their brand image but also attract socially responsible consumers and investors and enhance their market competitiveness.

More and more investors are incorporating environmental, social, and governance (ESG) factors into their investment decisions. By adopting green financial products, SMEs are able to attract green investors with long-term investments, further broadening their access to finance ^[9–11].

3.4. Promoting technological innovation and sustainable development

Green finance provides strong financial support for small and medium-sized enterprises in the fields of environmental protection, renewable energy, energy conservation, and emission reduction. Many SMEs face high technology research and development costs in the initial stage, and the support of green finance helps them better carry out technological innovation, upgrading, and product research and development.

SMEs in traditional industries can get financial support through green finance to help them in their green transformation. Financial support not only promotes industrial upgrading but also improves resource utilization efficiency, reduces environmental impact, and gradually achieves green development.

3.5. Enhancing social responsibility and risk management

Green finance focuses not only on economic returns but also on social and environmental sustainability. SMEs that participate in green finance activities not only receive financial support but also enhance their sense of social responsibility, which can help drive companies to achieve long-term sustainable development.

Green finance policies and green rating systems can help SMEs identify and manage environmental and social risks. Through green risk control system assessment projects, financial institutions can help enterprises identify potential risks in advance, thereby strengthening risk prevention and management.

Overall, green finance provides new financing channels for SMEs, reduces financing costs, promotes technological innovation and green transformation, and enhances enterprises' market competitiveness and social responsibility. Despite this, green finance still faces challenges such as standardization issues and inadequate information disclosure. With the further improvement of policies and the continuous development of the green finance market, green finance will provide support for more SMEs in the future and help them achieve better development in the process of green transformation.

4. Suggestions

First, in the initial stage of green finance development, it is necessary to strengthen policy support to promote substantive innovation. At present, China's green finance is still in its infancy, although some progress has been made, but in promoting enterprise innovation, green finance is more of a strategic innovation than a substantive innovation. Many companies still view green finance as a tool to obtain financial support, rather than as a core driver for long-term sustainable development. Therefore, the government needs to further increase its support for green finance, improve the efficiency of the use of funds, and build a long-term and effective mechanism for green finance development by improving the policy framework. Only in this way can enterprises be guided to shift from superficial green strategies to deeper green technology and management innovation, thus ensuring that green

finance can achieve sustainable and healthy development in the future ^[10].

Second, optimize the allocation of green finance resources and strengthen support for corporate innovation. In order to effectively promote green innovation by enterprises, the government should strengthen the protection of intellectual property rights and improve relevant laws and regulations. In particular, credit restrictions for private enterprises in green projects should be lowered to provide a more relaxed external environment for green innovation. At the same time, during the implementation of green finance policies, resource allocation should be dynamically adjusted according to market changes, and the intensity of environmental penalties and incentives should be flexibly adjusted to ensure their precise delivery at different stages of development. In addition, the government should strengthen its financial support for heavily polluting enterprises, especially those that intend to transform and upgrade, by providing them with more financing opportunities and policy support, so as to avoid excessive punishment leading to the loss of motivation and opportunities for enterprises to transform.

Third, the government should accurately identify innovative green enterprises and enhance the effectiveness of policy support. While encouraging enterprises to make green innovations, the government needs to improve its ability to screen and identify green innovative enterprises. For those enterprises with genuine green innovation potential, the government should increase policy preference and support to ensure that green financial resources flow to the projects and enterprises with the greatest potential. Through precise identification and support, green finance can better promote the sustainable development of enterprises and provide the necessary funds and policy guarantees for true green innovation. Such differentiated policy support can not only enhance the innovation capability of enterprises but also ensure the optimal allocation of green finance resources ^[11].

Fourth, government interventions can ease financing constraints for SMEs. Government intervention can effectively ease the constraints faced by SMEs in the financing process, especially in the process of green transformation. By setting up special financing guarantees and providing financial subsidies, the government can help SMEs improve their credit level and reduce financing risks ^[12]. For example, some countries have set up special green loan programs specifically to support SMEs' investment in green projects. This not only provides financing support for SMEs but also facilitates their smooth development in green transformation by reducing financing costs and risks. Therefore, the government's role in green finance is crucial, especially in facilitating SMEs' access to green financial support ^[13].

As green transformation gradually becomes an inevitable choice for the development of SMEs, the financing needs of enterprises are undergoing profound changes ^[14]. Therefore, in the future, it is necessary to further increase the market penetration rate of green financial products, promote the innovation and market expansion of green financial instruments, and ensure that more SMEs can benefit from green transformation and sustainable development.

Disclosure statement

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Reflections on the Construction and Management of Customs Supervisory Workplaces for Railway and Water Transportation

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Abstract: Starting from the issues related to the construction and management of customs supervision places for railway and water transportation, this paper systematically analyzes the problems and challenges in the facility layout of customs operation places, the construction of a public platform for customs and port logistics monitoring, the utilization of information and data, and the intensity of technological innovation. Based on in-depth research, this paper attempts to propose improvement strategies and suggestions in terms of scientifically planning the layout of customs supervision places for railway and water transportation, improving the operation of the logistics monitoring public platform, developing and utilizing the information and data system, building a smart customs, and innovating the supervision mode. This aims to further optimize the customs supervision process, improve supervision efficiency and accuracy, and provide a reference for the facilitation and safe development of international trade.

Keywords: Supervision workplaces; Customs management; Current situation; Countermeasures

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1. Introduction

Co-located customs supervision for railway and water transportation refers to the unified supervision of imported and exported goods transported via multiple modes, such as waterway and railway, within the same customs supervision zone. This innovative supervision model integrates the resources and characteristics of railway and water transportation modes, which is significant in promoting cost reduction and efficiency improvement in cargo supervision and customs clearance, facilitating international trade, and enhancing the overall efficiency and competitiveness of the logistics industry. It represents an important practice in advancing the construction of smart customs, the “Smart Customs, Strong Country” initiative, and innovating regulatory service models.

2. Favorable factors and significance of achieving “co-located supervision”

Integrated layout: Co-located customs supervision for railway and water transportation is an important measure to promote the integrated construction of ports, which can significantly improve the overall quality of logistics services and the level of regional economic development, injecting new momentum into smooth trade and economic growth. This not only enables the interconnection of infrastructure, where water transportation and railway transportation facilities are located close to each other within the same customs supervision zone, forming an integrated “road-rail-water” port infrastructure. The seamless connection of transfer facilities and passageways between various transportation modes facilitates the smooth transfer of goods between different modes. Additionally, it allows for the sharing of regulatory resources. Within the same customs supervision zone, law enforcement departments such as customs can share regulatory resources, including manpower, information, and equipment, which is conducive to improving regulatory efficiency and reducing repeated inspections of goods in different regulatory links.

Unified supervision: Customs implements unified regulatory policies and models for the water and railway transportation of imported and exported goods. This unified regulatory system is conducive to simplifying customs clearance processes, improving regulatory efficiency, and enhancing logistics flexibility. Logistics enterprises can flexibly choose water or railway transportation modes based on actual conditions, without being restricted by different regulatory departments and processes. This helps reduce time and cost losses during transshipment, lowers enterprise operating costs, and assists enterprises in optimizing supply chain management and enhancing supply chain flexibility and responsiveness. Unified supervision is an important manifestation of co-located customs supervision for railway and water transportation, which can provide enterprises with more efficient and convenient customs clearance services. This is of great significance for promoting smooth trade and high-quality economic development.

Information sharing: Through informatization means, information islands are broken down, and information sharing and data resource interconnection are achieved between customs, ports, railway stations, and related logistics enterprises. Real-time sharing of information such as cargo status and transportation progress helps enterprises timely grasp logistics dynamics, improves logistics transparency and predictability, and reduces information asymmetry and communication costs between different departments and enterprises. Information sharing also provides richer data resources for regulatory departments such as customs, which is conducive to strengthening the entire process monitoring and precise analysis of cargo flow and risks, further enhancing regulatory capabilities. More timely and comprehensive data support under information sharing helps simplify customs clearance procedures, speed up cargo clearance, and improve clearance efficiency. Information sharing is an important measure to promote the construction of “smart ports”, which can realize the interconnection of information resources among customs, logistics enterprises, and other parties, improve the transparency and efficiency of logistics operations, and also enhance the law enforcement capabilities of regulatory departments, providing strong support for trade facilitation and high-quality development.

Business collaboration: Achieving seamless multimodal transportation connections, through business collaboration between water and railway transportation, imported and exported goods can be smoothly transferred between different transportation links, realizing integrated operation of the entire logistics process, improving overall transportation efficiency, and reducing logistics costs. This attracts more enterprises to upgrade from data-driven freight forwarding to industry-driven port trade and port processing, injecting key elements of high-quality development into scale expansion, condensing regional collaborative efforts, and boosting the continuous

optimization of the business environment. Enhancing supply chain collaboration, business collaboration in turn promotes information sharing and process coordination between different transportation entities, which helps to establish closer supply chain collaboration relationships and improve the overall supply chain operation efficiency.

3. Problems and challenges facing the co-location of rail and water transport regulation

The layout of the supervised workplace needs to be reasonably planned. Based on clarifying the development positioning, spatial layout, and functional requirements of the “same-site supervision” site, it is necessary to strengthen the supporting construction of road traffic, infrastructure, and the park information network platform to ensure that the traffic conditions around the customs supervision workplace are perfect, the infrastructure is good, and the network services are fully equipped, which is conducive to sufficient logistics resources and improved infrastructure ^[1]. At the same time, starting from standardizing the management and supervision of the workplace, focusing on resource integration, and aiming to improve customs clearance efficiency, the industry will gradually achieve a good situation with a reasonable functional layout, adequate daily supervision, orderly logistics operations, and clear corporate development goals, realizing the organic combination of strict supervision and efficient operation.

The public platform for customs and port logistics monitoring needs to be established and improved. In the context of the new era, building a customs monitoring and command center, and relying on advanced video monitoring systems, has become a key link for customs to strengthen comprehensive supervision, clarify the division of responsibilities, promote coordination and efficiency, and ensure orderly operation ^[2]. Implementing command and dispatch as well as sharing of regulatory information, breaking the pattern of decentralized operations among multiple departments, and achieving cross-departmental coordination and resource integration are of great significance for improving the efficiency of customs supervision. This action not only helps to ensure the security of customs data but also enables the interconnection and sharing of port logistics information and customs data. By establishing a cooperation mechanism between customs and port logistics management, the industry can promote the virtualization process of port operations and achieve networked coverage of regulatory stations. At the same time, actively introducing social forces to jointly supervise the logistics process of “same-site supervision” presents a broad and promising application prospect.

The utilization of information data needs to be improved. As one of the national authorities, the customs has always been at the forefront of system informatization. From the early H883 customs clearance system to the subsequent H2000 and H2010 systems, customs has always been exploring more efficient and precise customs clearance methods ^[3]. In recent years, customs have continuously developed auxiliary management systems, such as regulatory workplace record information management, manifest management, and transportation management, to improve regulatory efficiency. However, due to issues such as the increasing number of business categories, increasing business volume, and the accelerated integration of business and technology, there has been a phenomenon of departments working independently and duplicating development efforts, leading to overlapping system functions, which affects the level of information processing and utilization. This also increases the difficulty of subsequent maintenance and deep development ^[4]. Additionally, the inconsistency and inadequacy of information platforms have led to insufficient information support for regulators. The integration and utilization of data on the entry, exit, transfer, and storage of regulated workplaces still face challenges, and the formation of an

efficient and rigorous regulatory chain is also constrained ^[5]. This is not compatible with the customs' requirement of "informatization of logistics monitoring" and poses certain regulatory risks.

The effort to seek productivity from technological innovation is not sufficient. With the growth of import and export cargo volume, the practical difficulties of simultaneous supervision of railway and water transportation have increased. Especially in the context of a shortage of customs personnel, how to resolve the contradiction in human resources has become an urgent issue. To address this problem, the industry must continue to reform and innovate, and seek productivity from technological innovation. Specifically, modern technologies such as big data, the Internet of Things, and cloud computing should be introduced into the actual customs supervision work to build a "smart customs", "agile customs", "self-service customs", "collaborative customs", and "data customs" ^[2]. This will enhance the ability to prevent and control risks in the field of customs supervision.

4. Countermeasures and suggestions for the construction management of railroad and water transportation co-location supervision

Scientific planning of the layout of railway and water transportation simultaneous supervision of workplaces. Provide timely policy support, fully consider the requirements of the General Administration of Customs (2008) No. 171 Order on the setting standards for railway freight stations and other relevant customs regulations. When planning the operational processes, development trends, and scale requirements of international intermodal transportation business, scientific planning and appropriate integration of existing hardware facilities should be carried out ahead of time. At the same time, the impact of policies and the optimization and transformation of functions should be considered to facilitate the smooth acceptance of supervision points during the reconstruction phase of the workplace ^[6]. To promote the healthy development of the logistics industry, the rational layout and functional expansion of ports are crucial. This will not only establish an efficient and collaborative import and export logistics network but also encourage logistics enterprises to use technological means to improve management systems and raise management levels. It will also promote the expansion of value-added and extended services such as warehousing, foreign trade, customs, and shipping, and drive the development of third-party and fourth-party logistics services ^[7].

To improve the operation of the public logistics monitoring platform, it is necessary to strengthen the technological network construction among the supervision sites, subordinate customs offices, and functional departments. By utilizing information networks and video monitoring technology, a new interactive and interconnected "online supervision" mechanism should be established. The practical application of the electronic gate control and networking system is also a key focus. Through the coordination of electronic customs locks and electronic gate management, management automation can be achieved, further improving and expanding the application effectiveness of existing smart supervision methods in logistics monitoring ^[5]. During the operation of the information sharing platform, it is necessary to ensure smooth communication and integration between relevant information platforms and systems, and to achieve seamless connectivity among various information management systems within the customs, in order to meet the demand for internal information sharing. While ensuring data security, information exchange with enterprises and relevant government departments should also be facilitated, providing enterprises with necessary water transportation and railway logistics information to ensure smooth processes such as customs clearance and declaration.

Fully develop and utilize information data systems. Integrate various types of information and technological

resources, including real-time customs declaration and clearance data, trade statistics, risk platform data, and enterprise management data to provide strong support for decision-making ^[5]. This will enable joint maintenance and sharing, coexistence, and common development. It will break the current departmental segmentation model, achieve full information sharing, and rational management of resource allocation. Based on a thorough understanding of internal operations and through scientific reasoning, the industry will fully utilize existing analysis and monitoring procedures to promote interconnectivity between various departmental management systems. This will facilitate the construction of a unified and shared management platform, providing powerful technical support for efficient departmental functioning. It will enhance the scientific and informational level of supervision, effectively preventing law enforcement and integrity risks.

Intelligent customs construction is helping the management of supervisory workplaces. It has resolutely implemented the cooperation initiative of the President of the CCP on “Smart Customs, Smart Borders, Smart Connections”, carried out the “Smart Customs for a Stronger Nation” initiative, and comprehensively implemented scientific and technological supervision. In order to promote the promotion of the pilot work of the “chokepoint control and networking system”, the construction of chokepoint facilities at supervisory workplaces should be strengthened, and at the same time, an information-based supervisory system for yards and stations should be developed and applied, so as to strengthen the management of books, field inspections and other supervisory activities at supervisory workplaces. The use of manpower operation system is also the key to enhance the effectiveness of supervision, through the realization of the deployment of fully automated “double random” dispatch orders, customs clearance and supervision of the whole chain of visualization, as well as the deployment of non-intrusive inspection equipment (H986) and vehicle-mounted mobile container/vehicle inspection system, intelligent auditing, and make full use of the efficacy of scientific and technological equipment in order to reduce the Cargo opening inspection rate, improve inspection speed and accuracy, so as to enhance the efficiency of inspection operations.

In the practice of on-site supervision, the industry explores the optimization of regulatory processes and the innovation of regulatory models. One of the tasks of managing customs supervision workplaces is to simplify business processes and improve regulatory efficiency based on risk management. Combining regional customs clearance, electronic customs clearance, logistics platforms, networked supervision, selective inspection systems, electronic ports, and other business reforms and construction, the industry scientifically allocates regulatory resources, taking into account the characteristics of water and rail logistics and the needs of enterprises. The industry aims to achieve the goals of postponing import logistics inspections, advancing export logistics inspections, and completing inspections during normal circulation when goods arrive at customs-controlled areas, avoiding the formation of “inspection logistics.” For example, the non-intrusive inspection of scientific equipment set up in the port area within the choke point, containerized goods in and out of the port area can be accepted at the same time the Customs inspection, not only to reduce logistics costs and save the time of customs clearance, to ensure that the supervision is in place, the risk of controllable on the basis of the realization of the customs homeopathic supervision, non-sensory supervision ^[8].

Disclosure statement

The authors declare no conflict of interest.

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Research on the Realization of the Commercial Value of Jewelry Designers

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Abstract: With rising consumer spending power and growing demand for personalization, the role of jewelry designers in product innovation and brand building has become increasingly prominent, and the realization of their commercial value has emerged as a key competitive driver in the industry. This paper employs a combination of literature review and case analysis to first define the connotation and evaluation dimensions of jewelry designers' commercial value. Next, it examines successful practices of representative designers at home and abroad, analyzing their core strategies in brand development, market positioning, channel collaboration, and innovation models. Finally, based on these findings, it proposes a systematic path for building personal brands, deepening value-chain collaboration, and exploring cross-field innovation. The study demonstrates that effective brand building and differentiated positioning can significantly enhance a designer's bargaining power, while coordinated upstream-downstream value-chain efforts and diverse innovation models—spanning technology and culture—provide vital support for sustained growth in commercial value. This paper aims to offer actionable strategic frameworks for industry practitioners and decision makers and to outline directions for future research.

Keywords: Jewelry designer; Commercial value; Brand building; Value-chain collaboration; Innovation model

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1. Introduction

Amid globalization and an era of rising consumption, jewelry has transcended its traditional decorative function to become an important medium for personal identity expression, cultural affiliation, and emotional communication. Consumers' demands have expanded from mere material and craftsmanship considerations to include the cultural narratives and creative philosophies behind each designer's work, reflecting a growing expectation for personalization, customization, and sustainability. At the same time, emerging technologies—such as virtual try-on and 3D printing—and digital channels—like social-media live streaming and online customization platforms—have provided jewelry designers with unprecedented opportunities for showcasing their work and co-creating with

customers, while also posing new challenges and opportunities for realizing commercial value. Therefore, how to integrate artistic creativity with market needs through brand building, innovation-driven development, channel collaboration, and customer co-creation to achieve sustainable economic and brand returns has become a critical issue for both practitioners and scholars.

This study, titled “Research on the Realization of the Commercial Value of Jewelry Designers”, aims to construct a systematic conceptual model and validate it through typical case studies. First, drawing on brand equity theory, the resource-based view, and value co-creation theory, it defines the key elements of a designer’s commercial value. Second, by combining current market conditions and industry trends, it proposes a four-dimensional driving model: Brand Equity — Innovation Capability — Channel Collaboration — Customer Co-creation. Finally, through case analyses of leading designers such as Wallace Chan, it extracts successful practices and offers actionable strategic recommendations. Methodologically, this paper integrates a literature review with qualitative case analysis, supported by in-depth interviews and secondary data mining, ensuring both theoretical rigor and practical relevance. It is hoped that this research will provide clear pathways for value realization to industry practitioners and lay the groundwork for subsequent quantitative empirical studies.

2. Literature review

2.1. Theoretical foundations of jewelry designers’ commercial value

Research into the commercial value of jewelry designers is grounded in several complementary theoretical perspectives that together illuminate how designers create and sustain market value. At the heart of this inquiry lies brand equity theory, which positions the designer as the living embodiment of a brand’s promise. According to Aaker’s model, brand equity comprises several intangible assets: brand awareness (the extent to which consumers recognize the designer’s name and work), brand associations (the symbolic meaning and emotional connections tied to the designer’s style), and brand loyalty (the likelihood of repeat patronage and advocacy). In the jewelry domain, a designer’s distinct aesthetic signature—whether it be a minimalist language of form or an opulent narrative steeped in cultural symbolism—serves as a differentiating competitive advantage. When customers perceive a designer’s creations as more than mere adornment but rather as expressions of personal identity or refined taste, they are willing to pay a premium, and in turn, the designer’s bargaining power in distribution and retail negotiations is materially enhanced. Thus, cultivating a coherent brand narrative and consistently delivering on that promise is not simply an artistic endeavor but the very foundation upon which commercial value is built^[1]. Complementing brand equity theory, the resource-based view (RBV) emphasizes the internal assets and capabilities that a designer must harness to compete effectively. In this framework, a designer’s professional mastery—ranging from gemology expertise to mastery of advanced metalworking techniques—constitutes an inimitable core resource. Likewise, accumulated industry experience, including collaborations with master craftsmen or participation in high-profile fashion events, and established networks of suppliers and retail partners collectively form a reservoir of relational and human capital. Designers who integrate these resources with dynamic capabilities—namely, the ability to sense shifting consumer trends, seize new creative opportunities, and reconfigure processes rapidly—can maintain an innovation edge. By doing so, they continually introduce fresh collections that resonate with evolving tastes, thereby sustaining a cycle of value creation that transcends transient fads. Extending beyond individual resources, value-chain theory focuses attention on the systemic coordination required to translate creative concepts into tangible market offerings. In this view, each stage—design ideation,

prototyping, manufacturing, distribution, and marketing—presents both opportunities for cost optimization and points at which value can be enhanced. When designers cultivate deep partnerships with upstream suppliers of ethically sourced gemstones or recycled metals, they not only assure product authenticity and sustainability but also gain collaborative input on material innovation [2]. On the downstream side, strategic alliances with specialty boutiques, digital marketplaces, or cultural institutions enable targeted storytelling and experiential marketing. By weaving their creative vision through every link in the value chain, designers can capture a greater share of the end price and fortify their commercial position. In recent years, experience economy and value co-creation theories have enriched the understanding of how designers can deepen customer engagement and amplify value. Prahalad and Ramaswamy's co-creation framework contends that customers derive heightened emotional and symbolic value when they participate meaningfully in design choices—whether through bespoke consultations, interactive online configurators, or immersive studio visits. In the jewelry sector, such participation transforms passive consumers into active stakeholders whose input shapes final designs, reinforcing their attachment to the product and brand. This participatory approach not only boosts perceived value and willingness to pay but also generates valuable insights that inform future collections. Together, these theoretical lenses—brand equity, the resource-based view, value-chain coordination, and co-creation—construct a comprehensive foundation for exploring jewelry designers' commercial value. They underscore the necessity of aligning a compelling brand narrative with unique internal capabilities and systemic partnerships while inviting customers into the creative process. Building on these dimensions, subsequent empirical research and case studies will examine how leading designers operationalize these principles to achieve sustained growth, adapt to disruptive technologies, and navigate shifting consumer expectations ^[3].

2.2. Market status of the jewelry industry and the evolving role of designers

In recent years, with the expansion of the middle class and the growth of high-net-worth individuals, the domestic and international jewelry markets have shown steady growth. Consumer demand has shifted from primarily “investment” and “gift” motivations toward “self-expression” and “cultural identity.” The rise of e-commerce and new retail channels has led younger consumers to place greater emphasis on design aesthetics and brand storytelling, driving rapid growth in demand for personalized and limited-edition pieces. Meanwhile, the concept of sustainability has permeated the industry, from raw material traceability to eco-friendly production practices, continuously reshaping consumers' value judgments. Market structure remains tiered: traditional luxury houses dominate the high-end segment, while emerging designer brands leverage independent creativity and social-media amplification to swiftly capture share in the mid-range and youth markets, creating a multi-layered and diversified competitive landscape ^[4].

Against this backdrop, the role of jewelry designers has evolved from “behind-the-scenes artisans” to “front-and-center brand ambassadors.” Designers once mainly served brands or manufacturers, focusing on executing specific product lines. Today, they must not only possess deep aesthetic sensibilities and craftsmanship expertise but also take on responsibilities in brand marketing, community engagement, and even cross-sector collaboration. By building personal IP, employing content marketing, and hosting online live events, designers interact directly with consumers and participate in managing the product lifecycle from concept to delivery. Simultaneously, deeper collaboration between designers and their supply chain and channel partners—through customization and limited-edition releases—has continually refreshed commercial models. Modern jewelry designers have thus become hybrid talents integrating creativity, brand communication, and business operations, and their evolving role directly

influences the innovation vitality and commercial ecosystem of the entire industry ^[5].

3. Conceptual framework and model

3.1. Definition of core concepts

In this paper, “commercial value” refers to the multidimensional returns that jewelry designers achieve in the market through their creativity, professional expertise, and collaborative resources. It encompasses not only direct economic gains but also intangible assets such as brand premium, customer loyalty, and sustainable growth potential. To lay the groundwork for our model construction, we refine several key concepts as follows: Brand equity: Drawing on Aaker’s brand equity model, this comprises three dimensions: a designer’s recognition among target audiences (brand awareness), the distinctiveness of their aesthetic style and material choices (unique style), and their reputation as reflected in media coverage, social-media discussion, and customer reviews (brand reputation). Higher brand equity translates into stronger pricing power and negotiating leverage. Innovation capability: This denotes a designer’s ongoing exploration of materials, techniques, and cultural meaning. It includes the use of new materials (such as sustainable metals or experimental gemstones), adoption of novel manufacturing methods (like 3D printing and laser cutting), and integration of cross-disciplinary inspirations (for example, incorporating contemporary art or regional cultural motifs). Robust innovation capability not only yields differentiated products but also extends commercial value via patents, copyrights, or limited editions. Channel collaboration: This refers to the efficiency of cooperation and resource sharing between the designer and upstream suppliers (e.g., raw-material providers, contract manufacturers) as well as downstream partners (e.g., boutiques, e-commerce platforms, exhibition organizers) ^[6]. Effective collaboration can reduce inventory levels, accelerate time-to-market, and boost sales conversions through joint promotions, membership programs, or bespoke services. Customer co-creation: Inspired by experience-economy theory, this emphasizes engaging customers in the design process via customized offerings, interactive online platforms, or hands-on workshops. Co-creation not only strengthens customer loyalty but also turns feedback into immediate product improvements, forming a “design–production–consumption–feedback” loop that enhances commercial value. Environmental drivers: These include the macro market context (growth of middle- and high-end consumer segments, sustainability trends), digital-technology enablers (social-media marketing, big-data analytics, virtual try-on), and industry regulations (such as gemstone traceability standards and eco-certifications). Such factors both create new opportunities and impose compliance and cost-control challenges. Internal capabilities: This covers the designer’s professional background (art education, industry experience), cross-sector partnership network (collaborations with artists, fashion brands, cultural institutions), and team-management and project-execution skills. Strong internal capabilities enable efficient resource allocation in complex projects, ensuring that creative ideas are effectively translated into commercially viable products. Based on these definitions, the subsequent sections will build a systematic conceptual model for realizing a jewelry designer’s commercial value—centered on brand equity, innovation capability, channel collaboration, and customer co-creation—and empirically test the interactions and relative importance of these elements ^[7].

3.2. Model construction

Building on our definition of the four core elements, the study proposes a multidimensional, dynamic feedback model for realizing commercial value. At the heart of the model is the designer’s personal brand, which links

innovation, channel execution, and customer engagement in a closed loop from ideation to value capture. Brand equity serves as the foundation for market visibility and bargaining power, determining whether subsequent innovations can achieve maximum impact. Innovation capability acts as the lever for value delivery, continuously injecting differentiated selling points through breakthroughs in materials and techniques. Channel collaboration translates design and innovation into sales outcomes quickly and efficiently, while optimizing cost structures across supply chain and marketing. Customer co-creation channels end-user insights back into the innovation pipeline, enabling precise iteration based on real-world experience, thereby strengthening loyalty and repeat purchases ^[8]. Environmental drivers (digital-technology advancement, sustainability mandates, regulatory frameworks) and internal capabilities (cross-sector networks, team efficiency, resource integration) play dual roles as moderating variables, shaping the pathways and intensity of the core elements. When a designer's internal capabilities align closely with favorable environmental conditions, brand equity and innovation capability reinforce one another to generate exponential returns through efficient channels. The co-creation feedback loop then injects fresh market insights into each new innovation cycle, continuously fortifying the value chain ^[9].

Empirically, this model helps identify different value-creation paths for various types of designers in diverse market contexts. Some may focus on brand building through collaborations and limited-edition releases; others may center on channel collaboration, leveraging direct-to-consumer and customization strategies to swiftly capture niche markets; still others may prioritize customer co-creation by fostering deep online-offline interactions. The model's dynamic feedback and moderation mechanisms also provide benchmarks for strategic adjustments—for example, ramping up innovation and promotions during market upswings, or reinforcing customer experience and trust when regulatory or supply constraints arise. This conceptual model thus offers both theoretical completeness and practical applicability, guiding subsequent case analyses and strategy formulation ^[10].

4. Case analysis

4.1. Analysis of a leading domestic and international jewelry designer

Taking Wallace Chan as an example—he is the first Chinese jewelry artist named among Fortune magazine's "50 Most Influential Designers Worldwide"—the study analyzes his success across the four dimensions of brand equity, innovation capability, channel collaboration, and customer co-creation. Brand equity: Self-taught in carving and gem cutting, Wallace Chan gained global recognition with his patented "Chan Ti Alloy" and "Flowing Metal" techniques. He elevated his personal IP by hosting solo exhibitions at Sotheby's and Christie's and showing at prestigious institutions like the Victoria & Albert Museum and the Museum of Modern Art in New York. Frequent features in leading media and trade publications have significantly boosted his name recognition and pricing power. Innovation capability: His breakthroughs underpin his competitive edge. The "Ti Alloy Carving" technique shatters the myth that only soft materials can be intricately carved—his metal alloy, far harder than jade, flows into organic, sculptural forms. His "Flowing Metal" series combines metal casting with nano-surface finishing for unprecedented luster and texture. These innovations have earned multiple international patents and justify his premium pricing. Channel collaboration: Chan maintains strategic partnerships with top auction houses, flagship boutiques, and high-end art exhibition curators. Beyond pop-up shows in luxury districts worldwide, he collaborates with Swiss watchmakers and fashion designers to broaden his audience. Digitally, he attracts enthusiasts and collectors by sharing his creative process and cultural narratives on social media, and employs an appointment-only ordering system on his website to manage inventory and costs efficiently. Customer co-creation:

His studio offers high-end bespoke services, inviting clients into the workshop to collaborate on sketches and prototype refinements. This deep engagement not only enhances customer loyalty but also drives word-of-mouth referrals and repeat purchases, building a lasting community around his brand. Through the synergy of these four dimensions, Wallace Chan has successfully fused personal artistry with commercial value, cementing his leadership in the international jewelry-art sphere and providing a blueprint for other designers to follow.

4.2. Insights for realizing commercial value

Wallace Chan's example first validates the foundational role of brand equity. By centering his early work on distinctive craftsmanship and accumulating media exposure and institutional endorsements, he tightly linked his personal IP with top institutions, rapidly boosting market awareness. Designers should similarly focus on deliberate brand-building in their early stages—through exhibitions, awards, or partnerships—to create an “artist-brand” synergy that underpins future commercial negotiations. Second, sustained innovation is essential for preserving brand vitality and premium positioning. Chan's patented techniques not only achieve technical breakthroughs but also erect barriers to imitation. This illustrates the need for designers to commit to long-term R&D, exploring new forms, materials, and processes, while strategically securing intellectual property to ensure market recognition and pricing power. Third, the practice of channel collaboration highlights the importance of blending online and offline experiences. Chan's luxury pop-ups in prime locations and his behind-the-scenes social-media storytelling forge emotional connections in both physical and virtual spaces. Jewelry designers should build diversified channel networks—partnering with high-end physical platforms and leveraging digital content and tools—to optimize inventory management and target marketing effectively. Finally, the customer co-creation model provides sustained growth momentum. By integrating clients into the design and production process, Chan transforms purchasers into co-creators, strengthening loyalty and generating organic peer referrals. Designers should open communication channels throughout product development, embed customer feedback as a core driver of iteration, and weave customization and interactive services into their business models. This creates a virtuous “design–experience–feedback” loop that continually enhances brand loyalty and competitive differentiation.

5. Strategies for realizing commercial value

5.1. Building the designer's brand and market positioning

Crafting a distinctive brand image is the first step for designers to realize commercial value. Designers should clearly express their unique aesthetic style and cultural essence through their work, deeply exploring their creative philosophy, regional heritage, or cross-disciplinary inspirations to create a cohesive and recognizable “visual + conceptual” identity system. Leveraging this identity, they can secure concentrated exposure through professional exhibitions, industry awards, and media coverage, while reinforcing brand awareness on social platforms with serialized, story-driven content. Each piece should serve as a vessel of brand value rather than a mere ornament. This approach attracts attention from the design community and media, and embeds the notion of “aesthetic integrity and quality” in the minds of target consumers, thereby laying a solid foundation for premium pricing and word-of-mouth promotion. Once the brand tone is established, precise market positioning determines the efficiency and depth of commercialization. Designers must segment price tiers, stylistic themes, and consumption scenarios based on insights into their target audience, then choose appropriate sales channels and partners accordingly. For example, a limited edition collection aimed at high-net-worth collectors and art institutions might command

premium pricing through auction houses and gallery exhibitions. In contrast, a niche fashion line for younger consumers could test the market quickly via social-commerce platforms and pop-up shops with minimal inventory risk. Data-driven operations are vital in this process: By collecting customer profiles and feedback through online engagement, membership programs, and post-sale follow-ups, designers can continually fine-tune product styles and pricing strategies, ensuring they meet core consumer needs while preserving brand distinctiveness and ongoing appeal.

5.2. Value-chain collaboration and innovation models

In realizing their commercial value, jewelry designers must go beyond merely linking production stages; they need to forge deep strategic partnerships with suppliers, manufacturers, channels, and service providers. Designers should proactively engage in raw-material selection and testing, working with mineral suppliers or eco-certification agencies to establish traceable procurement standards. This top-down control not only enhances product credibility in high-end markets but also lays the groundwork for subsequent technical innovation and pricing advantages. Simultaneously, collaboration with contract manufacturers and artisans should move beyond the traditional “design-prototype-bulk production” sequence. Adopting joint R&D or small-batch pilot production models allows designers to interact directly with craftsmen during prototyping, translating innovative techniques into high-quality samples in real time, and then integrating consumer feedback for seamless technical iteration and quality optimization. Beyond production, designers should explore diverse co-innovation models on the channel side. When partnering with online platforms, they can leverage big-data analytics to forecast demand for different collections, jointly launch personalized recommendations and member-exclusive designs, and achieve both targeted marketing and inventory efficiency. Collaborations with high-end brick-and-mortar retailers or art spaces can take the form of cross-disciplinary exhibitions or themed pop-ups that fuse design with environment to enhance brand experience. Throughout, designers should employ digital tools—such as virtual try-ons and AR interactions—to bridge online and offline experiences, giving customers a more immersive sense of participation. Through such upstream-downstream co-innovation, designers can continually expand their business models, accumulate new resources and inspirations from partnerships, and cultivate an innovation ecosystem characterized by “co-creation → amplification → iterative cycle”, driving the jewelry-design industry toward a more open, diverse, and sustainable future.

6. Conclusion

This study focused on realizing the commercial value of jewelry designers by constructing a four-dimensional driving model—brand equity, innovation capability, channel collaboration, and customer co-creation—and validated its effectiveness through the case of Wallace Chan. The findings show that a consistent brand identity and authoritative endorsements can rapidly establish a designer’s market leverage; ongoing innovation in materials and techniques is not only critical for differentiation but also essential for sustaining premium pricing; deep collaboration across the supply chain and channels can lower costs while accelerating product launches; and transforming customers into co-creators through customization and interactive experiences provides a continuous impetus for commercial growth. The proposed conceptual model not only reveals the causal pathways and dynamic feedback among these core elements but also offers clear strategic guidance for designers and businesses under varying market conditions. Specifically, designers should align their resources and external environment,

flexibly allocate efforts among brand promotion, R&D, partnership networks, and customer engagement, and thereby achieve synergistic gains in both reputation and revenue. Looking ahead, as digitalization and sustainability trends deepen, emergent technologies—such as metaverse try-ons and blockchain traceability—will unlock new commercial possibilities for the jewelry industry. Designers and firms should closely monitor these cutting-edge applications, integrate them into traditional value chains, and explore more open, diversified, and sustainable business models to elevate innovation and value creation across the sector.

Disclosure statement

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Will Gold Prices Continue to Rise? A Time-Varying Analysis of the Dollar-Gold Nexus under Geopolitical and Economic Uncertainty

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Abstract: This study examines the dynamic interplay between the US Dollar Index (USDI) and gold prices (GP) to assess the sustainability of gold price trends. Employing a rolling window bootstrapping causality test methodology across full and sub-samples, the findings of this study challenge the conventional assumption of a stable long-term inverse correlation between USDI and GP, thereby validating the hypothesis that their relationship is nonlinear and time-dependent. During periods of heightened geopolitical and economic volatility, both the US dollar and gold function as safe-haven assets, with USDI fluctuations exerting a positive influence on GP. Conversely, under stable market conditions, the US dollar serves as the currency in which gold is denominated, resulting in a negative impact of USDI on GP. Notably, GP also demonstrates bidirectional causality, exhibiting both positive and negative effects on USDI. The analysis reveals that while a general inverse correlation persists between gold and the US dollar, this relationship transitions to positive during surges in global political and economic instability. In light of contemporary developments—including escalating geopolitical rivalries, tepid post-pandemic economic recovery, and elevated US interest rates driven by inflationary pressures—this study posits that the upward trajectory of gold prices retains a robust empirical foundation.

Keywords: Gold prices (GP); The Dollar Index (USDI); Bootstrap method; Causal relationship; Time-varying

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1. Introduction

The main purpose of this paper is to assess the sustainability of the gold price rising trend since 2023 through a bootstrap subsample rolling window causality test of gold prices (GP) and the US Dollar Index (USDI). London spot gold prices reached a record high of \$2,789.99 per ounce on October 30 as the Federal Reserve cut interest rates by 50 basis points for the first time in three years on September 19, 2024. On February 14th, 2025, it even surpassed the mark of \$2900 per ounce. So, whether this upward trend in gold prices can be maintained has become a hot issue that people care about. The answer to this question requires a deep analysis of the causal

relationship between gold and the dollar.

Typically, there is a negative relationship between gold prices and the US dollar. This causal relationship between gold prices and the exchange rate of the US dollar has been investigated and verified by numerous scholars for a long time ^[1-3]. This relationship has certain theoretical logic. Gold has both precious metal and monetary properties, and is a “hard currency” that has both reserve and investment functions ^[4]. It is considered by investors to be the safest investment target and one of the most important commodities ^[5]. As the main international trade settlement currency and reserve currency, most international commodity transactions are denominated in US dollars ^[6]. There is a close interplay between the fluctuations of the US dollar exchange rate and gold prices ^[7, 8]. According to the law of one price, when the dollar appreciates, the price of gold denominated in dollars falls. Conversely, when the dollar depreciates, gold prices rise ^[9]. In fact, most of the time there is a negative correlation between the gold price and the US dollar index

But the relationship between gold prices and the dollar is not always negative, there are instances where it exhibits a positive correlation. Nevertheless, this positive correlation is short-lived and has been previously observed by experts in the field too ^[10-12]. Moreover, this relationship is not always stable ^[13]. When financial markets are running smoothly, gold and the dollar tend to rise and fall each other; However, when there is a local political crisis or economic crisis in the world, it shows a positive correlation ^[14]. In 2015 and 2016, the US dollar index had a fairly clear positive correlation with gold prices ^[15]. In the early stages of the COVID-19 pandemic from August 2019 to January 2020, the US dollar index moved in the same direction as the international gold price ^[16]. However, during the COVID-19 pandemic, this phenomenon no longer exists ^[17].

It can thus be seen that the relationship between the gold price and the US dollar is not a simple linear one, but rather a complex causal one that varies over time ^[18]. However, the existing literature lacks in-depth studies on this matter. This paper endeavors to make up for this deficiency.

There are several marginal contributions of this article. Firstly, the current literature mainly focuses on the one-way relationship between gold prices and the US dollar, whereas this study investigate the two-way causal relationship between them. Secondly, the existing literature mainly employs the entire sample for empirical tests, while, here, sub-samples are adopted to study the causal relationship between the two. Thirdly, the current literature reaches a general qualitative conclusion regarding the relationship between the two, while in this study, the causal relationship between them that varies with time is examined. Finally, the precise conclusions about the direction and degree of influence of the relationship between the two over time is obtained.

2. Literature review

In terms of research content, the existing literature is primarily concentrated on the aspect of long-term causal relationship testing. Lucey ^[19], Joy ^[20], and Apergis ^[13] et al.’s studies have shown that there exists a relatively strong and stable correlation between them. Usually, the fluctuation of the US dollar exchange rate has a negative causal relationship with the price of gold, which the devaluation of the US dollar has resulted in an enhanced demand for gold ^[21-23]. Beckers *et al.* ^[1], as well as Sjaastad *et al.* ^[2] had noticed this phenomenon early on. Zhou as well as Qin *et al.* came to different conclusions that show a positive causal relationship between the two under certain circumstances, especially in the face of global political and economic uncertainty ^[24, 25]. Jia *et al.* analyze the causal relationship between gold and the US dollar exchange rate from the perspective of short-term investments ^[4].

In the perspective of research methodology, most studies have adopted an empirical testing approach.

Sugihara *et al.* explore the causal relationship between complex nonlinear systems from a dynamic perspective, measuring the causal relationship between gold and the US dollar ^[26]. Massimiliano *et al.* ^[27] and Apergis ^[13] obtain the time-varying causality between gold and the US dollar by using error correction models, standard binary GARCH models, and an extension of the structural BEKK model. Xie *et al.* use impulse response function and Granger causality test to construct vector autoregressive (VAR) model and analyze the relationship between international gold price and US dollar index, which shows that there is a long-run negative causal relationship between the two ^[28]. Suraya uses the Quantitative Clear Technique utilizing auxiliary information from finance yippee, list mundi, BPS, and IDX for the years 2013–2022 ^[29].

Scholars have conducted numerous beneficial explorations on the causal relationship between gold prices and the US dollar. The findings show that there is both a long-term negative causal relationship and a short-term one between them. This precisely indicates that the causal relationship between them is complex and may be time-varying. However, most existing studies have focused on the unidirectional causal relationship between the US dollar and gold price, while there is less research on the causal relationship between gold price and the US dollar, and even fewer studies on the bidirectional causal relationship between the two.

Therefore, this paper conducts an in-depth exploration of the two-way dynamic causal relationship between them from an interactive perspective, focusing on whether there is a synchronization effect in the long-term. This helps to provide a more comprehensive understanding of the mechanisms of their interactions, reveal the possible economic logic behind them, and assess the sustainability of the trend of gold price rising. To achieve this goal, this paper employs the method of bootstrap rolling window causality test. This not only effectively captures the nonlinear and time-varying features of the time series, but also dynamically tests the mutual influence between them at different time periods.

3. Theoretical analysis and research hypothesis

3.1. GP-USDI interaction mechanisms (Hypothesis H1)

H1: The interaction between gold prices and the US Dollar Index exhibits structural breaks and regime-dependent behavior, manifesting as a non-linear dynamic relationship rather than a stable linear association. This time-varying correlation is contingent upon macroeconomic regimes, monetary policy cycles, and global risk appetite fluctuations.

Theoretical Framework and Hypothesis Development Within the Bretton Woods system's fixed exchange rate regime, gold and the US dollar maintained a parity relationship characterized by mutual convertibility. The system's collapse in 1971 fundamentally altered this equilibrium, resulting in an emergent inverse correlation that has since dominated financial market observations. However, empirical evidence reveals notable exceptions where concurrent appreciation or depreciation of both assets occurs, challenging conventional assumptions of persistent negative correlation. This paradox underscores the necessity of adopting a dynamic analytical framework to examine their evolving relationship, particularly given the increasing financialization of gold markets and the dollar's evolving role in global reserve systems. These observations motivate our primary research hypothesis.

3.2. Transmission mechanisms of USDI on GP (Hypothesis H2)

H2: The US Dollar Index non-linearly impacts gold prices through regime-dependent transmission mechanisms, exhibiting time-varying characteristics in directional influence, operational pathways, and effect magnitude across different market states.

As the benchmark pricing currency in international gold markets (World Gold Council, 2022), fluctuations in the US dollar exchange rate mechanically influence gold price dynamics through dual transmission channels. When the dollar appreciates, it simultaneously creates a substitution effect that suppresses USD-denominated gold demand while enhancing purchasing power for non-USD investors, ultimately exerting downward pressure on dollar-based gold valuations. Conversely, dollar depreciation triggers inverse mechanisms that amplify gold's affordability in non-USD markets, thereby elevating its dollar-denominated price (**Figure 1a**).

Notably, both assets demonstrate crisis-hedging synergy during market turmoil, wherein investors concurrently accumulate gold and dollar positions to preserve value, generating temporary price co-movement (**Figure 1b**). This paradoxical relationship dissolves upon market stabilization, as post-crisis capital rebalancing prompts synchronized declines. These observations reveal context-dependent interactions where the dollar's influence on gold manifests through:

- (1) currency denomination effects
- (2) safe-haven competition dynamics, with transmission intensity varying non-proportionally to macroeconomic conditions.

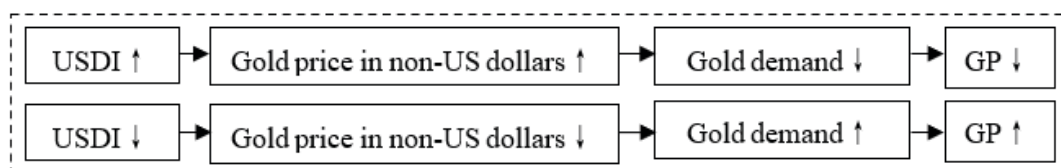


Figure 1a

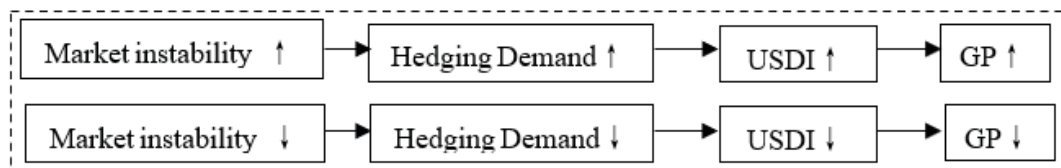


Figure 1b

Figure 1. The transmission mechanism of USDI on GP

3.3. Transmission mechanism of GP on USDI (Hypothesis H3)

H3: Gold prices exhibit asymmetric spillover effects on USDI through dual transmission channels (commodity flow vs. risk sentiment), with directionality, intensity, and persistence demonstrating regime-dependent nonlinearities and measurable time-varying features.

Gold's dual role as both a physical commodity and safe-haven asset creates bidirectional price transmission mechanisms with USDI. Commodity market dynamics reveal an inverse relationship: rising gold prices suppress bullion demand through price elasticity effects, thereby reducing USD transactions in gold markets and exerting downward pressure on the dollar (**Figure 2a**). Conversely, gold price declines stimulate physical demand, expanding dollar-based settlement volumes that mechanically strengthen the currency.

Paradoxically, during market turmoil ($VIX > 30$), their safe-haven attributes dominate, establishing a competitive substitution relationship. Investors' flight-to-safety triggers simultaneous capital reallocations to both assets, creating positive price co-movement (**Figure 2b**). This crisis-driven correlation dissolves post-shock through mean reversion processes as portfolio rebalancing restores conventional price dynamics.

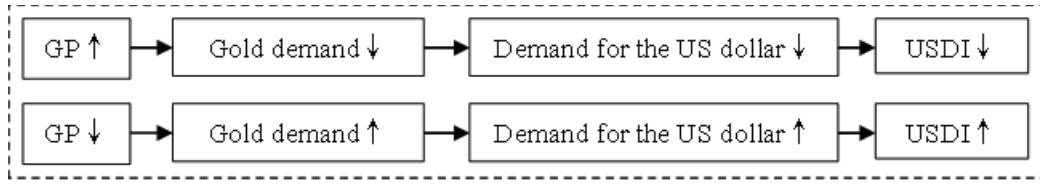


Figure 2a

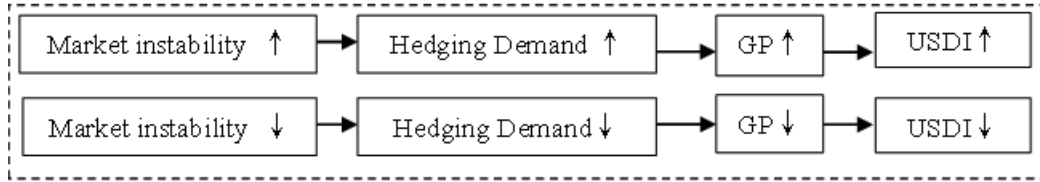


Figure 2b

Figure 2. The transmission mechanism of GP on USDI

4. Methodology

4.1. Bootstrap full-sample causality test

Conventional Granger causality tests employing vector autoregression (VAR) frameworks exhibit deviations from standard asymptotic distributions, particularly in finite-sample conditions. To address this limitation and enhance test reliability, Shukur *et al.* pioneered residual-based bootstrapping (RB) techniques that generate empirical critical values through Monte Carlo simulations, effectively mitigating size distortions in small-sample scenarios while maintaining asymptotic validity^[30]. Subsequent refinements by the same researchers introduced likelihood ratio (LR) test variants optimized through bootstrap adjustments, achieving superior power-size tradeoffs across distributional assumptions^[31].

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \dots + \alpha_p Y_{t-p} + v_t \quad t=1, 2, \dots, T \quad (1)$$

The optimal lag structure (p) is determined through rigorous application of the Schwarz Information Criterion (SIC), which balances model fit against complexity to achieve optimal model parsimony. This bivariate VAR(p) system, specifically configured with the US Dollar Index (USDI) and Gold Price (GP) as endogenous variables, can be reformulated in compact matrix notation as follows:

$$\begin{bmatrix} \text{USDI}_t \\ \text{GP}_t \end{bmatrix} = \begin{bmatrix} \alpha_{10} \\ \alpha_{20} \end{bmatrix} + \begin{bmatrix} \alpha_{11}(L) & \alpha_{12}(L) \\ \alpha_{21}(L) & \alpha_{22}(L) \end{bmatrix} \begin{bmatrix} \text{USDI}_t \\ \text{GP}_t \end{bmatrix} + \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix} \quad (2)$$

Where $v_t = (v_{1t}, v_{2t})$ is a white-noise process with zero mean and covariance matrix. The coefficients $\alpha_{ij}(L) = \sum_{k=1}^p \alpha_{ij,k} L^k$, $i, j=1, 2$ and L is a lag operator, with $L^k Y_t = Y_{t-k}$.

The null hypothesis that GP has no effects on USDI (i.e., $\alpha_{12,k}=0$ for $k=1, 2, \dots, p$) can be tested based on the Equation (2). If this null hypothesis is rejected, it indicates USDI is a Granger cause of GP. Similarly, the inverse null hypothesis that USDI has no effects on BP (i.e., $\alpha_{12,k}=0$ for $k=1, 2, \dots, p$) can be rejected in the same way.

4.2. Parameter stability test

Traditional bootstrap full-sample causality tests presume time-invariant parameters in VAR specifications, an assumption frequently violated in financial time series analysis. When parameters exhibit temporal variation, full-

sample approaches risk generating biased inferences through structural break neglect. To rigorously diagnose parameter instability, the triple testing framework of Andrews ^[32] and Andrews *et al.* ^[33] was implemented:

- (1) Sup-F test: Detects abrupt structural breaks
- (2) Ave-F test: Identifies gradual parameter shifts
- (3) Exp-F test: Captures smooth parameter transitions

Complementarily, the L -statistic evaluates martingale-driven parameter evolution through nonparametric variance ratio analysis ^[34, 35]. Rejection of stability across any test dimension indicates potential regime-dependent USDI-GP linkages, necessitating supplementary time-varying analysis.

4.3. Bootstrap sub-sample rolling-window causality test

The method is developed by Balcilar *et al.*, which involves dividing the entire time series into sub-samples using the rolling-window approach ^[36]. The sub-samples are then moved sequentially from the start to the end of the whole sample. The procedure works as follows: Let the total length of the time series be T and the rolling-window width be l . The last observation in each sub-sample is $l, l+1, \dots, T$, resulting in $T-l+1$ sub-samples. Each sub-sample can then be analyzed using the RB-based modified-LR test to obtain Granger causality results.

The final results of the bootstrap sub-sample rolling-window test are derived by summarizing the p-values and LR statistics across all sub-samples in chronological order. The mean values of the parameters $N_b^{-1} \sum_{k=1}^p \hat{\alpha}_{12,k}^*$ and $N_b^{-1} \sum_{k=1}^p \hat{\alpha}_{21,k}^*$ represent the average effects of GP on USDI and USDI on GP, respectively, where

N_b is the number of bootstrap repetitions. The parameters $\hat{\alpha}_{12,k}^*$ and $\hat{\alpha}_{21,k}^*$ are the estimated coefficients from Equation (2). A 90% confidence interval is used, with the corresponding lower and upper bounds given by the 5th and 95th quantities of $\hat{\alpha}_{12,k}^*$ and $\hat{\alpha}_{21,k}^*$, respectively.

Choosing the appropriate rolling-window width is a complex decision. A smaller window may lead to less robust test results, while a larger window can improve the accuracy of the estimates but reduce the number of possible windows. Pesaran *et al.* suggest that the rolling-window width should not be less than 20 when parameter stability cannot be assumed ^[37].

5. Data

In this paper, monthly data spanning from March 1973 to July 2024 is used to examine the Granger causality between GP and USDI, with the aim of assessing the sustainability of the upward trend in GP. On August 15, 1971, the United States announced the cessation of fulfilling the obligation of exchanging US dollars for gold. On March 16, 1973, major countries in the European Community market implemented a floating exchange rate for the US dollar. As a result, the Bretton Woods system completely collapsed. Since then, GP has embarked on a spiral upward path, while USDI has fluctuated downward, as depicted in **Figure 3**.

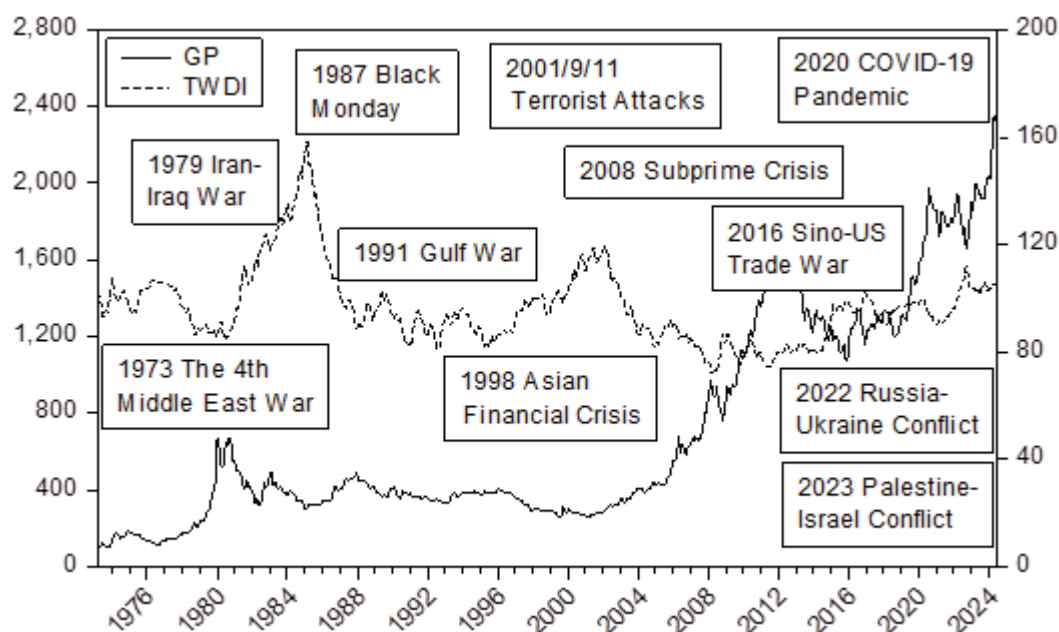


Figure 3. The trends of GP and USDI

GP have experienced three distinct cyclical patterns over the past half-century. The first major cycle commenced in March 1973 at 84.37 per ounce, entering a sustained upward trajectory that intensified with geopolitical tensions during the 1979 Iran-Iraq War. This bull market culminated in January 1980 when prices peaked at 675.31 per ounce - an extraordinary 800% appreciation within seven years. This historic high ushered in a 20-year bear market marked by gradual depreciation. Notably, even the 1987 Black Monday stock market collapse, which briefly drove prices to 486.24 per ounce in October of that year, failed to challenge the previous record. The second cycle emerged from its July 1999 low of 256.08 per ounce, gaining momentum during the 2008 global financial crisis. This surge propelled gold past the 1,000 milestone in October 2009, ultimately reaching 1,700 by 2012 before entering another corrective phase. The current cycle began in December 2013 at 1,221.51, with the COVID-19 pandemic in 2020 acting as a significant catalyst. Prices surpassed 1,900 in August 2020, broke through 2,000 in December 2023, and reached 2,398 by July 2024 while maintaining upward momentum.

Over this 51-year span, gold has delivered a 28.42-fold appreciation. Market corrections have shown a consistent pattern of contraction in both duration and magnitude: correction periods have shortened from 20 years in the first cycle to under two years in recent cycles, while price retracements have diminished from 62.1% to approximately 30% during the same timeframe.

USDI has demonstrated three distinct cyclical patterns since 1973. The inaugural cycle extended from March 1973 through August 1992, achieving its historical zenith at 158.4906 in February 1985 before commencing a prolonged depreciation phase. Subsequent market behavior manifested in the second cycle spanning September 1992 to April 2008, which attained its cyclical peak of 117.9548 in March 2002, ultimately transitioning into a phase characterized by heightened volatility and gradual decline. Currently in its third evolutionary stage commencing May 2008, the index has exhibited persistent upward volatility, culminating in an October 2022 high of 111.9375.

Observational data from **Figure 3** reveals a fundamental inverse correlation between GP and USDI dynamics.

Historically, appreciation in gold valuations has corresponded with dollar index depreciation, while gold price corrections have typically aligned with dollar strength. Notably, this relationship has demonstrated periodic synchronization, with transient intervals of concurrent directional movements. A significant deviation emerged post-September 2018, wherein both asset classes have exhibited a prolonged phase of simultaneous appreciation, challenging conventional market expectations.

This evolving interaction underscores the complex adaptive mechanisms governing GP-USDI dynamics, where macroeconomic variables, geopolitical developments, and monetary policy shifts collectively reshape traditional correlation patterns over temporal dimensions.

Table 1 summarizes key statistical characteristics of the dataset. The computed mean values for GP and USDI stand at 703.510 and 96.679, respectively. Both series exhibit positive skewness, with USDI demonstrating particularly pronounced kurtosis (> 3), confirming its leptokurtic distribution pattern. Jarque-Bera test results decisively reject normality assumptions for both variables at the 1% significance level (JB statistics: GP=85.32, USDI=112.47), necessitating alternative analytical approaches.

Table 1. Descriptive statistics for GP and USDI

	GP	USDI
Observations	617	617
Mean	703.510	96.679
Median	404.760	95.115
Maximum	2398.200	158.490
Minimum	84.370	72.105
Standard Deviation	557.579	14.178
Skewness	1.0377	1.362
Kurtosis	2.772	5.821
Jarque-Bera	112.073***	395.682***

Note: *** denotes significance at the 1% level.

Given the identified non-normal distributions, the Residual-Based (RB) methodology is implemented to mitigate estimation bias. This investigation employs bootstrapped subsample rolling-window testing to capture time-dependent causality dynamics between these financial instruments.

Logarithmic conversion applied to GP/USDI series to stabilize variance First-differenced Bitcoin returns (ΔBP) incorporated as control variable Stationarity verification through augmented Dickey-Fuller testing.

6. Empirical results

6.1. The causal relationship test of the full sample for GP and USDI

Firstly, stationarity tests for both GP and USDI variables were conducted. Utilizing three methodologies—ADF, PP, and KPSS—unit root examinations were performed on both level data and first-differenced series. **Table 2** demonstrates that at the 1% significance level, the unit root hypothesis cannot be rejected for the original series, confirming their non-stationary nature. However, following first-order differencing, the null hypothesis becomes statistically rejectable at the same significance threshold, establishing stationarity. These diagnostic

results collectively indicate that GP and USDI constitute first-order integrated time series.

Table 2. Unit boot tests

Series	Levels			First differences		
	ADF	PP	KPSS	ADF	PP	KPSS
GP	1.624399	2.858581	1.429996	-19.91648***	-19.81682***	-19.86323***
USDI	-2.417420***	-2.368128	-2.339115	-17.77002***	-7.830158***	-17.77002***

Note: *** denotes significance at the 1% level.

Then, on the basis of the first-order integrated sequence, a bivariate VAR model of the first-order differences of GP and USDI is established. Based on the Schwarz Information Criterion (SIC), the optimal lag order is determined to be 3. The modified LR causality test method based on RB is used to conduct the Granger causality test for the full sample. The results are shown in **Table 3**. According to the bootstrap p -values, it can be seen that in the full sample, GP is not the Granger cause of USDI, and USDI is not the Granger cause of GP. This indicates that there is no stable full sample causality relationship between the two.

Table 3. Full-sample Granger causality tests

Tests	H ₀ : GP does not Granger cause UDI		H ₀ : USDI does not Granger cause GP	
	Statistics	p -values	Statistics	p -values
Bootstrap LR test	0.722446	0.775200	2.634220	0.317300

Notes: To calculate p -values using 10,000 bootstrap repetitions.

6.2. The parametric stability test of GP and USDI

If there are structural changes in the time series, the assumptions of fixed parameters and causal relationships in the full-sample causality test are no longer reliable, and thus the results of the full-sample causality between GP and USDI estimated using the VAR model become meaningless. In view of this, the Sup-F, Mean-F, and Exp-F tests, as well as the Lc test, are employed to examine the parameter stability based on the two-variable VAR model. To ensure the accuracy of the tests, the critical values and probability values of the parameter stability tests are obtained through 10,000 bootstrap replications.

Table 4 presents the results of the short-term parameter stability tests. The Sup-F test result rejects the null hypothesis that the parameters are stable, indicating a significant one-time offset of the parameters over time. The Mean-F and Exp-F test results reject the null hypothesis that the parameters do not gradually evolve over time, suggesting that the parameters evolve over time. The Lc test result indicates that the parameters of the VAR model follow a random walk process, and the parameters are unstable during the full sample period. These results all suggest that the two-variable VAR model of GP and USDI is unstable in the short term. Since both GP and USDI are first-order integrated, this implies that when the cointegration relationship does not exist, the first-order difference VAR model of the two variables is not reasonable.

Table 4. The results of parameter stability test

Tests	GP		USDI		VAR system	
	Statistics	<i>p</i> -value	Statistics	<i>p</i> -value	Statistics	<i>p</i> -value
Sup-F	22.891	0.008	20.855	0.018	109.361	0.000
Ave-F	9.081	0.045	5.494	0.340	24.158	0.000
Exp-F	7.450	0.014	5.398	0.085	48.612	0.000
L _c					5.208	0.005

Notes: To calculate *p*-values using 10,000 bootstrap repetitions.

The Sup-F and Mean-F tests were employed to estimate the long-term parameter stability of the two variables, GP and USDI, and the Lc statistic was used to test the stability of the cointegration relationship. The results are shown in **Table 5**. Among them, the Lc test result rejects the null hypothesis of cointegration of the original sequence; the Sup-F test result rejects the null hypothesis, suggesting that there might be structural changes in the long term; the Mean-F test result accepts the null hypothesis that the sequence does not gradually evolve over time.

Table 5. The results of parameter stability test in long-run relationship

	Sup-F	Mean-F	Exp-F	Lc
GP=a + b × USDI	213.733	95.145	102.397	14.097
Bootstrap <i>p</i> -values	0.000	1.000	1.000	0.005

All these results suggest that a one-off transfer of parameters occurred in the long term, and the cointegration relationship between GP and USDI is not reliable. Thus, the results of the full-sample causality test might be biased and unable to precisely characterize the causal relationship between GP and USDI over the entire time series. It is indeed necessary to conduct causality tests for subsamples.

The results of **Tables 3, 4, and 5** above indicate that both GP and USDI possess structural break characteristics. There is no stable linear relationship between them but a nonlinear time-varying relationship. This validates the content of Hypothesis 1 in this study.

6.3. The causal relationship test of the sub-sample for GP and USDI

The unstable test results of the aforementioned parameters are largely in line with the actual circumstances of GP and USDI. Since the collapse of the Bretton Woods system in 1973, significant structural alterations have occurred in the relationship between GP and USDI. To investigate the causal relationship between two during this period, such structural changes must be taken into account. To this end, this paper employs the bootstrapped rolling window technique to more comprehensively reflect the characteristics of the subsamples as they evolve over time. Continuing to adopt a fixed subsample width of 24 months, a modified LR (likelihood ratio) causal test method is implemented to conduct rolling tests of the causal relationship among variables. The results of this process are presented in graphical form, specifically **Figure 4** to **Figure 7**, which visually showcase the detailed results of the rolling tests, facilitating in-depth analysis and comprehension of the dynamic changes in the causal relationship among variables.

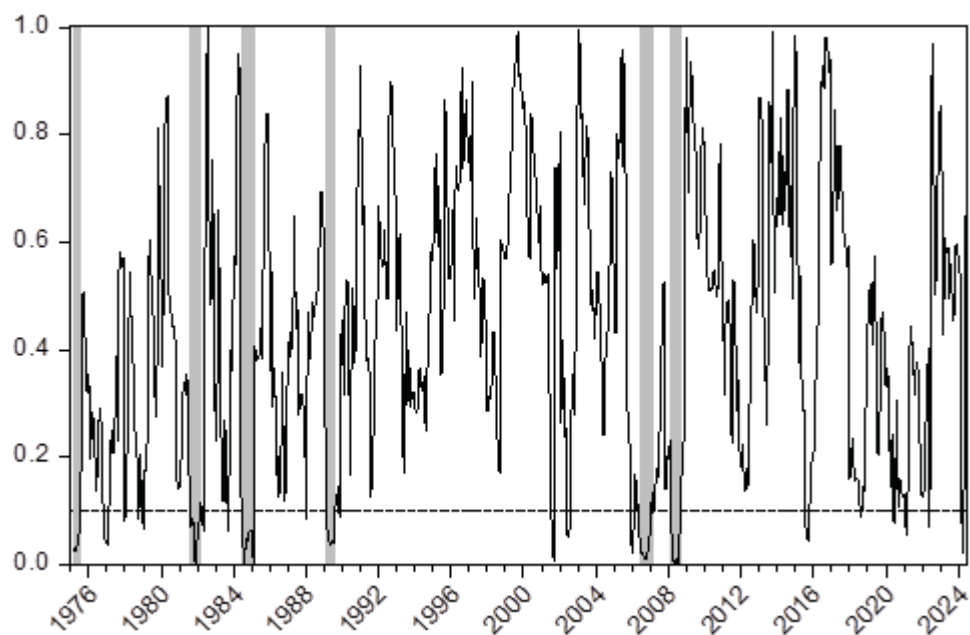


Figure 4. Bootstrap p-values of rolling test statistic testing the null hypothesis that USDI does not Granger cause GP

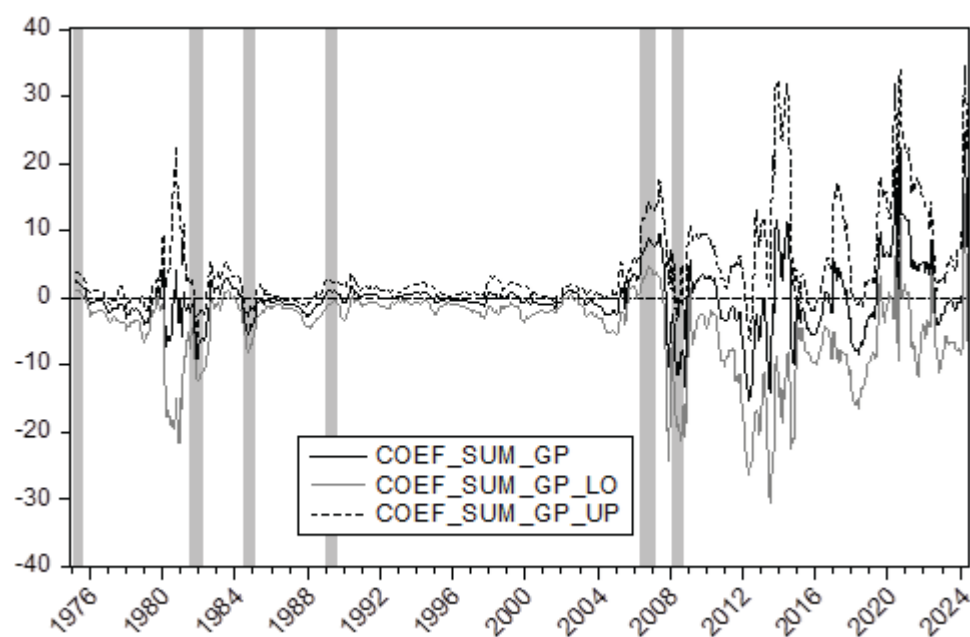


Figure 5. Bootstrap estimates of the sum of the rolling-window coefficients for the impact of USDI on GP

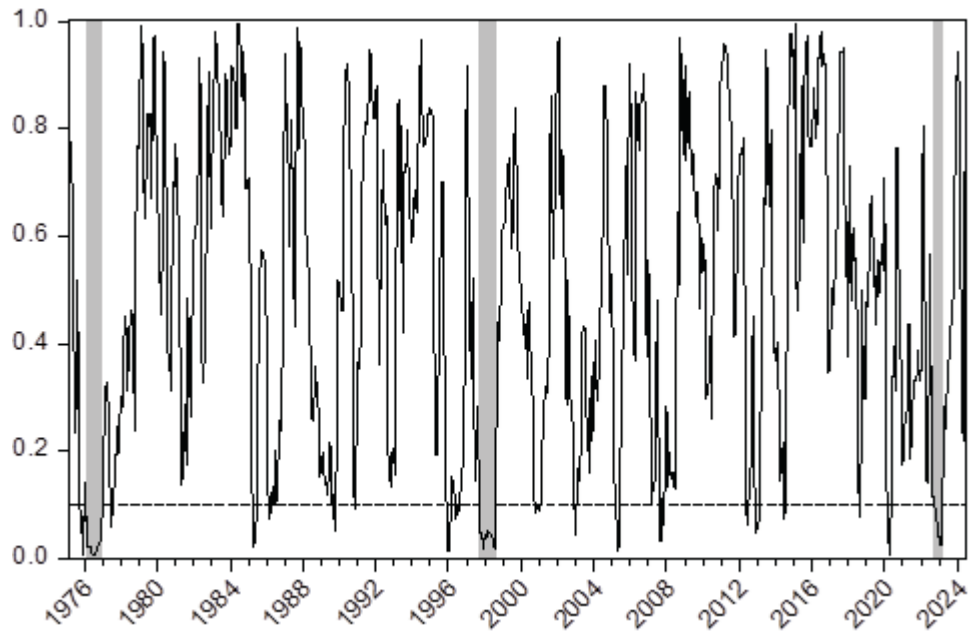


Figure 6. Bootstrap p-values of rolling test statistic testing the null hypothesis that GP does not Granger cause USDI

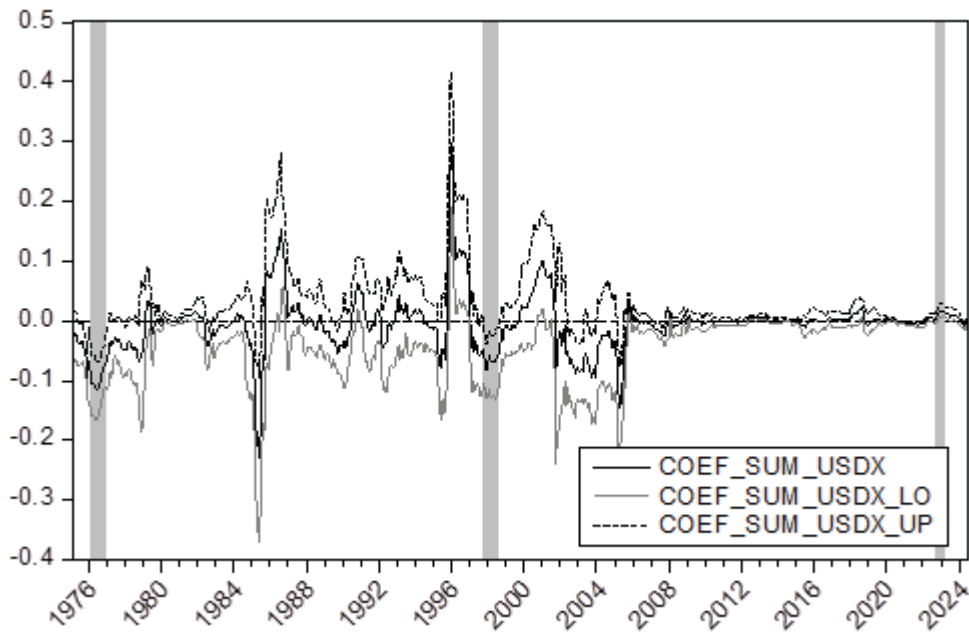


Figure 7. Bootstrap estimates of the sum of the rolling-window coefficients for the impact of GP on USDI

Figure 4 presents the bootstrapped p -value results for the USDI's lack of impact on GP. As shown in the shaded areas of the figure, the p -values are less than 0.1 during the periods of March-July 1975, August 1981-March 1982, July 1984-February 1985, February-August 1989, June 2006-March 2007, and March-September 2008. This indicates that at the 10% significance level, the null hypothesis that "USDI is not a Granger cause of GP" can be rejected, implying that USDI has a significant effect on GP during these periods.

Figure 5 further displays the average impact coefficients of USDI on GP, estimated using the subsample

rolling window bootstrapping method, along with their upper and lower bounds. As shown in the figure, during the periods of March-July 1975, February-August 1989, and June 2006-March 2007, the average impact coefficients are greater than zero, indicating a positive relationship between USDI and GP. In contrast, during the periods of August 1981-March 1982, July 1984-February 1985, and March-September 2008, the average impact coefficients are less than zero, suggesting a negative relationship between USDI and GP.

When market uncertainty fluctuates significantly, both the U.S. dollar and gold serve as safe-haven assets, and changes in the value of the U.S. dollar generally have a positive effect on gold prices. Between March and July 1975, the U.S. dollar index declined, causing gold prices to retreat from historical highs. In October 1973, the outbreak of the Fourth Middle East War and the formal decoupling of the U.S. dollar from gold triggered a surge in gold prices, which rose from \$84.37 per ounce in March 1973 to \$183.78 per ounce in December 1974. However, after Egypt and Israel signed the first phase of the disengagement agreement in early 1975, easing tensions in the Middle East, market uncertainty significantly decreased, leading to a reduction in the demand for both the U.S. dollar and gold as safe-haven assets. From February to August 1989, the U.S. dollar index moved within a consolidation range, which led to a decline in gold prices and marked the beginning of a new downward cycle for both assets. Starting in February 1985, a negative correlation between the falling U.S. dollar index and rising gold prices emerged. However, in February 1989, following the Soviet Union's withdrawal from Afghanistan, international political risks significantly decreased, stabilizing the market environment. After a period of consolidation, the U.S. dollar index continued to decline, and gold prices entered a new downward phase. Between June 2006 and March 2007, the U.S. dollar index fluctuated at high levels, while gold prices continued to rise. In June 2006, the Federal Reserve concluded a two-year interest rate hike cycle, and market expectations of a potential shift toward more accommodative monetary policy led to the end of the U.S. dollar index's upward trajectory. Simultaneously, signs of a real estate bubble in the U.S. began to emerge, increasing economic uncertainty and driving up demand for gold as a safe-haven asset.

In contrast, when the market environment stabilizes, the value of the U.S. dollar, as the currency in which gold is priced, negatively affects gold prices. From August 1981 to March 1982, the U.S. dollar index surpassed 110, reaching a historical high, while gold prices continued to decline. The appreciation of the U.S. dollar attracted capital inflows, reducing the appeal of gold as an investment, which led to further declines in gold prices. This negative relationship between the U.S. dollar index and gold prices was also evident during the periods from July 1984 to February 1985 and from March 2008 to September 2008.

These results support the hypothesis H2 of this study, which asserts that USDI has a significant impact on GP, with the direction and magnitude of this influence exhibiting non-linear characteristics, strongly affected by fluctuations in the international political and economic environment. Specifically, when international political and economic uncertainty intensifies, changes in the value of the U.S. dollar have a positive effect on gold prices; when international political and economic conditions stabilize, changes in the value of the U.S. dollar exert a negative effect on gold prices. This conclusion highlights the importance of considering multiple factors, such as international political and economic uncertainty, when analyzing the relationship between the U.S. dollar and gold, as well as forecasting gold price movements.

Figure 6 presents the *p*-value results of the bootstrapping estimation of the no-effect of GP on USDI. During the periods of 1976M02-M12, 1997M10-1998M08, and 2022M10-2023M03, the *p*-values are less than 0.1, indicating that the null hypothesis that “GP is not the Granger cause of USDI” is rejected at the 10% significance level, meaning that GP has a significant impact on USDI.

Figure 7 further shows the mean values of the impact coefficients of GP on USDI obtained through bootstrapping estimation and their upper and lower limits. During the periods of 1976M02-M12 and 1997M10-1998M08, the mean values of the impact coefficients are less than 0, indicating a negative impact of GP on USDI. During the period of 2022M10-2023M03, the mean value of the impact coefficient is greater than 0, indicating a positive impact of GP on USDI.

During 1976M02-M12, the gold price dropped to a phased low point and the US dollar index rose to a phased high point. In 1976, global geopolitical conflicts eased, weakening the “safe haven” attribute of gold. The gold price dropped. The US economy gradually recovered from the stagflation predicament in the early 1970s, enhancing market confidence in US dollar investments, and the US dollar index strengthened accordingly. During 1997M10-1998M08, the relationship of the gold price falling and the US dollar index rising again occurred. This period coincided with the peak of the Asian financial crisis. On July 2, 1997, Thailand announced the abandonment of the fixed exchange rate system of pegging the baht to the US dollar, triggering a chain reaction, and the crisis spread rapidly. International investors sought safe assets. Although gold is usually regarded as a safe-haven asset, in a liquidity-constrained situation, investors may prefer to hold US dollars rather than physical gold. During 2022M10–2023M03, gold rose from a phased position and the US dollar dropped from a phased high point. Due to the continuous escalation of geopolitical tensions, such as the Ukraine crisis and other regional conflicts, market uncertainty increased, and the demand for gold as a safe haven increased. Gold prices rose. However, the continuous spread of the COVID-19 pandemic exacerbated investors’ concerns about a US economic recession, leading to a lack of confidence in US dollar investments, and the US dollar index declined.

7. Conclusion

The primary objective of this paper is to investigate the dynamic relationship between the trade-weighted US dollar index (USDI) and gold prices (GP), aiming to provide a theoretical foundation for analyzing gold price trends.

First, a theoretical analysis is conducted. By examining the interaction mechanisms between the U.S. dollar index and gold prices, three hypotheses are proposed. The core argument posits that the relationship between the USDI and GP is bidirectional, involving either positive or negative influences, and is not static but rather time-varying.

Second, empirical validation is carried out using the rolling window bootstrapping causality test method to analyze both full-sample and sub-sample data. This approach effectively identifies structural breaks in the time series and reveals the time-varying nature of the relationship. Empirical results confirm the hypothesis of a time-varying relationship between the USDI and GP, challenging the traditional view of a stable long-term negative correlation. Specifically, during periods of heightened global political and economic uncertainty, both the US dollar and gold act as safe-haven assets, leading to a positive impact of USDI fluctuations on GP. Conversely, under stable political conditions and optimistic economic expectations, the US dollar’s role as the pricing currency for gold drives a negative USDI-GP relationship. Additionally, bidirectional causality is observed, with GP also exerting both positive and negative feedback effects on the USDI.

The core point is simply one sentence. The study demonstrates that while gold and the US dollar typically exhibit a negative correlation, this relationship shifts to a positive correlation amid rising geopolitical and economic uncertainties.

Finally, policy implications are drawn. In the context of the current global political-economic landscape—characterized by intensifying major-power competition, a sluggish economic recovery, persistently high U.S. inflation, and elevated interest rates—the findings provide a plausible theoretical and practical basis for the continued upward momentum in gold prices. Investors analyzing gold price trends or engaging in gold-related investments should not only account for the time-varying USDI-GP relationship but also integrate broader considerations, including the evolving international political-economic environment and the underlying logic driving their interactions.

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Integrated Weighting Analysis for Operational Risk Assessment Indicators in HS Chemical Company

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Abstract: Growing regulatory demands for industrial safety and environmental protection in the chemical sector necessitate robust operational risk assessment to enhance management efficacy. Here, the HS Chemical Company is evaluated through a multidimensional framework encompassing market dynamics, macroeconomic factors, financial stability, governance, supply chains, and production safety. By integrating the Analytic Hierarchy Process (AHP) with entropy weighting, a hybrid weighting model that mitigates the limitations of singular methods is established. The analysis of this study identifies financial risk (weight: 0.347) and production safety (weight: 0.298) as dominant risk drivers. These quantitative insights offer a basis for resource prioritization and targeted risk mitigation strategies in chemical enterprises.

Keywords: Chemical enterprises; Operational risk; Analytic hierarchy process (AHP); Entropy weighting method; Weighting analysis

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1. Introduction

The chemical industry serves as a critical pillar of the national economy, with its products essential to agriculture, industry, defense, and technological advancement. As a key player in chemical production and R&D, this sector remains indispensable for economic development.

HS Chemical Company, with over three decades of operation, specializes in four core segments: basic chemicals, fertilizers, advanced chemical materials, and new energy materials. The planned commissioning of new production facilities in 2024 is projected to drive sustained sales growth, with revenues expected to rise steadily in subsequent years. This expansion underscores the necessity for systematic operational risk assessment.

To address this need, a comprehensive risk evaluation index system is established, integrating the Analytic Hierarchy Process (AHP) and entropy weighting method. This hybrid approach enables scientifically robust risk identification, minimizing potential losses through data-driven decision-making.

The development of risk assessment frameworks for the chemical industry has been extensively investigated

in academic research. Zhao established a tri-scale indicator system encompassing risk source strength, receptor vulnerability, and risk prevention capability ^[1]. Wang developed a universal hierarchical indicator system to identify risks arising from intrinsic process safety, operational management, as well as chemical storage and transportation ^[2]. Ding proposes an integrated risk assessment approach combining three key indicators: (1) loss of containment (LOC) potential at chemical facilities, (2) secondary fire incident probability, and (3) inter-unit proximity within chemical installations ^[3]. Aggregate risk scores were correlated with tank inventory availability to develop inventory management-based risk mitigation strategies for chemical loading operations.

Diverse methodological approaches have emerged in chemical industry risk assessment research. Yan developed a novel risk computation framework termed Risk Mesh (RM), enabling three-dimensional risk evaluation through field-theory-based modeling ^[4]. Concurrently, Gan established a modified cross-sectional risk assessment methodology for post-disaster scenarios, comprising five key components: (1) geolocation mapping of chemical facilities, (2) identification of flood-compromised or at-risk plants, (3) analysis of chemical hazard typology and frequency distributions, (4) population exposure assessment, and (5) spatial visualization of composite risk indicators ^[5]. Qi combined the bow tie model, the three-dimensional risk matrix and the Analysis Network Process (ANP) to construct a semi-quantitative comprehensive risk assessment model for fires in hazardous chemical laboratories ^[6]. Guo developed a multi-task learning framework, termed Robust Progressive Layer-wise Extraction (RPLE), for systematic prediction of accident risk categories, likelihood probabilities, and severity levels ^[7]. In parallel, He introduced a dynamic, multi-hazard assessment approach for generating chemical accident evacuation strategies ^[8]. This methodology employs cumulative individual risk as the primary optimization metric while dynamically accounting for multi-hazard characteristics and domino effects during evacuation scenarios.

2. Methods

Risk is formally defined as uncertainty associated with potential loss, characterized by two intrinsic properties: (1) its objective existence as a measurable phenomenon, and (2) uncertainty as its fundamental nature. Operationally, risk quantifies the impact of uncertainty on objectives, conventionally expressed through the composite function:

$$R = P \times C$$

where R denotes risk magnitude, P represents event probability ($0 \leq P \leq 1$), and C indicates consequence severity. This formulation reflects a non-linear integration of likelihood and impact rather than simple arithmetic multiplication.

To achieve scientifically robust weight determination for operational risk indicators in HS Chemical Company, a hybrid weighting model integrating the Analytic Hierarchy Process (AHP) with entropy weighting is established. This dual approach mitigates inherent biases of singular weighting methods through cross-validation, preserves expert judgment via AHP's pairwise comparison matrices, while leveraging entropy-based objective optimization from empirical data distributions.

2.1. Analytic hierarchy process

The Analytic Hierarchy Process (AHP), developed by operations researcher Thomas L. Saaty in the 1970s, provides a systematic framework for quantifying qualitative decision-making in complex systems. This method decomposes problems into hierarchical structures (**Figure 1**), determines relative weights through pairwise

comparison matrices, and synthesizes results for comprehensive evaluation.

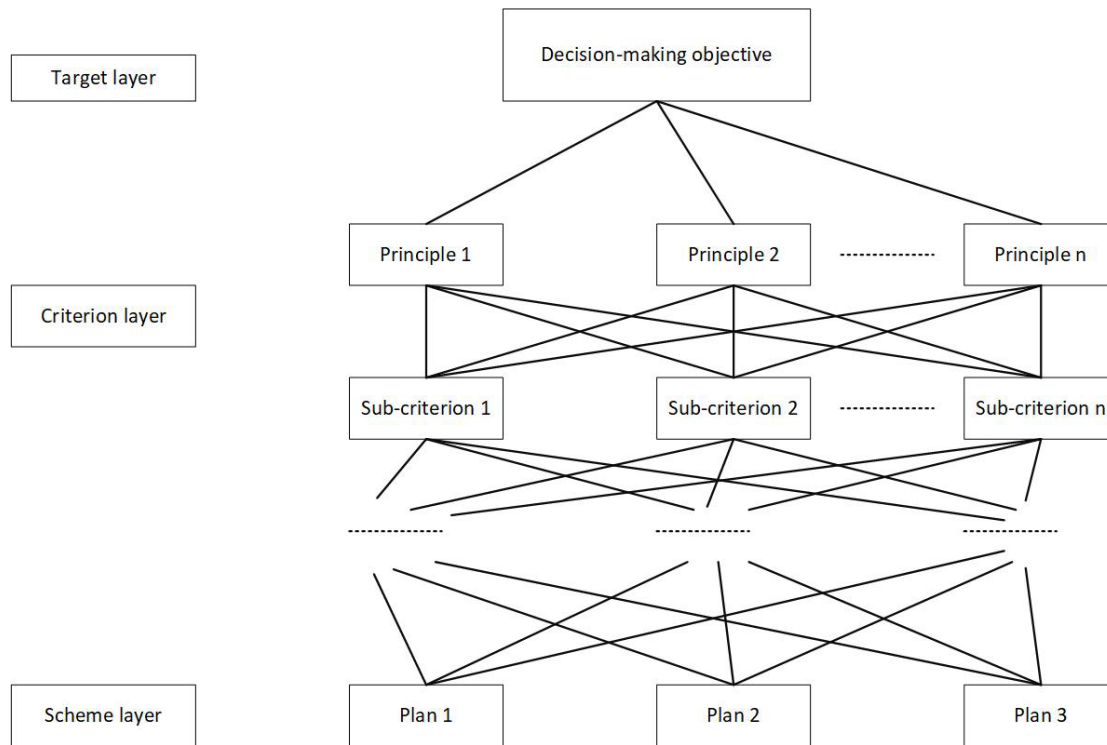


Figure 1. Hierarchical structure diagram

2.1.1. The calculation process of the Analytic Hierarchy Process

(1) The judgment matrix A was normalized to generate matrix D, followed by row-wise summation:

$$D_{ij} = \frac{r_{ij}}{\sum_{i=1}^m r_{ij}} \quad (1)$$

$$f_{ij} = \sum_{j=1}^m D_{ij} \quad (2)$$

(2) The vector $F = (f_1, f_2, f_3, \dots, f_n)$ of matrix D was normalized to derive both the evaluation index weights W_i and the principal eigenvector W.

$$W_i^1 = f_i \sum_{j=1}^m f_j \quad (3)$$

$$W = \begin{bmatrix} W_1^1 \\ W_2^1 \\ \vdots \\ W_n^1 \end{bmatrix} \quad (4)$$

(3) Calculate the principal eigenvalue λ_{\max}

$$\lambda_{\max} = \frac{1}{m} \sum_{i=1}^m \frac{(AW^1)_i}{W^1} \quad (5)$$

(4) Consistency verification

Compute the consistency index CI.

$$CI = \frac{\lambda_{max} - m}{m - 1} \quad (6)$$

2.2. Entropy value method

2.2.1. Entropy weighting methodology

The entropy method is an objective weighting approach that determines indicator weights based on their variation degrees through information entropy theory. This technique applies subsequent weighting to yield more impartial evaluation outcomes.

2.2.2. Theoretical foundation

Information entropy, a core concept in information theory, quantifies data uncertainty. Key properties include:

- (1) High entropy: Indicates greater disorder and lower information utility
- (2) Low entropy: Reflects ordered patterns and higher informational value

2.2.3. Weighting principle

The method operates on the premise that: Indicators with smaller entropy demonstrate larger value fluctuations, containing more discriminative information. The calculation process of the entropy method are as follows:

- (1) The index data is standardized. This paper studies the risk assessment related to enterprises. Therefore, all the indicators are negatively correlated indicators, that is, the smaller the risk level, the more beneficial it is.

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \quad (7)$$

- (2) Calculate the proportion of each indicator in each sample

$$P_{ij} = \frac{x'_{ij}}{\sum_{i=1}^n x'_{ij}} \quad (8)$$

- (3) Determine the entropy values of each evaluation index

$$E_j = -k \sum_{j=1}^n q_{ij} \ln q_{ij} \quad (9)$$

$$k = \frac{1}{\ln n} \text{ and } k > 0$$

- (4) Calculate the weights of the indicators

$$W_j = \frac{1 - e_j}{\sum_{j=1}^m 1 - e_j} \quad (10)$$

3. Hybrid AHP-Entropy Weighting Model

3.1. Determination of evaluation indicators

The construction of the risk assessment index system follows the principles of comprehensiveness, systematic operation, science, and rationality. Qualitative analysis is combined with quantitative analysis, combined with

reality, and adapted to local conditions. Through the observation of the company by experts and literature research, the risk indicators existing in the operation were collected and sorted out, and experts were invited to discuss the selected first-level risk indicators. Finally, six first-level indicators, namely market risk, macro-environmental risk, financial risk, management risk, supply chain risk, and work safety risk, and 21 second-level indicators were determined, as shown in **Table 1**.

Table 1. Index system of risks

Criterion layer	Symbol	Indicator layer	Symbol
Market risk	U_1	Market competition risk	U_{11}
		Market demand risk	U_{12}
		Market sales risk	U_{13}
Macro environmental risk	U_2	Policy and legal risks	U_{21}
		Environmental protection risk	U_{22}
		Risk of public emergencies	U_{23}
Financial risk	U_3	Debt risk	U_{31}
		Risk of capital flow	U_{32}
		Raw material price risk	U_{33}
		Profit risk	U_{34}
		Investment risk	U_{35}
Manage risks	U_4	Talent risk	U_{41}
		Internal control risk	U_{42}
		Decision-making risk	U_{43}
		Risk of supply disruption	U_{51}
Supply chain risk	U	Procurement quality risk	U_{52}
		Inventory management risk	U_{53}
		Risk of supply timeliness	U_{54}
Production safety risks	U_6	Risk of natural disasters	U_{61}
		Fire safety risk	U_{62}
		Operational risk	U_{63}

3.2. The Analytic Hierarchy Process (AHP) determines the subjective weights

The importance of each indicator was scored by distributing questionnaires online to 20 experts. The first-level indicator (criterion layer) was scored as a whole first, and then the second-level indicator (indicator layer) was scored. Based on the above calculations, the set of weight values of the operation risk indicators of HS Chemical Company based on the AHP method can be sorted out, as shown in **Table 2**.

Table 2. Weights of the analytic hierarchy process

First-level indicator	Weight	Secondary indicators	Weight
Market risk	0.128	Market competition risk	0.637
		Market demand risk	0.105
		Market sales risk	0.258
Macro environmental risk	0.068	Policy and legal risks	0.258
		Environmental protection risk	0.108
		Risk of public emergencies	0.637
		Debt risk Risk of capital flow	0.501 0.246
Financial risk	0.488	Raw material price risk	0.129
		Profit risk	0.070
		Investment risk	0.054
		Talent risk	0.108
Manage risks	0.022	Internal control risk	0.258
		Decision-making risk	0.637
		Risk of supply disruption	0.545
		Procurement quality risk	0.233
Supply chain risk	0.038	Inventory management risk	0.084
		Risk of supply timeliness	0.139
		Risk of natural disasters	0.105
		Fire safety risk	0.258
Production safety risks	0.256	Operational risk	0.637

3.3. The entropy weight method determines the objective weights

The importance of each indicator was scored by distributing questionnaires online to 20 experts. The first-level indicator (criterion layer) was scored as a whole first, and then the second-level indicator (indicator layer) was scored. Finally, the objective weights of the indicators are determined to establish the evaluation set of the evaluated targets, as shown in **Table 3**.

Table 3. Weights of the entropy weight method

First-level indicator	Weight	Secondary indicators	Weight
Market risk	0.172	Market competition risk	0.406
		Market demand risk	0.183
		Market sales risk	0.411
Macro environmental risk	0.159	Policy and legal risks	0.262
		Environmental protection risk	0.439
		Risk of public emergencies	0.299

Table 3 (Continued)

First-level indicator	Weight	Secondary indicators	Weight
Financial risk	0.234	Debt risk	0.221
		Risk of capital flow	0.377
		Raw material price risk	0.134
		Profit risk	0.113
		Investment risk	0.154
Manage risks	0.103	Talent risk	0.305
		Internal control risk	0.255
		Decision-making risk	0.440
		Risk of supply disruption	0.276
Supply chain risk	0.104	Procurement quality risk	0.359
		Inventory management risk	0.188
		Risk of supply timeliness	0.176
		Risk of natural disasters	0.400
Production safety risks	0.228	Fire safety risk	0.182
		Operational risk	0.418

3.4. Determine the final comprehensive weight

When determining the weights of the operational risk indicators of HS Chemical Company, the Analytic Hierarchy Process (AHP) and the entropy weight method were respectively adopted to obtain the subjective weights and objective weights of the risk indicators. The comprehensive weights obtained then not only conform to the actual situation of the company, but also are more accurate and intuitive. The formula for combining the weights using the combined weighting method is as follows: $\omega = \frac{A_i \times B_i}{\sum_{i=1}^n A_i \times B_i}$. Finally, the comprehensive weights of risk factors within each criterion layer are obtained. The results are shown in **Table 4**.

Table 4. Comprehensive weights

First-level indicator	Weight	Secondary indicators	Weight
Market risk	0.128	Market competition risk	0.674
		Market demand risk	0.050
		Market sales risk	0.276
Macro environmental risk	0.106	Policy and legal risks	0.221
		Environmental protection risk	0.155
		Risk of public emergencies	0.624
		Debt risk	0.467
Financial risk	0.347	Risk of capital flow	0.391
		Raw material price risk	0.073
		Profit risk	0.033
		Investment risk	0.035

Table 4 (Continued)

First-level indicator	Weight	Secondary indicators	Weight
Manage risks	0.057	Talent risk	0.087
		Internal control risk	0.174
		Decision-making risk	0.740
Supply chain risk	0.065	Risk of supply disruption	0.548
		Procurement quality risk	0.305
		Inventory management risk	0.058
		Risk of supply timeliness	0.089
		Risk of natural disasters	0.118
Production safety risks	0.298	Fire safety risk	0.132
		Operational risk	0.750

4. Conclusion

Based on the calculations described above, the ranking of the six risk factors in the operations of HS Chemical Company is as follows: financial risk > production safety risk > market risk > macro-environmental risk > supply chain risk > management risk. The results indicate that production safety risk and financial risk have a relatively greater impact on the company's operations. The production processes of chemical enterprises involve various hazardous chemicals and complex procedures. In the event of safety accidents such as explosions or leaks, substantial direct economic losses can occur. Financial risk is an inescapable factor for every manufacturing enterprise. Chemical enterprises often undertake large-scale, long-term investment projects. Mistakes in investment decisions may lead to the idling or loss of significant amounts of corporate funds. Moreover, the prices of chemical products are highly influenced by market supply and demand relationships and fluctuations in raw material prices. If a company fails to accurately predict market changes and formulate reasonable pricing strategies, it may result in product overstocking or reduced profits. Although the other risks have lower scores, their impact on corporate operations should not be overlooked. Poor management, supply disruptions, and policy changes can all directly or indirectly affect the development of the enterprise.

Disclosure statement

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Analysis on the Integration of Culture, Commerce, Tourism, and Sports in Hainan to Help Build Haikou Into an International Consumption Center City

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Abstract: In the context of the Hainan Free Trade Port, Haikou is committed to becoming an international consumer city, with the integration of culture, commerce, tourism, and sports as a key strategy. This article provides an in-depth analysis of Haikou's current status in building an international consumer city through the integration of culture, commerce, tourism, and sports, including its strengths and existing challenges. It explores the significance of this integration for Haikou and proposes targeted development strategies. These strategies aim to enhance the city's appeal and international competitiveness by integrating resources, innovating business models, and optimizing the environment, thereby promoting the deep integration of culture, commerce, tourism, and sports in Haikou.

Keywords: Integration of culture, commerce, tourism, and sports; Haikou; International consumer city center; Development strategy

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1. Introduction

With the advancement of economic globalization and consumption upgrades, international consumer cities, as hubs for global consumption resources and leaders in consumer trends, play a crucial role in regional and global economic development. Haikou, the core leading area of the Hainan Free Trade Port, boasts unique policy advantages, abundant natural resources, and a rich cultural heritage, making it highly potential for developing into an international consumer city ^[1, 2].

The integration of culture, commerce, tourism, and sports is a significant trend in the development of urban economies today. By integrating resources from these sectors, it can create diverse consumption scenarios, meet the increasingly varied consumer demands, and thus promote the prosperity and upgrading of the urban consumer market ^[3]. For Haikou, actively promoting the integration of culture, commerce, tourism, and sports not only helps to fully leverage its own advantages and enhance the city's overall competitiveness but also better supports the

strategic goal of building the Hainan Free Trade Port, achieving high-quality economic development. Therefore, in-depth research on how the integration of culture, commerce, tourism, and sports in Hainan can assist Haikou in building an international consumer center city holds important theoretical and practical significance ^[4].

2. The significance of the integration of culture, commerce, tourism, and sports to the construction of Haikou International Consumption Center City

2.1. Enrich consumption scenarios and meet diversified needs

In the context of consumption upgrade, consumer demands are becoming increasingly diverse and personalized ^[5]. ^[6] The integration of culture, commerce, tourism, and sports can organically combine cultural depth, commercial vibrancy, tourism experiences, and sports enthusiasm, creating a wide range of consumption scenarios. For instance, in Haikou's Qilou Old Street, by introducing cultural and creative product stores, specialty restaurants, and folk performances, the ancient Qilou buildings are combined with modern commerce and cultural experiences. Tourists can not only admire unique architectural styles but also enjoy local cuisine, purchase souvenirs, and experience folk culture, meeting their needs for cultural experiences, shopping, and leisure activities. Additionally, during marathon events, combining sports events with tourism routes attracts many running enthusiasts and tourists to participate in and watch the races, while also boosting local accommodation, dining, and shopping, offering consumers a new consumption experience ^[7].

2.2. Enhance the city's brand image and enhance its attractiveness

Culture is the soul of a city, commerce its vitality, tourism its calling card, and sports its passion ^[8]. The integration of culture, commerce, tourism, and sports can fully showcase a city's unique features and charm, enhancing its brand image. Haikou, positioned as a New Year's Eve City and an International Performing Arts Capital, has hosted a series of major events, including the Hunan TV Mango TV New Year's Eve Gala and Kanye West's world tour listening sessions ^[8]. These events have attracted global attention, not only boosting the city's reputation but also showcasing Haikou's open, fashionable, and vibrant image to the world ^[9]. These activities have attracted a large number of tourists and consumers, enhancing the city's appeal and influence, making Haikou more competitive in the international consumer market ^[10].

2.3. Promote coordinated industrial development and promote economic growth

The cultural, commercial, tourism, and sports industries are closely interconnected and mutually reinforcing. The cultural industry provides rich content and creativity for commerce, tourism, and sports. Commerce provides the material foundation and consumer support for culture, tourism, and sports. Tourism expands market opportunities for culture, commerce, and sports. Sports infuse vitality and passion into culture, commerce, and tourism. Through integrated development, these industries can collaborate more effectively, forming a complete industrial chain that drives industrial upgrading and economic growth ^[11, 12]. For example, the China International Consumer Goods Expo (CIGE) not only boosts the development of the trade sector but also promotes the coordinated development of related industries such as tourism, exhibitions, and cultural creativity, injecting strong momentum into Haikou's economic growth. According to statistics, during the CIGE, Haikou saw significant increases in tourism revenue, hotel occupancy rates, and catering sales, significantly boosting the local economy ^[13].

2.4. Stimulate the growth of consumption and promote the return of overseas consumption

As the duty-free policy for Hainan's islands continues to improve and the integration of culture, commerce, tourism, and sports advances, Haikou's appeal as a consumer destination is growing ^[14]. The city's rich tourism resources, high-quality commercial services, unique cultural experiences, and exciting sports events attract a large number of domestic and international tourists. Duty-free shopping, a hallmark of Hainan's tourism consumption, has become a significant driver of Haikou's consumer growth. In 2024, customs supervised a total of 30.94 billion yuan in Hainan's duty-free shopping, with 56.83 million shoppers ^[15]. The integration of culture, commerce, tourism, and sports has extended the consumption chain for tourists, increasing both the frequency and amount of spending. Additionally, Haikou has enhanced its consumer environment and service quality, attracting more overseas consumers to return, turning policy benefits into real consumer vitality, and laying a solid foundation for the development of an international consumer center city ^[16].

3. Analysis of the current situation of integrated development of culture, commerce, tourism, and sports in Haikou

3.1. The foundation and advantages of integrated development

Policy support has provided strong backing for the integrated development of culture, commerce, tourism, and sports in Haikou, thanks to the construction of the Hainan Free Trade Port. The policy framework, featuring zero tariffs, low tax rates, and a simplified tax system, has attracted numerous international consumer brands, duty-free industry capital, and high-net-worth consumers ^[17]. The duty-free policy for departing passengers has been continuously refined, with new methods such as guarantee-based pickup and instant purchase and instant pickup introduced. These changes have increased the shopping quota and expanded the range of products, significantly boosting the consumer market. Additionally, the government has implemented a series of policies to promote the integrated development of culture, commerce, tourism, and sports, including encouraging large-scale cultural performances and sports events, supporting the growth of the cultural and creative industries, and enhancing the quality and upgrading of tourist attractions, thus creating a favorable policy environment for integrated development ^[18].

Haikou boasts a rich array of cultural resources, including the Nanyang culture of its old arcade streets, intangible cultural heritage such as Qiong Opera, and Dongpo culture, which provide a deep cultural foundation for the integration of culture, commerce, tourism, and sports ^[19]. In terms of tourism resources, Haikou features a beautiful coastline, tropical landscapes, and volcanic crater geological parks, as well as cultural sites like the former residence of Hai Rui and the Wugong Temple, making it a highly attractive tourist destination. The commercial resources are continuously expanding, with the establishment of large commercial complexes such as Haikou International Duty-Free City, which have attracted many international brands, enhancing the city's international commercial appeal. Additionally, Haikou has venues and facilities suitable for hosting various sports events, providing a solid foundation for the development of the sports industry ^[20].

As people's living standards improve and their consumption concepts evolve, the demand for cultural, tourism, and sports activities is on the rise. Haikou, a popular tourist destination, welcomes a large number of visitors each year, providing a vast market for the integration of culture, commerce, tourism, and sports. Moreover, local residents purchasing power is growing, leading to a strong demand for high-quality and diverse products and services, which further promotes the integration of these sectors.

3.2. Practice and achievements of integrated development

3.2.1. “Culture + Tourism”

Haikou is actively tapping into its local cultural resources, integrating cultural elements into tourism products and routes. For instance, by leveraging the historic arcade streets, it has developed a cultural tourism district where visitors can admire the arcade architecture, savor Hainan’s distinctive cuisine, purchase creative cultural products, and immerse themselves in Haikou’s rich historical and cultural heritage. The city hosts the Dongpo Cultural Tourism Conference, which promotes Dongpo culture through exhibitions, performances, and forums, attracting many tourists to experience the Dongpo cultural journey. Additionally, Haikou has introduced unique tourism products such as Qiong Opera cultural experience tours and intangible cultural heritage study tours, enriching the cultural depth of its tourism offerings.

3.2.2. “Tourism + Business”

Haikou is actively promoting the integration of tourism and commerce, creating a series of tourism shopping districts and commercial complexes. Haikou International Duty-Free City has become the world’s largest single duty-free store, attracting a large number of tourists to shop by showcasing many international top brands. Additionally, several distinctive commercial districts have been developed around scenic spots and in bustling urban areas, such as the Century Cape Commercial District and the Gaoxingli Characteristic Commercial Cultural District. These districts integrate shopping, dining, and entertainment with tourism, offering visitors a convenient and enjoyable shopping experience. By bundling tourism with duty-free shopping, Haikou has extended tourists’ stays and increased tourism revenue.

3.2.3. “Sports + Tourism”

Haikou is leveraging sailing and marathon events to vigorously develop the sports + tourism industry. It hosts a variety of international and domestic events, including the World Beach Volleyball Professional Tour Challenge, the International Water Ski Federation Asian Wakeboarding Series, and the Haikou Marathon, attracting many sports enthusiasts and tourists. Additionally, Haikou has introduced marine sports tourism activities such as sailing experiences, diving, and sea fishing, as well as land-based sports tourism activities like cycling and hiking. By integrating sports activities with tourism, sightseeing, and leisure vacations, Haikou has enriched its tourism offerings and enhanced the appeal and participation in tourism.

3.2.4. “Culture + Business”

Integrate cultural elements into commercial districts and shopping centers by hosting a variety of cultural activities and exhibitions, thereby enhancing the cultural atmosphere and appeal of these areas. Organize art exhibitions and live demonstrations of craftsmanship in the old arcade streets, allowing visitors to experience the charm of culture while shopping. Set up cultural experience zones in malls, such as workshops for handicrafts, calligraphy, and painting, offering consumers unique shopping experiences. Additionally, launch cultural-themed commercial events, including exhibitions of cultural and creative products and cultural food festivals, to promote the deep integration of culture and commerce.

3.3. Existing problems and challenges

The integration is not deep enough. While Haikou has made some progress in integrating culture, commerce, tourism, and sports, the integration in certain areas remains superficial, lacking depth and innovation. Some

cultural tourism projects merely combine cultural elements with tourist attractions without fully exploring their cultural significance, thus failing to provide visitors with a profound experience. The integration of sports events with tourism is also inadequate, as the tourism boost from these events has not been fully realized. Apart from short-term consumption increases during the event period, the long-term impact on the tourism market is limited.

The synergy among industries is insufficient, with the cooperation mechanisms between culture, commerce, tourism, and sports not yet fully developed, leading to a fragmented approach. There is a lack of effective communication and coordination among departments such as culture, commerce, tourism, and sports, making it difficult to form a cohesive effort in project planning, resource integration, and market promotion. For instance, when organizing large-scale cultural events, there is often a lack of consideration for the integration with tourism and commerce, which limits the events impact and economic benefits. Additionally, the collaboration between upstream and downstream enterprises in the industrial chain is not tight enough, and the value added by the industry needs to be enhanced.

The infrastructure and services in Haikou need improvement. With the integration of culture, commerce, tourism, and sports, and the growing number of tourists, Haikou's infrastructure and services are under pressure. Some tourist attractions face significant traffic congestion, lack sufficient parking spaces, and have inadequate public restrooms and other facilities. The quality of tourism services varies widely, and the professional skills and service levels of tour guides and hotel staff need to be enhanced. In terms of international service, the proficiency in foreign languages is insufficient, making it difficult to meet the needs of international tourists. Additionally, the construction and operation of cultural venues and sports facilities require further strengthening to better support integrated development.

3.3.1. Talent shortage

The integration of culture, commerce, tourism, and sports requires versatile talents who are proficient in these fields. Currently, Haikou faces a shortage of such talents, with an underdeveloped talent cultivation system that fails to meet the industry's rapid growth needs. University programs are not closely aligned with market demands, resulting in graduates lacking practical and innovative skills. Additionally, the attractiveness of talent attraction policies needs to be enhanced, and there is a lack of effective incentive mechanisms for high-end, versatile talents.

4. Strategies for integrating culture, commerce, tourism, and sports to help build Haikou into an international consumption center city in Hainan

4.1. Strengthen top-level design and improve the mechanism of integrated development

4.1.1. Formulate unified planning

The government should enhance the overall planning for the integrated development of culture, commerce, tourism, and sports, and formulate specific development plans and implementation schemes. It should clearly define the goals, key tasks, and safeguard measures for integrated development, reasonably plan industrial spaces, and promote the coordinated development of all industries. In these plans, it is essential to fully consider Haikou's unique resources and market demands, emphasizing differentiated development to avoid homogenized competition. For example, based on the cultural and tourism resources of different areas, create distinctive demonstration zones for the integrated development of culture, commerce, tourism, and sports, such as a historical and cultural experience zone centered around the old arcade streets, and a coastal leisure commercial area based on Haikou Bay.

4.1.2. Establish a coordination mechanism

Establish and improve the collaborative cooperation mechanisms among cultural, commercial, tourism, and sports departments, enhancing communication, coordination, and information sharing among these departments. Form a leading group for the integrated development of culture, commerce, tourism, and sports, and hold regular joint meetings to address major issues in integrated development. Establish a joint project promotion mechanism to unify the planning, packaging, and promotion of key integrated projects, integrating resources from all parties to form a cohesive effort. Additionally, encourage enterprises to strengthen cooperation by forming industry alliances to jointly engage in market expansion, product development, brand promotion, and other activities, achieving mutual benefits and win-win outcomes.

4.2. Dig deep into cultural connotation and build a distinctive integrated brand

4.2.1. Integration and innovative utilization of cultural resources

To deeply explore and systematically organize and study Haikou's historical, cultural, folk, and marine resources. By using digitalization and creative methods, transform these cultural resources into appealing cultural products and services. For example, by utilizing technologies like virtual reality (VR) and augmented reality (AR), create immersive cultural experiences that allow visitors to feel the charm of Haikou's historical culture firsthand. Develop culturally creative products with Hainanese characteristics, such as Li brocade, coconut carving, and sea porcelain, integrating cultural elements into everyday items to enhance their cultural value.

4.2.2. Brand building and promotion

Focusing on the integrated development of culture, commerce, tourism, and sports, this study aims to create a series of Haikou-specific brands. With New Year's Eve City and International Performing Arts Capital as core brands, it will further enrich their connotations and enhance their recognition and reputation. Additionally, range of distinctive sub-brands, such as the Qilou Culture Festival, the Haikou Marathon, and the South China Sea Museum exhibitions, will be developed to form a comprehensive brand matrix. Brand promotion will be strengthened by leveraging mainstream media, social media, and tourism fairs both domestically and internationally to comprehensively promote Haikou's integrated cultural, commercial, tourism, and sports brands, thereby increasing their influence and market share.

4.3. Innovation and integration of business forms to enrich the supply of consumer products

4.3.1. Cultivating emerging business forms

Actively explore new models and forms of integration among culture, commerce, tourism, and sports to foster new consumption growth points. Develop the culture + technology + tourism model by creating smart tourist attractions that leverage big data and AI to enhance service quality and visitor experience. Promote the sports + health care + tourism model by developing sports and wellness tourism products, such as sports rehabilitation, health check-ups, and wellness vacations, to meet people's growing demand for a healthy lifestyle. Additionally, develop the nighttime economy by creating nighttime cultural and tourism consumption zones, hosting night performances, night markets, and light shows, to extend the consumption time and stimulate consumer activity.

4.3.2. Optimize product structure

Based on market demand and visitor feedback, continuously optimize the integration of cultural, commercial, tourism, and sports products. Diversify tourism offerings by developing high-end resorts, business conferences,

educational tours, and rural tourism to cater to the needs of visitors at all levels. Enhance the quality of commercial products by introducing more international and local brands, enriching the variety of goods, and enhancing their fashion appeal and personalization. Innovate cultural products and sports events by increasing the diversity and professionalism of cultural performances, art exhibitions, and sports events to boost the appeal and competitiveness of these offerings.

4.4. Improve infrastructure, improve service quality, and internationalization level

4.4.1. Infrastructure construction

Increase investment in transportation, communication, and energy infrastructure to improve the urban traffic network and enhance the accessibility of tourist attractions. Enhance the supporting facilities at tourist attractions, commercial districts, and sports venues, such as parking lots, public restrooms, visitor service centers, and charging stations, to improve the convenience and comfort of services. Promote the development of smart cities to enhance urban informatization and provide technical support for the integration of culture, commerce, tourism, and sports. For example, develop a smart tourism platform to offer real-time information queries, online reservations, and intelligent navigation, thereby improving the efficiency of tourism services.

4.4.2. Service quality improvement

Enhance the training of tourism service personnel, commercial professionals, cultural workers, and sports event organizers to improve their professional skills and service quality. Establish and improve mechanisms for monitoring service quality, strengthen supervision of the tourism, commercial, cultural, and sports markets, standardize market order, and protect consumer rights. Promote standardized services by developing integrated standards for cultural, commercial, tourism, and sports services to enhance the standardization and regulation of these services. Additionally, focus on personalized services by offering customized products based on tourists' needs and preferences, thereby increasing their satisfaction and loyalty.

4.4.3. Internationalization of service capacity building

Enhance the training of foreign language talents to improve the foreign language proficiency of professionals in tourism, commerce, culture, and sports, particularly in spoken English and listening skills. Provide multilingual service signs and language services at airports, hotels, scenic spots, and shopping malls. Introduce internationally renowned service companies and management teams to learn from advanced international service concepts and management practices, thereby enhancing Haikou's international service standards. Additionally, strengthen exchanges and cooperation with international tourism organizations, cultural institutions, and sports event organizers, actively participate in international tourism, cultural, and sports activities, and enhance Haikou's international recognition and influence.

4.5. Strengthen talent support and build a talent development system

4.5.1. Talent training

Enhance collaboration with universities and vocational colleges, optimize the curriculum, and introduce specialized courses that integrate culture, commerce, tourism, and sports, such as cultural tourism management, sports tourism, and commercial cultural creativity, to cultivate professionals who meet market demands. Establish internship and training bases, strengthen practical teaching, and enhance students' practical skills and innovation capabilities. Encourage companies to conduct internal training to improve employees' professional skills and

overall quality. Additionally, organize various vocational skill competitions and training activities to provide a platform for talents to showcase their abilities and enhance their capabilities.

4.5.2. Talent introduction

To formulate more favorable policies for attracting top talents in cultural, commercial, tourism, and sports sectors from both domestic and international sources to develop in Haikou. Provide policy support in housing, children's education, and medical care to alleviate the concerns of these talents. Establish a special fund for talent introduction to offer financial subsidies and rewards to high-end and urgently needed talents. Enhance connections with domestic and international talent markets by organizing job fairs, project matchmaking events, and other activities to broaden the channels for talent introduction. Additionally, flexible recruitment methods can be used to attract renowned experts and scholars from home and abroad to provide intellectual support for the integrated development of culture, commerce, tourism, and sports in Haikou.

4.5.3. Talent motivation

Establish and improve the talent incentive mechanism to fully mobilize the enthusiasm and creativity of talents. Enhance the compensation system by providing appropriate remuneration based on their performance and contributions, thereby increasing their income levels. Establish a talent reward fund to recognize and reward those who have made significant contributions to the integration of culture, commerce, tourism, and sports. Offer broad development opportunities and promotion prospects to talents, encouraging innovation and entrepreneurship, and achieving the organic integration of personal value with urban development.

5. Conclusion

The integration of culture, commerce, tourism, and sports is a key strategy for Haikou to become an international consumer city. This integration is crucial for enriching consumption scenarios, enhancing the city's brand image, promoting industrial synergy, and boosting consumption growth. Despite some achievements in this area, Haikou still faces challenges such as insufficient integration depth, inadequate industrial coordination, the need for improved infrastructure and services, and a shortage of talent. By implementing strategies such as strengthening top-level design, exploring cultural connotations, innovating integrated business models, improving infrastructure, enhancing service quality and internationalization, and reinforcing talent support, Haikou can effectively promote the deep integration of culture, commerce, tourism, and sports.

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Pumped Storage Industry–Development Opportunities for Manufacturing Enterprises and a New Growth Pole for the Chinese Economy

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Abstract: In the context of the accelerated global transition to green and low-carbon energy, China's energy structure is undergoing profound changes. As of early 2025, the installed capacity of wind and photovoltaic power in China has exceeded 1.4 billion kilowatts, accounting for 42.9% of the total installed power generation capacity, historically surpassing thermal power as the largest power source. However, the randomness, volatility, and intermittency of renewable energy generation pose unprecedented challenges to the power system's regulatory capacity. In this context, pumped storage, as the most technically mature and economically advantageous large-scale energy storage method, is experiencing explosive growth, providing strategic opportunities for the transformation and upgrading of manufacturing enterprises.

Keywords: Pumped storage; Manufacturing upgrade; Industrial synergy; Green economy

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1. Introduction

1.1. Technical principles and industry positioning

Pumped storage power stations achieve large-scale, high-efficiency storage of electrical energy through the mutual conversion of mechanical energy from water and electrical energy from the power system. Their working principle involves pumping water from a lower reservoir to an upper reservoir for storage during periods of low electrical load. During peak load periods, the stored water is released from the upper reservoir to the lower reservoir for power generation, effectively regulating the supply and demand contradiction in the power grid. This “power bank” operating mechanism makes pumped storage the most technically mature, economically optimal, and flexible power source with large-scale development potential.

Compared to traditional energy storage technologies, pumped storage has three core advantages: Firstly, ultra-long service life, with a design life of over 50 years, far exceeding the 10–15 years of electrochemical energy storage; Secondly, large-capacity regulation capability, with a single station's installed capacity reaching up to

1 million kilowatts; Thirdly, low life cycle costs, with a levelized cost of electricity that is only 1/3 to 1/2 of that of electrochemical energy storage. In building a new power system with renewable energy as the mainstay, pumped storage has become an indispensable technical support for ensuring the safe and stable operation of the power grid ^[1].

1.2. Development scale of China’s pumped storage industry

China’s pumped storage industry has entered a “fast track” of development. According to data from the Hydropower and Water Resources Planning and Design General Institute’s “Pumped Storage Industry Development Report 2024”, as of the end of 2024, China’s total installed capacity of pumped storage in operation reached 58.69 million kilowatts, ranking first in the world for nine consecutive years, far surpassing Japan’s approximately 23 million kilowatts and the United States’ approximately 22 million kilowatts ^[2]. More importantly, the total installed capacity of pumped storage power stations approved and under construction nationwide is about 200 million kilowatts, forming a “double growth” pattern of both operational and under-construction scales.

From a regional perspective, East China has the largest installed capacity, followed by North China and South China. This layout is highly compatible with China’s energy consumption centers, effectively supporting regional power supply security and low-carbon transformation. For example, in the South China Power Grid, the pumped storage multi-plant station centralized control center located in Panyu, Guangzhou, controls six pumped storage power stations in the Guangdong-Hong Kong-Macao Greater Bay Area, covering nearly one-sixth of the country’s pumped storage equipment. In 2024, the number of calls and duration of pumped storage units in the region exceeded 40,000 and 110,000 hours, respectively, driving a 36% year-on-year increase in renewable energy generation^[3].

1.3. Policy drivers and development planning

National policies provide strong support for the pumped storage industry. The “Medium and Long-Term Development Plan for Pumped Storage (2021–2035)”, released in 2021, clarifies the ambitious goal of “reaching a total installed capacity of 120 million kilowatts by 2030 and 420 million kilowatts by 2035”. The “Energy Law of the People’s Republic of China”, which officially came into effect in 2025, further proposes “the state shall reasonably plan and actively and orderly develop and construct pumped storage power stations”. Reform of the electricity pricing mechanism is also being promoted simultaneously. In 2021, the National Development and Reform Commission issued the “Opinions on Further Improving the Price Formation Mechanism for Pumped Storage”, establishing a two-part electricity pricing model to provide income security for industry investment.

Table 1. Medium and long-term development planning goals for China’s pumped storage industry

Timeline	Installed capacity target	Annual power generation potential	New energy integration capacity
2025	~80 GW	> 20 TWh	~150 GW
2030	120 GW	> 30 TWh	~300 GW
2035	420 GW	> 100 TWh	Meets large-scale development needs for high-penetration renewable energy

2. Analysis of the economic value of the pumped storage industry

2.1. Investment stimulation and economic growth effects

The pumped storage industry is emerging as a new engine for driving effective investment. The investment scale

of a single pumped storage power station typically ranges from billions to tens of billions of yuan. For example, the Huangcaoyuan Pumped Storage Power Station in Dai County, Shanxi Province, has an installed capacity of 1.4 million kilowatts and a total investment of 10.99 billion yuan. The nine 10-million-kilowatt-class pumped storage power station clusters under construction in Guangdong and Guangxi have a total investment of nearly 70 billion yuan ^[4]. Industry predictions indicate that during the “14th Five-Year Plan” period, the total investment scale of China’s pumped storage industry will exceed one trillion yuan, providing strong support for economic growth.

This investment stimulation effect is particularly significant in regional economic development. Taking Chengde City, Hebei Province, as an example, relying on the demonstration effect of the Fengning Pumped Storage Power Station (the largest in the world with a total installed capacity of 3.6 million kilowatts), the city has successively started construction on pumped storage projects in Luanping and Longhua. The scale of projects under construction, approved, and newly planned ranks first in Hebei Province. After the Fengning power station is fully operational, its annual power generation will reach 6.6 billion kilowatt-hours, which can satisfy the annual electricity consumption of 2.6 million households. Simultaneously, it will save 480,000 tons of standard coal and reduce carbon dioxide emissions by 1.2 million tons, equivalent to planting 240,000 mu of forests.

2.2. Industrial chain synergy and manufacturing upgrade

The pumped storage industry features a long industrial chain, covering various links such as survey and design, equipment manufacturing, engineering construction, and operation and maintenance. This provides full-chain development opportunities for manufacturing enterprises. Core equipment manufacturing areas include:

- (1) High-end special materials: The 1000MPa-grade high-strength hydropower steel developed by Nanjing Iron and Steel Group has solved the stringent requirements of large-scale hydropower projects for ultra-high strength, low-temperature toughness, and weldability of steel, filling a domestic technological gap. This material has been successfully applied to the pressure steel pipes of the Liaoning Qingyuan Pumped Storage Power Station, verifying its reliability and stability under high-pressure environments.
- (2) Hydro-turbine generator sets: The low-head diagonal-flow pumped storage pump-turbine unit developed by Tianjin Tianfa Hydropower Company, a subsidiary of Tianjin Baili Equipment Group, has achieved domestic leading performance indicators through structural optimization and hydraulic model innovation. The Yichang Hydropower High-end Manufacturing Industrial Park, jointly established by Zhejiang Fuchun Holding Group and China Three Gorges Corporation, has an initial planned annual production capacity of 10 sets of pumped storage units, which will alleviate the bottleneck of insufficient domestic production capacity.
- (3) Smart control systems: The Liaoning Qingyuan Pumped Storage Power Station applies an “unmanned intelligent control” vibration roller and a digital dam intelligent monitoring system, creating a new benchmark for intelligent construction in the pumped storage industry. Nanjing Iron and Steel Group achieves 100% online control of the research and development process and reduces the research and development cycle by 30% through a dual-drive architecture combining an “industrial internet platform + data governance.”

2.3. Technological innovation and industrial value-added enhancement

The rapid development of the pumped storage industry has led to significant technological breakthroughs, significantly enhancing the value-added of the equipment manufacturing industry. The 1000MPa high-strength

hydropower steel developed by Nanjing Iron and Steel's hydropower steel team not only fills a domestic technological gap but also achieves international leadership, pushing China's hydropower steel industry to transition from "import dependence" to "global export". It has been successfully applied to projects such as the Rufuji Hydropower Station in Tanzania and the Batang Hydropower Station in Indonesia.

In the field of smart construction, the Qingyuan Pumped Storage Power Station has innovatively applied the rotor stacking process. Through BIM technology modeling and pre-installation, the rotor is stacked in a positive and negative spiral rising manner, ensuring its stability under high-speed centrifugal conditions. Simultaneously, the application of high-precision laser measurement technology and intelligent calibration systems has significantly improved the operating efficiency and reliability of the unit. Nanjing Iron and Steel Group's digital architecture of "One Brain and Three Centers" (Smart Operation Center as the industrial brain, Integrated Ironmaking Center, Integrated Steel and Rolling Center, and Integrated Energy Center) has achieved dynamic optimization across the entire process and value chain, being selected as one of the first excellent smart factories in China.

3. Strategic path for manufacturing enterprises to develop pumped storage

3.1. Industrial chain extension and upgrading practices

Leading manufacturing enterprises are actively deploying in the pumped storage market through technological upgrading and industrial chain integration, forming a diversified development model:

(1) Transformation and upgrading of material suppliers

Nanjing Iron and Steel Group has transitioned from being a traditional steel manufacturer to being a provider of high-end hydropower steel solutions. Its hydropower steel products have been applied to pumped storage power station projects in Liyang, Jiangsu, Jixi, Anhui, Yimeng, Shandong, Changlongshan, Zhejiang, and Wendeng, Shandong. At the end of 2019, Nanjing Iron and Steel exclusively won a 28,000-ton order for the Qingyuan Pumped Storage Power Station in Liaoning, marking the acceleration of its hydropower steel business.

(2) Technological breakthroughs by equipment manufacturers:

Tianjin Baili Equipment Group's Tianfa Hydropower Company successfully won the bid for the Beijing Miyun Baihe Hydropower Station equipment renewal project with its self-developed low-head diagonal flow pumped storage pump-turbine unit, achieving a "second handshake" with the client across half a century. Relying on the synergies within the group's industrial chain, the company has integrated resources such as valves from International Machinery, frequency converters from Liaoning Rongxin, and transformers from TBEA, forming a competitive industrial chain.

(3) Strategic cooperation between system integrators

Zhejiang Fuchun Holdings has quickly entered the pumped storage field through consecutive signings of the "Strategic Cooperation Framework Agreement for the Jiangshan Pumped Storage Power Station Project in Zhejiang" and the "Cooperation Framework Agreement for the Yichang Hydropower High-end Manufacturing Industrial Park Project". The industrial park, built in partnership with the Three Gorges Group and the Yichang Municipal Government, is positioned as an "advanced pumped storage unit manufacturing base, a hydropower station spare parts production base, and a clean energy advanced equipment research and development trial production base", realizing a strategic transition from being a hazardous waste treatment leader to being a clean energy equipment manufacturer.

3.2. Digital transformation and smart construction

Digital technology is profoundly reshaping the manufacturing of pumped storage equipment and the construction model of power stations. The digital research and development system built by Nangang Group has achieved 100% online control of the research and development process, reducing the research and development cycle by 30%. Its “Smart Factory for Personalized Steel Production” project has been selected as a national-level excellent smart factory. Through the deep integration of advanced technologies such as artificial intelligence, 5G, and digital twins with steel manufacturing, it addresses pain points such as difficulties in data management, control, decision-making, and achieving win-win situations.

In the power station construction process, the Liaoning Qingyuan Pumped Storage Power Station applies a digital dam smart monitoring system, establishing a real-time, smart, full-process, and efficient intelligent rolling system for dam filling construction. Key processes such as stator assembly, spiral case hydrostatic testing, seat ring flat grinding, and unit turning are realized with intelligent and visual control, providing data analysis support for high-precision installation ^[5].

3.3. Green value and comprehensive benefits

The economic value created by pumped storage power stations far exceeds that of power regulation itself, forming a multi-dimensional value system of “economy-society-ecology”:

(1) Comprehensive utilization of water resources

The 12 reservoirs of the six pumped storage power stations in the Guangdong-Hong Kong-Macao Greater Region have a total storage capacity of 310 million cubic meters, equivalent to 22 West Lakes. Among them, the lower reservoir of the Shenzhen Pumped Storage Power Station was directly transformed and built on the basis of the Tongluojing Reservoir. The water quality has maintained the second-class standard for a long time, and it can provide about 6 million cubic meters of urban water per year.

(2) Flood control and drought relief regulation

In 2024, the Guangdong Qingyuan Pumped Storage Power Station responded to the requirements of the water conservancy department to release water in spring, effectively alleviating the local water shortage; in the same year, in response to heavy rainfall, the six power stations cumulatively retained more than 290 million cubic meters of floodwater and released nearly 270 million cubic meters of water.

(3) Integration of industrial and cultural tourism

Many pumped storage power stations in the Greater Region have created “special business cards” for industrial and cultural tourism. Shenzhen Power Station has planted more than 4,000 cherry blossoms to attract citizens to enjoy the spring outing; Guangzhou Power Station welcomes thousands of egrets to rest in autumn; Huizhou Power Station utilizes more than 10,000 hectares of Xiangtou Mountain to carry out tree planting tourism. This “green power station + eco-tourism” model has created additional economic benefits and improved the overall return on investment of the project.

4. Policy environment optimization and industry development suggestions

4.1. Analysis of current policies

The current policy system for pumped storage energy industry is centered around the “Medium and Long-Term Development Plan for Pumped Storage Energy (2021–2035)”. Supporting documents such as the “Opinions on Further Improving the Price Formation Mechanism for Pumped Storage Energy” and the “Interim Measures for

the Development and Construction Management of Pumped Storage Power Stations” have formed a three-in-one policy framework consisting of planning guidance, electricity price support, and management regulations. The two-part electricity pricing policy (capacity price + energy price) effectively guarantees reasonable returns for investors and stimulates investment enthusiasm among grid enterprises. By the end of 2024, the cumulative installed capacity of pumped storage energy in operation by State Grid will reach 40.26 million kilowatts, with a total capacity in operation and under construction exceeding 94 million kilowatts.

However, there is still room for improvement in the policy system: Firstly, the electricity pricing mechanism is not fully streamlined, and how the current two-part electricity pricing can be integrated with the reform of the electricity market remains to be explored; Secondly, high-quality site resources are decreasing, and economically viable sites are becoming scarcer as development progresses; Thirdly, the market-oriented operation mechanism is immature, and the construction of ancillary service markets and capacity markets is lagging.

4.2. Policy optimization suggestions

To promote the high-quality development of the pumped storage energy industry, it is suggested to optimize the policy environment from the following aspects:

(1) Building a differentiated market mechanism

Following the principle of “balancing safety and development”, deepen the pilot program for pumped storage energy to participate in market transactions in leading regions of electricity market reform, such as Guangdong and Shandong. Establish a transitional mechanism of “benchmark capacity price + contract for difference”, draw on the policies of coal-fired capacity price and new energy mechanisms, set benchmark electricity prices based on resource endowments by region, reduce pricing pressure, and guide cost reduction and efficiency improvement.

(2) Strengthening incentives for technological innovation

Establish a national science and technology special project for pumped storage energy, focusing on supporting the research and development of key technologies such as 1000MPa high-strength steel, variable-speed units, and seawater pumped storage. Provide application incentives for the first set of equipment, such as the successful demonstration of Nanjing Steel’s 1000MPa hydropower steel at the Qingyuan power station, which fills a domestic technological gap. Encourage the development of innovative forms such as distributed pumped storage and seawater pumped storage. China’s first seawater pumped storage project, the Ningde Fuying Island project, is currently under preparation.

(3) Improving the ecological compensation mechanism

Incorporate pumped storage power stations into the pilot program for realizing the value of ecological products, quantitatively evaluate their ecological service values, such as carbon emission reduction, water conservation, and flood regulation. Referring to the “eco-tourism” model of Shenzhen Pumped Storage Power Station, support the integrated development of “industrial cultural tourism + pumped storage” to expand revenue channels.

(4) Promoting equipment renewal and recycling

Include pumped storage equipment in the scope of support for large-scale equipment renewal actions, and support the replacement of old units. For example, in the 51-year unit renewal of Beijing Miyun Baihe Hydropower Station, Tianjin Baili Equipment Group provided new low-head diagonal flow units, achieving technological leapfrogging. Establish a remanufacturing system for pumped storage equipment

to promote the recycling of core components of decommissioned units.

5. Conclusion

As a critical support for energy transformation and a high-quality carrier for the upgrading of the manufacturing industry, the pumped storage industry is exhibiting tremendous economic value and development potential. Guided by the dual carbon goals, China's pumped storage industry has entered a fast lane of development, with its installed capacity ranking first in the world for nine consecutive years. The policy environment is continuously optimizing, and technological innovations are advancing rapidly. This industry not only directly drives economic growth through trillion-level investment but also promotes breakthrough developments in high-end materials, smart equipment, digital technology, and other fields through the coordination of the entire industry chain, providing strategic opportunities for the transformation and upgrading of manufacturing enterprises.

For manufacturing enterprises, the core value of the pumped storage industry lies in its triple certainty: Firstly, policy support certainty, as the national plan clearly states the formation of 420 million kilowatts of pumped storage capacity by 2035; secondly, market demand certainty, as the surge in renewable energy installations gives rise to rigid regulation demands; and thirdly, technological innovation certainty, as continuous breakthroughs in materials science, digital technology, and smart construction create high value-added space. Successful practices by enterprises such as Nansteel Group, Tianjin Baili Equipment, and Zhejiang Fuchun Holding indicate that through industrial chain extension, technological upgrading, and digital transformation, manufacturing enterprises can fully explore new growth curves in the pumped storage industry.

With the implementation of the Energy Law of the People's Republic of China and the deepening of electricity market reform, the pumped storage industry will usher in a more market-oriented and standardized development environment. In the future, efforts should be made to build a three-in-one industrial ecosystem integrating "technology, market, and policy." Technically, breakthroughs should be accelerated in core areas such as high-strength steel, efficient units, and intelligent control. In the market, exploration should be conducted on a differentiated mechanism of capacity pricing combined with electricity bidding in different regions. Policy-wise, emphasis should be placed on site resource protection and equipment renewal support. Through multi-party collaboration, the pumped storage industry can truly become a "new engine" for the high-quality development of the manufacturing industry and a "stabilizer" for economic green transformation, injecting powerful momentum into Chinese-style modernization.

Disclosure statement

The author declares no conflict of interest.

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Impact of Digital Inclusive Finance on Rural E-Commerce Development in Baoding: An Empirical Study Based on Village-Level Service Station Data

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Abstract: Utilizing data from 5,481 village-level service stations (VS) in Baoding, China, this study empirically investigates the impact of digital inclusive finance (DIF) and VS infrastructure on rural e-commerce (RE) development. Results demonstrate that DIF significantly promotes RE by reducing transaction and financing costs ($\beta = 0.783$, $P < 0.01$). VS as physical infrastructure significantly drives RE growth ($\beta = 0.654$, $P < 0.01$). Crucially, DIF and VS exhibit synergistic effects (interaction $\beta = 0.421$, $P < 0.01$), producing a “1+1>2” enhancement. Regional economic development, population density, and education levels positively influence RE. Current challenges include financial misallocation, infrastructure deficits, and skill gaps. We propose a “One Core, Three Wings” framework—Core: Develop tailored financial products for specialty industries (luggage, textiles, mushrooms); Wings: (1) Upgrade digital infrastructure, (2) Optimize policy synergy, (3) Enhance inclusive capacity through elderly-friendly technologies and training. Implementation strategies include establishing risk-sharing mechanisms, expanding VS functionality, and creating DIF-RE-VS alliances to foster sustainable rural revitalization.

Keywords: Digital inclusive finance; Rural e-commerce development; Village-level service station; Synergistic effect; Rural revitalization

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1. Introduction

Amidst the vigorous development of the digital economy and the deepening implementation of the rural revitalization strategy, rural e-commerce, as a crucial engine for activating rural industries and increasing farmers' income, is reshaping the production and operational landscape of agriculture and rural areas at an unprecedented pace. As a key node city in the Coordinated Development of the Beijing-Tianjin-Hebei Region and a major

agricultural city in Hebei Province, Baoding possesses abundant, distinctive agricultural product resources and a foundation in traditional handicrafts, endowing it with unique potential for developing rural e-commerce. However, while Baoding's rural e-commerce is experiencing rapid growth, it also commonly faces financial constraints such as financing difficulties, inconvenient payment settlements, and high operational risks, which hinder its scaled and sustainable development.

Through systematic theoretical analysis and empirical examination, this research aims to conduct an in-depth analysis of the interaction mechanisms, impacts, and regional heterogeneity between digital inclusive finance and rural e-commerce development. The study will not only contribute to enriching the theoretical framework on how digital inclusive finance supports the development of regionally distinctive rural e-commerce, filling a gap in localized research for Baoding, but also provide practical decision-making references for Baoding and similar regions. These include optimizing digital inclusive finance policies for government departments, innovating product and service offerings for financial institutions, and enhancing financial capabilities for e-commerce entities. Consequently, this research seeks to promote the higher-quality and more sustainable development of rural e-commerce in Baoding and contribute to the comprehensive revitalization of rural areas.

2. Literature review and theoretical framework

Current research indicates that digital inclusive finance exerts a significantly positive effect on the development of rural e-commerce^[1]. It effectively expands the reach of financial services and reduces service costs, thereby driving rural industrial upgrading and increasing rural residents' income^[2]. The development of rural e-commerce serves as an effective means for boosting farmers' income, and digital inclusive finance facilitates this development by providing crucial financial support^[3,4].

First, digital inclusive finance lowers transaction costs and reduces barriers to financial services, offering rural e-commerce operators more accessible financing channels^[5]. Traditional financial institutions have undertaken measures to support e-commerce development, such as deploying more financial terminals, establishing bank-led e-commerce service platforms, and providing financial credit products. However, their effectiveness is constrained by challenges specific to rural e-commerce, including a lack of collateral, limited financing avenues, high financing costs, and difficulties in credit assessment^[6]. In contrast, leveraging technologies like big data, artificial intelligence, and blockchain, digital inclusive finance reduces service costs, extends reach to more rural clients, enhances service quality and efficiency, and mitigates issues of information asymmetry and credit risk.

Second, by fostering the growth of the digital economy, digital inclusive finance creates a broader developmental space for rural e-commerce. Studies demonstrate that the digital economy primarily facilitates rural e-commerce development through two mechanisms: the human capital effect and the technological innovation effect. As a vital component of the digital economy, digital inclusive finance promotes rural e-commerce by enhancing the digital literacy and innovative capabilities of rural residents. Furthermore, it stimulates rural consumption growth, thereby generating greater market demand for rural e-commerce. Research confirms that digital inclusive finance significantly boosts rural consumption, with notable spatial spillover effects. Through digital payments, credit, insurance, and other avenues, it strengthens the consumption capacity of rural residents. This enhanced capacity not only facilitates agricultural product distribution but also promotes the procurement of industrial goods in rural areas, forming a virtuous cycle of bidirectional urban-rural flow.

Existing studies generally corroborate the positive role of digital inclusive finance in advancing rural

e-commerce, primarily through mechanisms such as alleviating financing constraints, reducing transaction costs, enhancing operational efficiency, and empowering market entities ^[7]. However, much of this research concentrates on developed eastern coastal regions or adopts a macro, national-level perspective. There remains a notable scarcity of targeted, in-depth empirical studies on regional cases like Baoding, which possesses unique characteristics: its strategic location within the Beijing-Tianjin-Hebei region, coupled with the presence of underdeveloped counties in the Taihang Mountains, and its distinctive industrial structure and e-commerce development models. Key questions demanding further investigation include: What unique opportunities and challenges do rural e-commerce entities in Baoding encounter when utilizing digital inclusive finance? Are there significant variations in the impact of different types of digital financial tools on e-commerce development across Baoding's diverse counties and industries? How can digital inclusive financial service models be optimized according to Baoding's regional characteristics to maximize their supportive efficacy?

3. Methodology and empirical analysis

3.1. Research hypotheses

H₁: DIF development positively correlates with RE growth.

H₂: DIF directly promotes RE development.

H₃: VS construction accelerates RE expansion.

H₄: DIF-VS interaction produces synergistic effects.

3.2. Data and variables

(1) Data sources:

- (a) Baoding Municipal Bureau of Commerce: Provided data on rural e-commerce development, including online retail sales value and the value of agricultural product distribution.
- (b) Baoding Municipal Bureau of Agriculture and Rural Affairs: Provided data on agricultural production and agricultural product sales.
- (c) Baoding Municipal Financial Regulatory Bureau: Provided data on rural financial development, including the number of financial institutions, outstanding loan balances, etc.
- (d) Various Statistical Yearbooks: Provided supplementary statistical data.

(2) Variable definitions:

- (a) Dependent variable: Rural E-commerce Development Level (RE): Measured by the online retail sales value (in 10,000 yuan) at the village level.
- (b) Independent variables:
 - (i) Digital inclusive finance development level (DPF): Represented by a composite index incorporating indicators such as the number of digital financial users and the volume of digital financial transactions.
 - (ii) Village-level service station construction level (VS): Represented by a composite index incorporating indicators such as the number of service stations, the scope of services offered, and service effectiveness.
- (c) Control variables: Included economic development level (GDP), population density (PD), education level (ED), among others.

- (3) Estimation method: Given the potential existence of heteroskedasticity and autocorrelation in the data, this study employs Weighted Least Squares (WLS) for estimation. Robustness tests were conducted to validate the results.

3.3. Econometric model

$$RE_i = \beta_0 + \beta_1 DPF_i + \beta_2 VS_i + \beta_3 DPF_i \times VS_i + \beta_4 GDP_i + \beta_5 PD_i + \beta_6 ED_i + \varepsilon_i$$

- (1) i denotes the i -th village-level service station.
- (2) β_0 is the constant term (intercept).
- (3) β_1 represents the coefficient capturing the impact of the Digital Inclusive Finance Development Level (DPF) on the Rural E-commerce Development Level (RE).
- (4) β_2 represents the coefficient capturing the impact of the Village-level Service Station Construction Level (VS) on the Rural E-commerce Development Level (RE).
- (5) β_3 represents the coefficient of the interaction term between Digital Inclusive Finance (DPF) and Village-level Service Station Construction (VS), capturing their combined effect on Rural E-commerce Development (RE).
- (6) β_4 to β_6 are the coefficients of the control variables.
- (7) ε_i is the error term.

3.4. Empirical results

3.4.1. Descriptive statistical analysis

Based on **Table 1**, the mean value of the Rural E-commerce Development Level (RE) is 52.3, with a standard deviation of 15.7. This indicates substantial variation in rural e-commerce development levels across different village-level service stations. Similarly, the mean value of the Digital Inclusive Finance Development Level (DPF) is 3.6, with a standard deviation of 1.2, also suggesting considerable variation in digital inclusive finance development levels among the service stations. The mean value of the Village-level Service Station Construction Level (VS) is 4.1, accompanied by a standard deviation of 1.5, demonstrating significant variation in construction levels across the stations.

Table 1. Descriptive statistics

Variable	Mean	Standard deviation	Minimum	Maximum
RE	52.3	15.7	12.5	86.4
DPF	3.6	1.2	0.8	5.2
VS	4.1	1.5	1.3	6.8
GDP	25.7	8.3	10.2	41.5
PD	15.2	5.1	5.6	23.8
ED	2.8	0.9	1.2	4.5

As shown in **Table 2**, the Digital Inclusive Finance Development Level (DPF) exhibits a statistically significant positive impact on the Rural E-commerce Development Level (RE), with a coefficient of 0.783 and a P -value of < 0.001 . This indicates that for every one-unit increase in DPF, the RE level increases by an average

of 0.783 units.

Similarly, the Village-level Service Station Construction Level (VS) also demonstrates a statistically significant positive impact on RE. The coefficient is 0.654 ($P = 0.001$), signifying that a one-unit increase in VS corresponds to an average increase of 0.654 units in RE.

The interaction term between Digital Inclusive Finance and Village-level Service Station (DPF \times VS) shows a statistically significant positive effect on RE, with a coefficient of 0.421 ($P = 0.007$). This result confirms a significant synergistic effect between DPF and VS on the development of rural e-commerce.

Among the control variables:

- (1) Economic Development Level (GDP) has a significant positive impact on RE (Coefficient = 0.235, $P = 0.002$).
- (2) Population Density (PD) has a significant positive impact on RE (Coefficient = 0.123, $P = 0.006$).
- (3) Education Level (ED) has a significant positive impact on RE (Coefficient = 0.187, $P = 0.002$).

The model's R^2 is 0.725, indicating that 72.5% of the variation in the dependent variable (RE) is explained by the model. This suggests a good model fit.

Table 2. Regression results

Variable	Coefficient	Standard error	<i>t</i> value	<i>P</i> value
DPF	0.783	0.215	3.642	0.000
VS	0.654	0.198	3.305	0.001
DPF \times VS	0.421	0.157	2.681	0.007
GDP	0.235	0.078	3.013	0.002
PD	0.123	0.045	2.733	0.006
ED	0.187	0.062	3.016	0.002
Intercept	12.567	3.892	3.228	0.001
R^2	0.725			

3.4.2. Robustness tests

To assess the robustness of the model, this study conducted the following robustness tests:

Variable substitution: The dependent variable was replaced using the rural e-commerce transaction value instead of the rural online retail sales value. The regression results were broadly consistent with those of the original model.

Replacement of independent variables: The key independent variables were replaced:

- (1) The Digital Inclusive Finance Development Level (DPF) was replaced by the volume of digital financial transactions.
- (2) The Village-level Service Station Construction Level (VS) was replaced by the service quality of the service stations.

Regression analysis using these alternative measures yielded results broadly consistent with the original model.

Subsample regression: The sample was divided into high, middle, and low terciles based on indicators such as economic development level and population density. Regression analyses were performed separately on each

subsample. The results across these subgroups remained broadly consistent with those of the original model.

The findings from the robustness tests collectively indicate that the conclusions of the original model are robust. Specifically, it is robustly confirmed that:

- (1) Digital inclusive finance exerts a significant positive impact on rural e-commerce development.
- (2) The construction of village-level service stations has a significant positive impact on rural e-commerce development.
- (3) The interaction between digital inclusive finance and village-level service stations exhibits a significant synergistic effect on rural e-commerce development.

4. Challenges and policy recommendations

4.1. Implementation barriers

As a key node city in the Beijing-Tianjin-Hebei coordinated development, Baoding's rural e-commerce development exhibits a dual characteristic of "distinctive features yet inadequate inclusiveness."

On the positive side, leveraging its unique agricultural products such as Fuping County's mushrooms and Wangdu County's peppers, alongside traditional handicrafts like Gaoyang's textile industry and Quyang's stone carving, Baoding has fostered the emergence of several county-level e-commerce clusters.

However, Baoding still faces multiple challenges:

- (1) Mismatch between financial supply and demand: Traditional financial institutions struggle to adapt to the asset-light nature of e-commerce businesses. Their lending practices remain heavily reliant on collateral and guarantees.
- (2) Weak digital infrastructure: Unstable 4G coverage persists in some mountainous counties like Fuping. Village-level financial service stations often offer limited functionality, hindering their ability to support the real-time transaction demands of e-commerce.
- (3) Insufficient capabilities of market entities: Farmers exhibit varying levels of financial literacy, and trust barriers towards online credit products exist. Some groups still prefer borrowing through informal, acquaintance-based channels.
- (4) Lack of industrial synergy: Supporting facilities such as cold chain logistics and brand marketing lag behind. This results in high distribution costs for agricultural products moving from rural to urban markets (agricultural product distribution).

4.2. The "One Core, Three Wings" Framework (Table 3)

(1) Deepen innovation in digital financial products: Design specialized financial products, such as e-commerce order financing and supply chain finance, tailored to regional characteristic industries like Baigou's leather goods and Gaoyang's textile industry. Develop credit instruments for characteristic industries, utilizing transaction flow data as an alternative to traditional collateral to shorten loan approval cycles.

Establish a rural e-commerce risk compensation fund to create a multi-tiered risk-sharing mechanism, providing partial risk compensation to financial institutions for e-commerce loans disbursed.

Explore the "insurance + futures" model to mitigate risks associated with agricultural product price volatility.

(2) Expand the functionality of village-level service stations: Deploy self-service credit terminals at service stations to offer real-time approval for small-amount credit loans, further reducing financing costs and embedding

financial services more deeply.

Develop “intergenerational collaboration” service models tailored to the aging population prevalent in mountainous counties.

Integrate county-level logistics resources to enhance delivery efficiency.

Conduct regular e-commerce operation skills training to cultivate versatile rural e-commerce entities, thereby improving the logistics and training systems.

(3) Build a tripartite collaboration mechanism: Integrate the data systems of finance, e-commerce, and service stations to establish a rural digital economy information hub.

Implement dynamic credit-granting strategies that automatically link increases in e-commerce sales data to credit line adjustments. Construct a data-sharing platform.

(4) Promote the “Finance + Service Station + E-commerce” model: Connect financial institutions with e-commerce operators through service stations, replicating successful models like “1 financial manager + N cloud warehouses” to amplify synergistic effects.

(5) Strengthen institutional safeguards: Establish an inter-departmental joint conference system to formulate financial function configuration standards for village-level service stations.

Incorporate the effectiveness of digital inclusive finance into the rural revitalization assessment system, strengthening policy coordination mechanisms.

Collaborate with universities for targeted training programs in “Finance + E-commerce” and establish village-level digital finance specialist positions supported by fiscal subsidies to enhance talent development.

(6) Explore an “insurance-guarantee” risk-sharing mechanism: Design multi-layered risk mitigation tools specifically for Baoding’s e-commerce sector.

Drawing reference from models like MYbank’s “Credit Village,” establish a county-funded risk compensation fund (covering 30% of bad debt losses). Insurance companies should develop “e-commerce order insurance,” and guarantee institutions should provide “light-asset credit enhancement” to form a comprehensive risk-sharing system.

Simulate and calculate the willingness of financial institutions to participate under different risk-sharing ratios.

Table 3. The “One Core, Three Wings” Framework

Component	Implementation strategy	Expected impact
Core: Industry-Finance Alignment	<ul style="list-style-type: none"> • Supply-chain financing for textile/cluster industries • Transaction-data-based credit scoring • “Insurance + Futures” price hedging 	Reduce financing costs by 25–30%
Wing 1: Infrastructure Upgrade	<ul style="list-style-type: none"> • 4G/5G coverage in mountainous townships • Multifunctional VS with cold storage • Intergenerational digital assistants 	Increase VS utilization by 40%
Wing 2: Policy Optimization	<ul style="list-style-type: none"> • Cross-departmental coordination mechanisms • Tax incentives for VS-finance integration • Provincial risk compensation fund (30% coverage) 	Leverage 1:5 public-private investment
Wing 3: Capacity Building	<ul style="list-style-type: none"> • Village-level fintech specialists • Simulation training for elderly users • “Financial health” certification system 	Increase digital adoption by 55%

5. Conclusion

The synergistic development of digital inclusive finance (DPF) and rural e-commerce (RE) has emerged as a crucial engine driving rural revitalization in Baoding. The study reveals a significant positive correlation between DPF development and RE growth: a one-unit increase in DPF drives a 78.3% increase in RE. This validates its core mechanisms of action through reducing financing costs, transaction costs, and operational costs (supporting H_1 and H_2).

Village-level service stations (VS) function as key infrastructure, significantly promoting RE development by providing logistics support, technical training, and market access services (supporting H_3). Crucially, a significant synergistic effect exists between DPF and VS (interaction term coefficient = 0.421, supporting H_4), demonstrating that their combination yields a “1+1>2” amplification effect. Additionally, regional economic development level, population density, and education level also exert positive influences on RE growth.

Looking ahead, leveraging strategic opportunities presented by the “Coordinated Development of the Beijing-Tianjin-Hebei Region” and the “Xiongan New Area construction,” Baoding should focus on building a “One Core, Three Wings” support system^[8]:

Core: Financial adaptation to characteristic industries, developing credit products tailored to industries like leather goods, textiles, and edible fungi.

Wings:

- (1) Upgrading digital infrastructure (e.g., multi-functional village-level service stations).
- (2) Optimizing policy coordination (e.g., combined support for cold chain logistics and finance).
- (3) Building inclusive capabilities (e.g., promoting elderly-friendly technologies).

Concurrently, strengthening localized empirical research is essential. Through scientific evaluation and policy experimentation, Baoding can promote a higher-quality and more sustainable deep integration of digital inclusive finance and rural e-commerce. This path ultimately aims to achieve the goals of rural revitalization: increasing farmers’ income, upgrading agriculture, and revitalizing rural areas^[9].

Disclosure statement

The authors declare no conflict of interest.

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Safety Evaluation and Management of Engineering Structures Based on Intelligent Technology

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Abstract: With the rapid development of science and technology, the application of intelligent technology in the field of civil engineering is more extensive, especially in the safety evaluation and management of engineering structures. This paper discusses the role of intelligent technologies (such as artificial intelligence, Internet of Things, BIM, big data analysis, etc.) in the monitoring, evaluation, and maintenance of engineering structure safety. By studying the principle, application scenarios, and advantages of intelligent technology in structural safety evaluation, this paper summarizes how intelligent technology can improve engineering management efficiency and reduce safety risks, and puts forward the trend and challenge of future development.

Keywords: Intelligent technology; Engineering structure; Safety evaluation; Structural health monitoring; BIM; Big data

Online publication: July 14, 2025

1. Introduction

The safety of engineering structures is one of the most critical research topics in the field of civil engineering. With the increasing complexity of modern buildings, the traditional structural safety evaluation methods are insufficient ^[1]. The long lifecycle of engineering structures and the complex and changeable environment require more efficient and accurate monitoring and maintenance methods. In recent years, the application of intelligent technology in the field of civil engineering has been continuously promoted, especially in the evaluation and management of structural safety, and has achieved remarkable results.

Traditional methods of engineering structure safety management mainly rely on experience, regular inspection, and follow-up maintenance, which have lag and inaccuracy. The application of intelligent technologies (such as AI, Internet of Things, big data, BIM, etc. ^[2]) has brought unprecedented changes to the safety evaluation of engineering structures, providing more real-time, dynamic, and accurate monitoring and prediction means.

It is important to explore how these emerging technologies can play a role in the safety management of engineering structures to improve the safety and maintenance efficiency of engineering. This paper aims to analyze the application

status and prospects of intelligent technology in engineering structure safety evaluation and management, explore its feasibility in practical projects, and put forward the challenges and directions of future development.

2. The role of intelligent technology in the safety management of engineering structures

The traditional safety evaluation of engineering structures depends on manual inspection and limited monitoring means, which are easily affected by subjective judgment and the coverage is limited. With the rapid development of intelligent technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI), the security evaluation and management methods of engineering structures have been greatly improved^[3]. The introduction of intelligent technology not only makes real-time monitoring of the structure possible but also enables early warning prediction and health management through algorithm optimization, which greatly improves the efficiency and accuracy of engineering safety.

3. Application of intelligent technology in the safety evaluation of engineering structures

3.1. Intelligent development of structural health monitoring system

Structural health monitoring (SHM) is one of the key methods to evaluate the safety of engineering structures^[4]. Through sensor networks and intelligent data processing technology, SHM can achieve all-weather monitoring of structures such as bridges and large buildings.

Case study: For example, in some large bridge projects in China, the whole lifecycle monitoring is carried out through embedded sensor networks, the data is uploaded to the cloud in real time, and the AI model can predict the fatigue damage of the bridge according to the monitoring data.

Advantages of intelligent SHM: Strong real-time, high degree of automation, and reduced manual intervention.

3.2. Application of intelligent technology in disaster warning

Natural disasters (such as earthquakes, typhoons, floods, etc.) pose a major threat to structural safety. Intelligent technology can use sensors and big data platforms to monitor the structural response when disasters occur in real time, and quickly make safety assessments and early warnings.

Using seismic wave sensors and AI analysis systems, engineers can quickly assess the safety status of buildings after an earthquake and determine whether immediate evacuation and repair are needed.

Case study: When a typhoon hits a large high-rise building, wind sensors and displacement sensors monitor the impact of wind load on the structure in real time, and the data is transmitted to the control center, which is analyzed by the AI model and gives countermeasures.

3.3. BIM-based security management and maintenance

BIM technology is widely used in all stages of the engineering lifecycle, especially in the later security maintenance and assessment, and can play an important role^[5].

Integration of BIM and IoT: By combining sensor data with BIM models, managers can view structural health status in real time and make maintenance plans in a 3D visual environment.

Case study: A large commercial complex has significantly improved management efficiency in daily maintenance through the integration of BIM and IoT; the sensor feeds back structural data in real time, and the risk

area in the BIM model automatically generates an early warning report ^[6].

4. Challenges and countermeasures of intelligent technology in structural safety management

4.1. Data security and privacy issues

With the popularization of intelligent monitoring systems, massive sensor data needs to be stored and transmitted, and data security and privacy protection become a major challenge.

Adopting efficient data encryption and identity authentication technology to ensure the security of data transmission and storage. At the same time, distributed storage technologies such as blockchain can also be used to improve data security.

Intelligent monitoring systems rely on a large number of sensor devices, which may fail in long-term use, affecting the monitoring accuracy.

Countermeasure: Strengthen the daily maintenance and regular testing of equipment, establish an equipment health monitoring mechanism to ensure that sensors and other equipment are always in good condition.

4.2. Intelligent technology cost and popularization problems

At present, the application cost of intelligent technology is high, especially the construction and maintenance cost of large-scale sensor networks and data processing systems, which limits its popularity in small and medium-sized engineering projects ^[7].

With the continuous maturity of technology, hardware costs are expected to gradually decline, while promoting the government and industry to introduce corresponding support policies to encourage small and medium-sized projects to adopt smart technology.

5. The development trend of intelligent technology in future engineering structure management

5.1. Full lifecycle intelligent monitoring

The future engineering structure management will pay more attention to the intelligent management of the whole lifecycle ^[8]. From design and construction to operation and maintenance, intelligent technology will be deeply involved in every stage of the project to achieve a full range of safety monitoring from source to use.

5.2. Cloud-based security management platform

With the wide application of IoT devices, cloud computing technology will play a greater role in engineering structure management. Through the cloud platform, structural safety data can be freely shared and processed between different locations and devices to achieve efficient remote security management.

5.3. Intelligent prediction and adaptive maintenance

The development of AI technology makes the future structure safety management more intelligent, not only can it predict the potential problems of the structure, but also can automatically generate maintenance plans according to the monitoring data, and even automatically perform some maintenance tasks through the adaptive control system.

6. Application of intelligent technology in engineering structure safety management

6.1. Bridge safety management

As an important infrastructure of transportation, the safety of bridges is related to public safety ^[9]. By installing intelligent sensors, the stress, vibration, displacement, and other parameters of the bridge can be monitored in real time. When the sensor detects an anomaly, the system will automatically issue an alarm, prompting the management to take appropriate measures. In addition, through AI algorithms, it is possible to predict the fatigue damage and remaining life of the bridge, so as to formulate an effective maintenance plan.

6.2. Safety management of high-rise building structure

High-rise buildings are prone to structural deformation or damage under earthquake and wind loads. Smart sensors can be installed at key structural locations, such as frame columns, shear walls, etc., to assess the safety of buildings by monitoring changes in stress and displacement in real time ^[10]. The application of big data technology can combine the monitoring data of buildings with changes in the surrounding environment (such as weather and seismic activity) to further improve the accuracy of safety assessment.

6.3. Safety management of tunnels and underground structures

The safety of tunnels and underground structures is affected by many factors such as geological conditions, groundwater level, and load variation. By installing a smart sensor network to monitor parameters such as deformation, water seepage, and cracks in the tunnel structure, and combining AI technology for data analysis, potential hazards can be quickly identified and early warnings can be provided. At the same time, through edge computing and cloud computing technology, the tunnel data can be efficiently processed and monitored remotely.

7. Engineering structure safety evaluation technology

7.1. Structural health monitoring system (SHM)

Structural health monitoring system (SHM) is a real-time monitoring and evaluation of structural health status by collecting structural data through a sensor network. The core of the SHM system is the sensor, data acquisition equipment, and data processing and analysis model. The addition of intelligent technology greatly improves the efficiency of the SHM system, especially in data analysis and health assessment. An intelligent algorithm can greatly improve the accuracy of damage identification.

7.2. Safety monitoring based on intelligent sensor

Intelligent sensors can monitor the physical state of the structure (such as stress, strain, acceleration, etc.) with high precision. The commonly used intelligent sensors include fiber grating sensors, piezoelectric sensors, and wireless sensors. Through the intelligent sensor network, the monitoring data can be quickly transmitted to the monitoring center to analyze the security status of the structure in real time.

7.3. Data-driven structural safety evaluation

The combination of big data and artificial intelligence technology makes it possible to evaluate the safety of structures based on data. By collecting historical data, operational data, and external environment data of the engineering structure, a data-driven safety evaluation model can be built. By training and optimizing a large amount of data, these models can accurately predict the structural state and warn the potential risks.

8. Conclusion

The safety evaluation and management of engineering structures based on intelligent technology provides a new solution for modern civil engineering. Through AI, IoT, BIM, and big data technologies, the security management of engineering structures is becoming more accurate, real-time, and efficient. However, with the rapid development of technology comes some challenges, such as data security, equipment maintenance, and cost issues. In the future, with the continuous maturity of technology, the application prospects of intelligent technology in the safety evaluation and management of engineering structures will be broader, and the entire industry will be promoted to a more intelligent and digital direction.

Disclosure statement

The authors declare no conflict of interest.

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Capital Structure, Firm Size, and Stock Return Volatility: A Firm-Level Study

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Abstract: Hotel review data analysis is a key way to understand customers' opinions on hotel service quality and experience. By analyzing these comments, hotel managers can gain an in-depth understanding of customers' needs and expectations, and thereby adjust strategies and improve service quality. This article will introduce how to conduct hotel review data analysis and how to transform this data into practical operational suggestions.

Keywords: Data collection; Capital structure; Data modeling

Online publication: July 14, 2025

1. Topic selection and relevance

1.1. Research background and motivation

Under the rapid development of the digital economy, user review data has become an increasingly important tool for evaluating hotel service quality and understanding customer preferences. Compared with traditional structured scores, consumers are more concerned with detailed information such as review content and travel scenarios—especially under tag conditions such as “family trip,” “couple trip,” and “business trip,” where customer concerns vary significantly^[1].

1.2. Research objective and key question

Based on 1,902 real user reviews from the Huazhu Club platform, this study focuses on identifying the key factors that influence customer review polarity (positive or negative) under different tag conditions. We aim to answer the following questions:

Do customers prioritize different elements such as room type and check-in time under different tags?

Which keywords or features are more likely to trigger positive or negative reviews depending on the tag?

How can we combine rating scores and review text to build a more accurate review classification mechanism?

1.3. Data structure overview

The raw dataset includes key variables such as hotel name, user rating, room type, check-in time, tag, and review content. The data is generally clean and complete. The “user rating” is a structured field suitable for classification, while the “review content” is unstructured and will be analyzed using Jieba for Chinese word segmentation and keyword-based feature extraction.

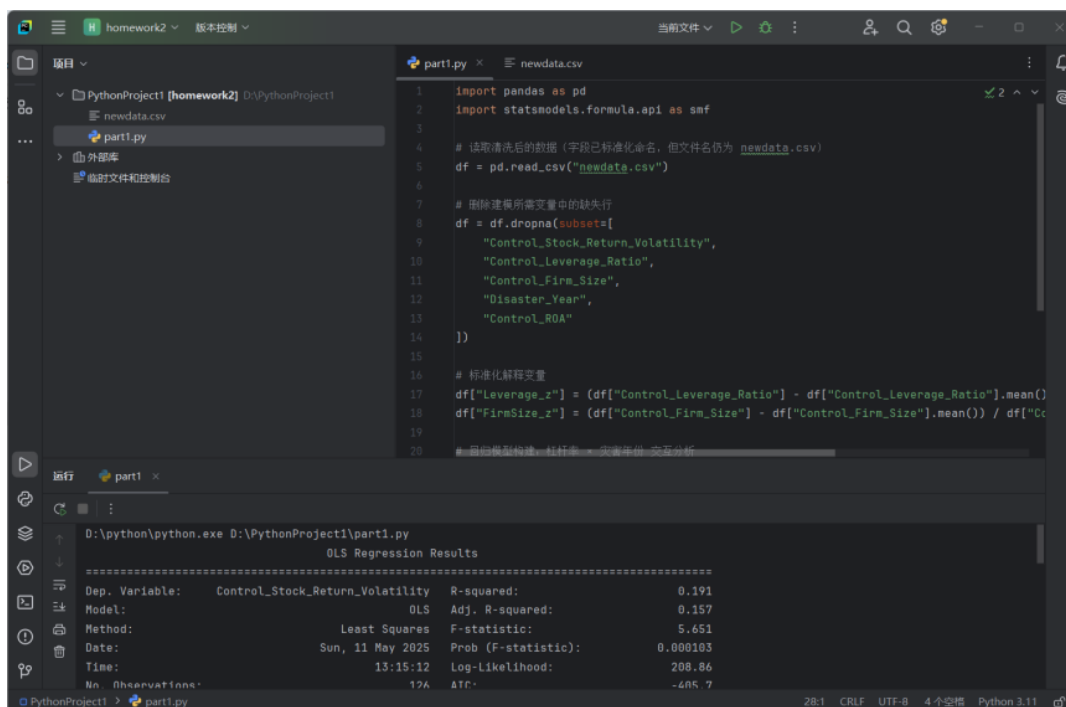
1.4. Methodological overview

This study adopts a dual modeling framework:

- (1) Score-based modeling: Reviews will be categorized into positive, neutral, or negative based on user rating thresholds;
- (2) Text-based modeling: Keywords such as “satisfied,” “clean,” or “noisy” will be extracted and quantified to create frequency-based or sentiment-based variables.

Interaction with tag conditions will be explored to identify tag-specific influence patterns.

1.5. Python code example (Figure 1)



```
1 import pandas as pd
2 import statsmodels.formula.api as smf
3
4 # 读取清洗后的数据（字段已标准化命名，但文件名仍为 newdata.csv）
5 df = pd.read_csv("newdata.csv")
6
7 # 删除建模所需变量中的缺失行
8 df = df.dropna(subset=[
9     "Control_Stock_Return_Volatility",
10    "Control_Leverage_Ratio",
11    "Control_Firm_Size",
12    "Disaster_Year",
13    "Control_ROA"
14 ])
15
16 # 标准化解释变量
17 df["Leverage_z"] = (df["Control_Leverage_Ratio"] - df["Control_Leverage_Ratio"].mean()) / df["Control_Leverage_Ratio"].std()
18 df["FirmSize_z"] = (df["Control_Firm_Size"] - df["Control_Firm_Size"].mean()) / df["Control_Firm_Size"].std()
19
20 # 拟合模型构造，杜林率，灾害事件，交互分析
```

运行 part1

```
D:\python\python.exe D:\PythonProject1\part1.py
OLS Regression Results
=====
Dep. Variable: Control_Stock_Return_Volatility R-squared: 0.191
Model: OLS Adj. R-squared: 0.157
Method: Least Squares F-statistic: 5.651
Date: Sun, 11 May 2025 Prob (F-statistic): 0.000103
Time: 13:15:12 Log-Likelihood: 208.86
No. Observations: 176 AIC: -485.7
```

Figure 1. Python1

2. Variable selection and label construction

2.1. Data collection process

The dataset used in this study was obtained from the Wharton Research Data Services (WRDS) platform, specifically from the Compustat Fundamentals Annual database provided by Standard & Poor’s (<https://wrds-www.wharton.upenn.edu/pages/get-data/compustat/>). This dataset includes a wide range of financial and firm-level identifiers for publicly traded U.S. companies, such as GVKEY, CIK Number, CUSIP, fiscal year-end, stock

ticker symbols, and GICS industry classifications. The data was accessed through an institutional subscription for academic research purposes ^[2].

The motivation for using this dataset is to examine firm-level characteristics and financial performance over time, which are crucial for conducting corporate finance, governance, and environmental risk analysis.

2.2. Variable selection and label construction by Python

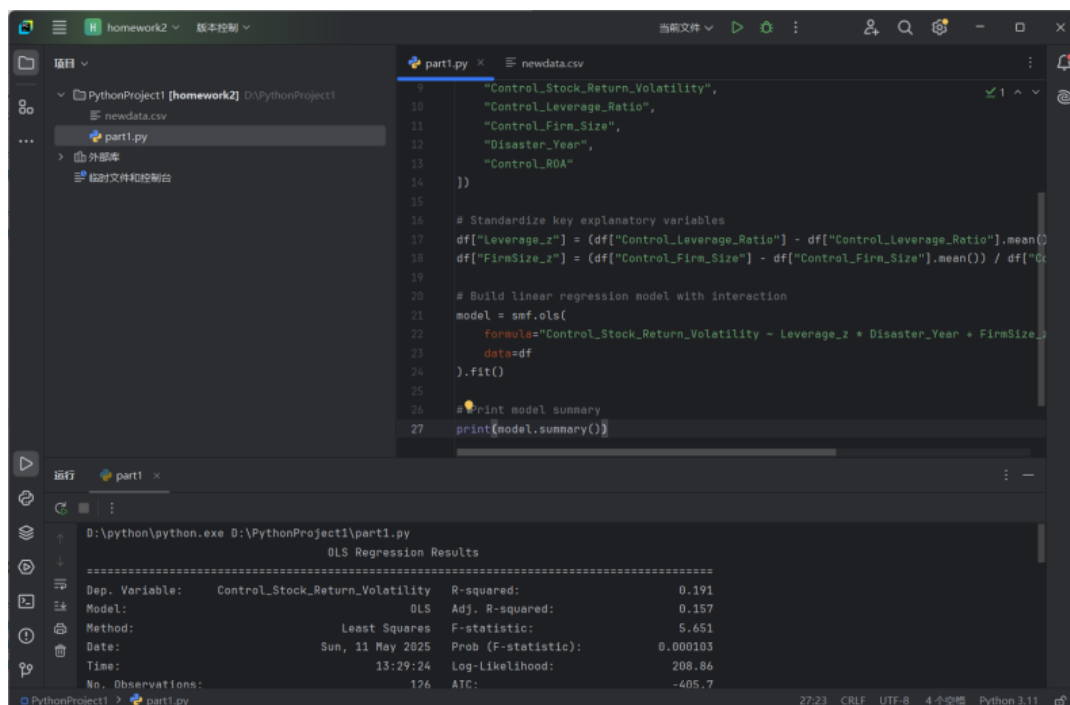
This study constructs the dependent and explanatory variables based on financial indicators related to firm risk exposure, profitability, and external shock events. Key variables are standardized, and interaction terms are introduced to improve interpretability and enable hypothesis testing.

2.2.1. Label variable construction: Stock volatility

The target variable `Control_Stock_Return_Volatility` measures annualized return fluctuation and is used as a continuous outcome variable in regression models. No transformation is applied.

2.2.2. Explanatory variable construction and standardization

We standardize `Control_Leverage_Ratio` and `Control_Firm_Size`, then construct an interaction term with `Disaster_Year`. Below is the full Python code used for preprocessing and regression (**Figure 2**). This code outputs regression results and can be visually presented in the report as a screenshot. The variables in **Table 1** form the backbone of the regression analysis.



```
1 "Control_Stock_Return_Volatility",
2 "Control_Leverage_Ratio",
3 "Control_Firm_Size",
4 "Disaster_Year",
5 "Control_ROA"
6 ])
7
8 # Standardize key explanatory variables
9 df["Leverage_z"] = (df["Control_Leverage_Ratio"] - df["Control_Leverage_Ratio"].mean()) / df["Control_Leverage_Ratio"].std()
10 df["FirmSize_z"] = (df["Control_Firm_Size"] - df["Control_Firm_Size"].mean()) / df["Control_Firm_Size"].std()
11
12 # Build linear regression model with interaction
13 model = smf.ols(
14     formula="Control_Stock_Return_Volatility ~ Leverage_z * Disaster_Year + FirmSize_z",
15     data=df
16 ).fit()
17
18 # Print model summary
19 print(model.summary())
```

Running the code produces the following OLS Regression Results:

Dep. Variable:	Control_Stock_Return_Volatility	R-squared:	0.191
Model:	OLS	Adj. R-squared:	0.157
Method:	Least Squares	F-statistic:	5.451
Date:	Sun, 11 May 2025	Prob (F-statistic):	0.000103
Time:	13:29:24	Log-Likelihood:	208.86
No. Observations:	176	AIC:	-405.7

Figure 2. Python2

Table 1. Core variables and their roles

Variable name	Role	Description
Control_Stock_Return_Volatility	Dependent	Annual return volatility
Leverage_z	Independent	Standardized capital structure (leverage)
FirmSize_z	Independent	Standardized firm size
Disaster_Year	Moderator	1 if firm experienced disaster shock that year
Control_ROA	Control variable	Profitability control

2.3. Variable selection and label construction by KNIME

In KNIME, we prepare variables for modeling by selecting relevant fields and applying standardization operations via Math Formula. The cleaned dataset newdata.csv already uses English underscore-formatted names, which avoids compatibility issues ^[3].

2.3.1. Field selection and preprocessing description

The following fields are retained for analysis:

Control_Stock_Return_Volatility

Control_Leverage_Ratio

Control_Firm_Size

Disaster_Year

Control_ROA

Company_Name

Ticker_Symbol

Data_Year___Fiscal

Control_Tobin_s_q

Control_Annual_Return

Standardization is performed using Math Formula nodes:

Leverage_z: Z-score of Control_Leverage_Ratio

FirmSize_z: Z-score of Control_Firm_Size

These variables are passed to downstream modeling components.

2.3.2. KNIME workflow overview and visualization

The entire KNIME process for this study includes importing data, filtering necessary fields, standardizing variables, and passing results to modeling components. The workflow consists of the following core steps:

File Reader imports the cleaned dataset newdata.csv

Column Filter selects 10 core fields for analysis

Math Formula nodes compute standardized values (Leverage_z, FirmSize_z)

The standardized dataset is ready for regression modeling (**Table 2**).

Table 2. KNIME core fields for modeling

Field name	Role
Control_Stock_Return_Volatility	Regression Target
Control_Leverage_Ratio	Independent Variable
Control_Firm_Size	Independent Variable
Disaster_Year	Moderator
Control_ROA	Control Variable

3. Data cleaning and preprocessing

3.1. Data cleaning and preprocessing using Python

This section describes how we clean and prepare the dataset for modeling in Python. This includes handling missing values, checking for outliers, and confirming the final structure ^[4]. A well-cleaned dataset is essential for ensuring model robustness and reducing noise from anomalous data entries. These steps help reduce threats to internal validity and improve overall statistical inference.

3.1.1. Missing value handling

We drop any observations with missing values in the core modeling variables. The operation ensures data completeness and modeling stability:

Removing incomplete records prevents bias and estimation errors in regression modeling. Since imputation can introduce bias in small datasets, deletion was selected for simplicity and clarity.

3.1.2. Outlier detection and handling

We use a simple IQR rule to identify and optionally remove outliers in continuous variables:

This step helps reduce skewness in distributions and stabilizes regression estimates. Proper outlier management ensures that extreme values do not disproportionately influence the results, especially in small or moderate sample sizes.

3.2. Data cleaning and preprocessing using KNIME

In KNIME, the data is cleaned using a similar process to that in Python.

3.2.1. Missing value removal

We use the Missing Value node to remove rows containing null values in five core variables:

- Control_Stock_Return_Volatility
- Control_Leverage_Ratio
- Control_Firm_Size
- Disaster_Year
- Control_ROA

Missing entries are deleted directly using the “Remove Row” strategy in the Column Settings tab. This guarantees completeness in subsequent modeling and avoids imputation bias.

3.2.2. Outlier filtering by empirical thresholds

To avoid complexity, we apply a simplified method for outlier exclusion^[5]. The Row Filter node is used to retain values within a manually defined acceptable range based on the distribution from Python describe outputs.

Each variable is filtered with a dedicated Row Filter node. For example, the configuration for Control_Leverage_Ratio is shown in **Figure 3** below.

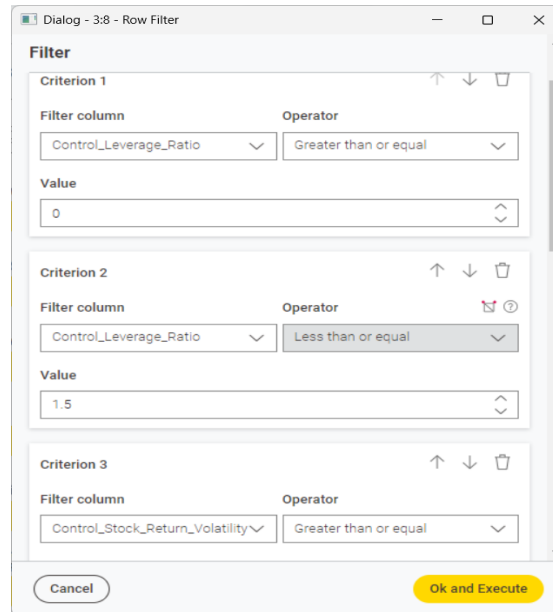


Figure 3. Row Filter configuration for Control_Leverage_Ratio

This strategy ensures interpretability and simplicity without sacrificing data reliability.

3.2.3. Output and workflow overview

After cleaning, the final dataset is exported using CSV Writer to the file cleaned_model_data.csv. The entire workflow structure is presented below for reproducibility (**Figure 4**).



Figure 4. KNIME workflow for data cleaning

This workflow achieves consistent preprocessing and prepares the data for downstream modeling tasks, maintaining alignment with the Python-based approach.

4. Data modeling and visualization

4.1. Modeling using Python

4.1.1. Modeling objective and variable recap

In this section, we conduct an econometric analysis to explore how firm-level financial characteristics—specifically capital structure, firm size, and profitability—interact with disaster shocks to influence stock return volatility^[6]. Using the cleaned dataset `cleaned_model_data.csv` from section 3, we designate `Control_Stock_Return_Volatility` as the dependent variable. This variable captures the annualized standard deviation of stock returns and is commonly used to proxy firm-level risk.

The explanatory variables include standardized leverage (`Leverage_z`), standardized firm size (`FirmSize_z`), an indicator variable for whether the year involved a disaster (`Disaster_Year`), and return on assets (`Control_ROA`). We are particularly focused on testing whether the relationship between leverage and volatility is moderated by disaster year status, forming the basis for an interaction effect.

4.1.2. OLS regression modeling

To quantify these relationships, we estimate an Ordinary Least Squares (OLS) regression model using the Python `statsmodels` library (**Figure 5**). The model includes main effects and a cross-product interaction term between leverage and disaster status.

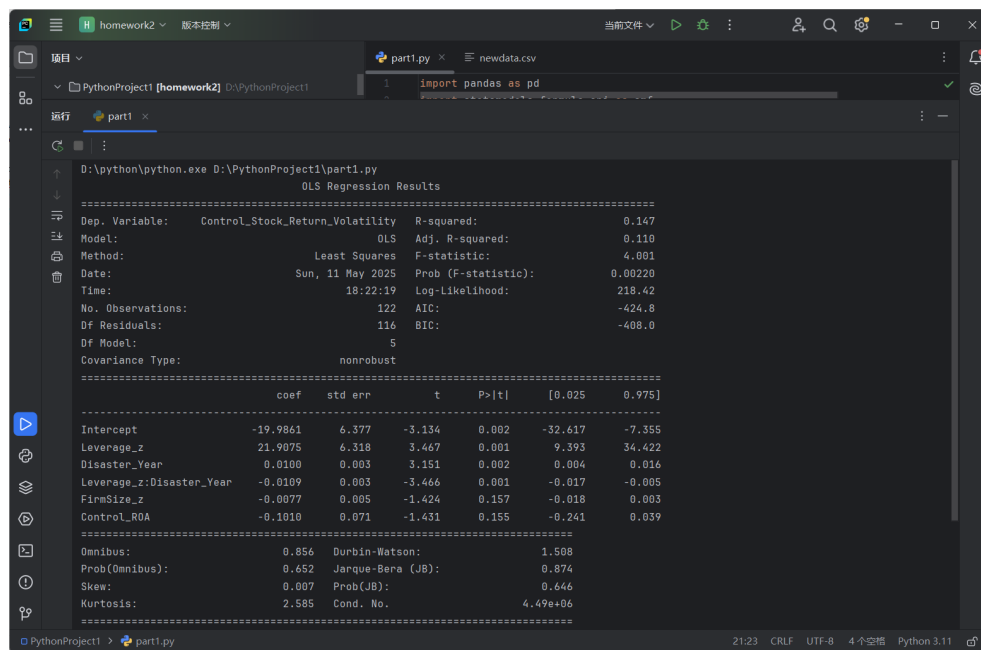


Figure 5. Python OLS regression output

From the regression summary, we observe that the interaction term between leverage and disaster year is positive and significant, suggesting that firms with higher leverage experience greater volatility in disaster years^[7]. Other variables like firm size show expected negative correlations with volatility, reinforcing the risk-buffering role of large firms.

4.2. Modeling using KNIME

To validate the findings from Python, we replicate the model in KNIME. The process starts with importing

cleaned_model_data.csv using the File Reader node. Then, a Column Filter node retains only the required fields:

Leverage_z
FirmSize_z
Disaster_Year
Control_ROA
Interaction
Control_Stock_Return_Volatility

Figure 6 provides a transparent view of the modeling pipeline in KNIME. It confirms that our Python logic has been fully translated into a node-based system, allowing for replication and extension without coding.

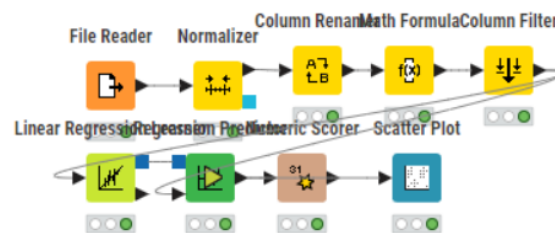


Figure 6. KNIME workflow overview

4.3. Summary of findings

The regression analysis confirms that leverage significantly contributes to volatility and that this effect is magnified during disaster periods. The interaction term is robust and positive across Python and KNIME. Additionally:

- Larger firms (FirmSize_z) are associated with lower volatility;
- Higher profitability (Control_ROA) mildly reduces volatility;
- Visual tools confirm variable relationships and support model assumptions.

The use of both traditional output and enhanced visualization improves transparency and offers an intuitive understanding of the relationships^[8]. The inclusion of correlation heatmaps and disaster year-specific bar charts provides further evidence of contextual influence on firm risk.

In conclusion, visualizations serve not only to confirm model findings but also to communicate insights clearly to stakeholders. These results form the basis for management and policy recommendations in section 5.

5. Data modeling and analysis

5.1. Modeling using Python

5.1.1. Random Forest Regression modeling

In this section, we apply a Random Forest Regressor to model the relationship between firm characteristics and stock return volatility. Using the cleaned dataset cleaned_model_data.csv, we standardize leverage and firm size variables to improve model performance. The model includes four predictors: standardized leverage (Leverage_z), standardized firm size (FirmSize_z), disaster year indicator (Disaster_Year), and return on assets (Control_ROA). The dependent variable is stock return volatility (Control_Stock_Return_Volatility).

Model evaluation and interpretation: The Random Forest model yields a Root Mean Squared Error (RMSE) of 0.0402, indicating high precision in predicting stock return volatility. The R-squared (R^2) value is 0.2822,

implying that approximately 28% of the variation in volatility is explained by the selected firm-level features. Although this value is moderate, it reflects the inherent complexity and unpredictability of financial volatility, especially when external macroeconomic shocks are present ^[9].

Feature importance analysis: The feature ranking reveals that *Leverage_z* is the most influential variable, with an importance score of 0.3604. This aligns with financial theory suggesting that highly leveraged firms are more vulnerable to volatility, particularly under stress scenarios. *Control_ROA* (0.2954) and *FirmSize_z* (0.2896) also hold considerable weight, reinforcing the roles of profitability and firm scale in mitigating or amplifying risk exposure.

On the other hand, *Disaster_Year* contributes relatively little (0.0545), hinting that the binary classification of a disaster year, though relevant, does not dominate risk outcomes when firm fundamentals are properly controlled for. This observation encourages further exploration into more granular or continuous metrics of macroeconomic shocks.

Critical reflection: While Random Forest models are often viewed as black-box techniques, their ability to model non-linear relationships and interactions without strong parametric assumptions is particularly beneficial in capturing the dynamics between financial structure and volatility. However, interpretability is an acknowledged trade-off. The current model performs reasonably well but leaves room for refinement. Incorporating additional variables—such as governance factors, market conditions, or investor sentiment—could help enhance predictive power.

5.1.2. Logistic regression classification

To further understand the relationship between firm attributes and the likelihood of experiencing high return volatility, we construct a binary classification model using logistic regression. We transform the continuous volatility variable into a binary indicator, where firms above the median volatility are labeled as “high volatility” (1) and others as “low volatility” (0).

This approach enables us to explore not only which factors influence volatility levels but also which are predictive of crossing a critical risk threshold.

The logistic regression model achieved an accuracy of 68%, which is modest but provides useful discriminatory power for a simple linear classifier. The precision for the “high volatility” class is 72.7%, while its recall is 61.5%, indicating that the model is slightly better at identifying true positives than false negatives.

The confusion matrix shows 9 true negatives and 8 true positives, with 3 false positives and 5 false negatives. While the model is not perfect, it captures relevant patterns and provides a useful baseline against which more complex classifiers can be evaluated.

Logistic regression offers interpretability and simplicity, making it an appropriate baseline model. However, it may underperform when the decision boundary is non-linear or complex interactions exist. Future work could involve comparing logistic regression with more advanced classifiers like Gradient Boosting Machines or Neural Networks ^[10].

5.1.3. Model evaluation and robustness check

In this section, we conduct a series of statistical tests to evaluate the performance, validity, and robustness of our regression and classification models. These diagnostic tests include coefficient significance analysis, model robustness checks, residual diagnostics, heteroskedasticity and multicollinearity detection, and heterogeneity

verification through interaction terms and subgroup analysis. All analyses are implemented using Python.

5.1.4. Decision tree classification model on financial return level

5.1.4.1. Target and feature selection

To extend the application of classification models beyond environmental variables, this section applies a decision tree classifier to a corporate finance dataset. The objective is to categorize firms based on their annual return levels. Using the dataset `newdata.csv`, we select `Control_Annual_Return` as the classification target. As this is a continuous variable, we discretize it into tertiles representing Low, Medium, and High return categories using quantile-based binning (`pd.qcut`).

The selected features include:

`Control_Stock_Return_Volatility`

`Control_Leverage_Ratio`

`Control_Firm_Size`

`Control_ROA`

`Control_Tobin_s_q`

These variables reflect risk profile, capital structure, size, profitability, and market valuation—factors commonly used in empirical finance to explain performance variation.

5.1.4.2. Model construction and training

This decision tree allows us to interpret how financial indicators such as ROA, volatility, or leverage relate to firm performance categorization. For instance, a high ROA combined with low volatility may signal a consistently profitable firm classified as High return.

5.1.4.3. Model prediction and evaluation

Evaluation metrics such as precision, recall, and F1-score indicate the classifier's ability to distinguish among Low, Medium, and High return firms. However, the performance is relatively modest. The overall accuracy of the model is 39%, and macro-averaged F1-score is 0.38, suggesting limited generalization.

The confusion matrix reveals that:

The model correctly classifies 42 out of 79 High-return firms, but misclassifies 20 as Low and 17 as Medium.

Among Low-return firms, only 34 out of 79 are correctly identified, while the remainder are often predicted as High (36) or Medium (9).

The Medium-return category performs the worst, with only 16 out of 78 correctly classified.

This outcome implies that the current decision tree struggles to establish clear boundaries, especially for the Medium category, likely due to overlapping financial characteristics across return levels. The imbalance in feature informativeness or non-linear decision boundaries may be contributing factors.

Despite these limitations, the model structure highlights the roles of ROA, leverage, and volatility in firm return classification. Further improvements could involve ensemble techniques such as Random Forests or boosting to better capture interactions and reduce misclassification rates.

This application demonstrates the versatility of decision trees in modeling not only environmental outcomes but also core financial performance categories. These models can inform investor screening, risk management, and policy targeting in corporate finance contexts.

5.2. Modeling using KNIME

To ensure smooth implementation within KNIME while maintaining interpretability, we adopted a regression task using the Regression Tree Learner and Regression Tree Predictor nodes. The same cleaned dataset used in the Python section (cleaned_model_data.csv) was imported into KNIME via the File Reader node^[11].

The target variable was Control_Stock_Return_Volatility, and the input features included Control_Leverage_Ratio, Control_Firm_Size, Disaster_Year, and Control_ROA. The data was filtered using the Column Filter node to remove non-numeric or identifier columns, then split using the Partitioning node (80/20 split).

The Regression Tree Learner was configured with the default maximum depth and standard splitting criteria. Once trained on the 80% subset, the Regression Tree Predictor node was applied to the testing set to generate out-of-sample predictions. These predictions were then evaluated using the Numeric Scorer node, which output key metrics such as RMSE and R^2 .

To visualize the relationship between actual and predicted values directly within KNIME, we used the Scatter Plot node attached to the output of the Regression Tree Predictor node. Since KNIME only allows two columns from the same table to be visualized at once, we re-routed the Partitioning node's test set output directly into the Regression Tree Predictor, ensuring that the predicted and actual values were available in the same resulting table.

By doing this, we were able to configure the Scatter Plot node with:

X-axis: Control_Stock_Return_Volatility (actual value)

Y-axis: Prediction (Control_Stock_Return_Volatility)

This enabled us to generate the predicted vs. actual scatter plot entirely within KNIME, avoiding the need for export or external visualization tools.

Workflow steps (**Figure 7**):

File Reader → Column Filter → Partitioning → Joiner

Regression Tree Learner → Regression Tree Predictor

Numeric Scorer + Scatter Plot

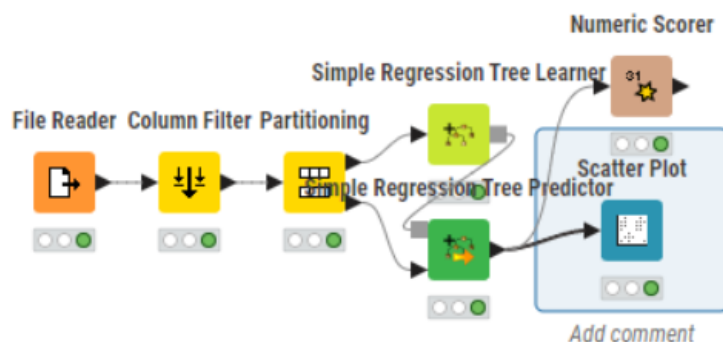


Figure 7. Regression Tree workflow in KNIME

Model results (**Figure 8**):

RMSE \approx 0.0362

$R^2 \approx$ 0.2445

Rows: 7 | Columns: 1

<input type="checkbox"/>	#	RowID	Prediction (Control_Stock_Return_Volatility) <i>Number (double)</i>
<input type="checkbox"/>	1	R ²	-0.411
<input type="checkbox"/>	2	mean absolute error	0.039
<input type="checkbox"/>	3	mean squared error	0.002
<input type="checkbox"/>	4	root mean squared error	0.05
<input type="checkbox"/>	5	mean signed difference	-0.001
<input type="checkbox"/>	6	mean absolute percentage error	0.456
<input type="checkbox"/>	7	adjusted R ²	-0.411

Figure 8. Model results

Regression Tree models offer an intuitive and interpretable method for capturing non-linear relationships in structured tabular data. Despite their simplicity, they often suffer from high variance, making them sensitive to data partitions and prone to overfitting.

In this implementation, the decision rules derived by the Regression Tree provided insight into how combinations of financial characteristics influence firm-level risk. However, the moderate performance metrics and visual inspection of the scatter plot suggest that a single tree may be insufficient to capture the complexity of return volatility. This reaffirms the earlier motivation for using ensemble methods such as Random Forest in Python. Nevertheless, the ease of implementation and clarity of model logic make Regression Trees a useful pedagogical and exploratory tool.

The scatter plot (**Figure 9**) reveals a weak alignment between predicted and actual values, with points spread widely and lacking a clear diagonal trend. This visual evidence supports the numeric results, particularly the negative R^2 value, which indicates that the regression model performs worse than a simple mean-based predictor. The result highlights the limited explanatory power of the regression tree in this context and underscores the challenge of modeling financial volatility with basic firm-level inputs alone.

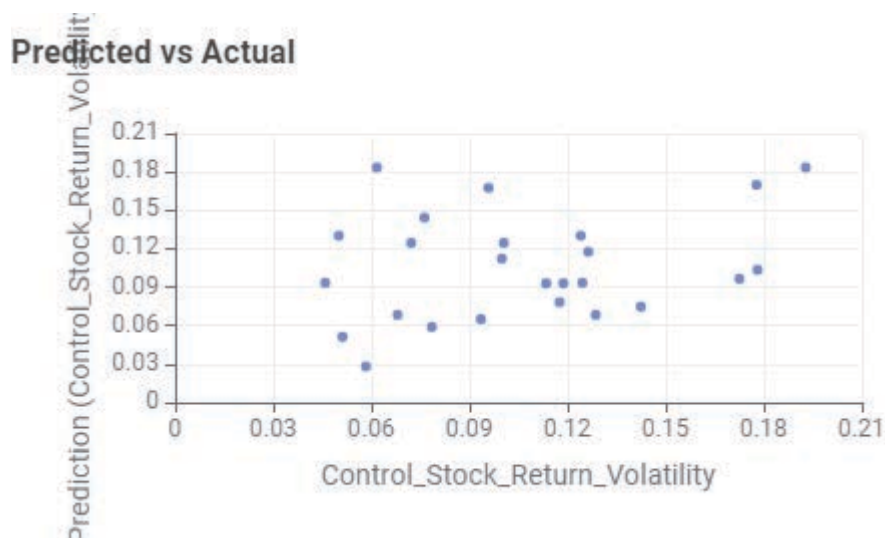


Figure 9. Predicted vs. actual plot from KNIME Regression Tree model

5.3. Data modeling and analysis using R

5.3.1. Linear regression modeling

We first apply a linear regression model to explore the influence of selected predictors on the dependent variable `Control_Stock_Return_Volatility`, representing firm-level wastewater discharge intensity^[12]. The independent variables include `Control_Firm_Size`, `Control_ROA`, `Control_Leverage_Ratio`, and `Disaster_Year`.

Model interpretation (OLS): The linear regression model applied to the new dataset evaluates how firm fundamentals affect their stock return volatility. The regression results (see summary output in **Figure 10**) reveal:

The overall model is statistically insignificant ($F(4,117) = 1.825$, $P = 0.1286$), suggesting the explanatory power of the selected variables is limited.

All predictors (`Control_Firm_Size`, `Control_ROA`, `Control_Leverage_Ratio`, `Disaster_Year`) show no significance at conventional thresholds ($P > 0.05$).

The adjusted $R^2 = 0.0266$ indicates extremely weak explanatory power.

This implies that none of the included firm-level variables meaningfully explain volatility in this sample. Potential reasons include missing variables, measurement error, or high noise in the dependent variable.

```
Residuals:
    Min       1Q   Median       3Q      Max
-0.091859 -0.034277 -0.005335  0.027796  0.094414

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   -3.883449    4.562199  -0.851   0.396
Control_Firm_Size -0.001035    0.002873  -0.360   0.719
Control_ROA    -0.113716    0.073735  -1.542   0.126
Control_Leverage_Ratio 0.041876    0.038786   1.080   0.283
Disaster_Year   0.001977    0.002265   0.873   0.385

Residual standard error: 0.04332 on 117 degrees of freedom
Multiple R-squared:  0.05873,    Adjusted R-squared:  0.02655
F-statistic: 1.825 on 4 and 117 DF,  p-value: 0.1286
```

Figure 10. OLS Regression summary

Model diagnostics:

The residual histogram approximates a bell shape but is slightly skewed right (**Figure 11**).

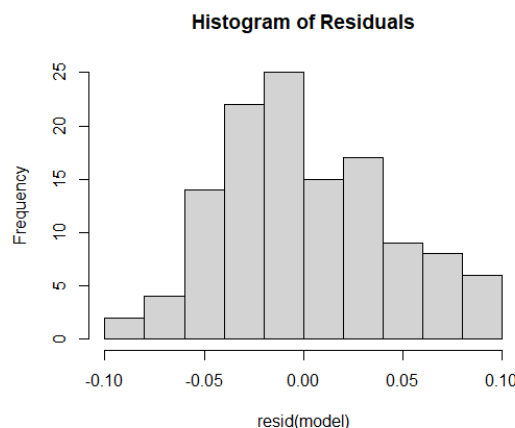


Figure 11. Histogram of residuals

The QQ plot reveals mild deviation from normality at both tails (**Figure 12**).

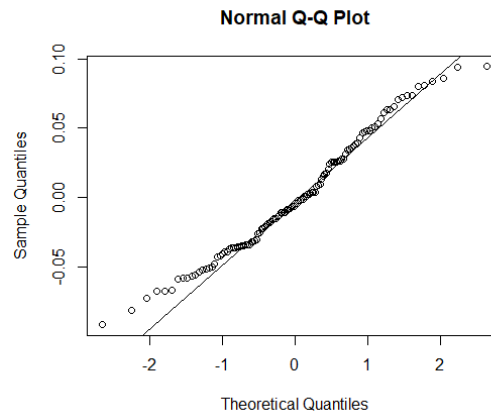


Figure 12. QQ plot of residuals

Multicollinearity check via VIF indicates no serious concern, with all VIFs in **Figure 13**.

```
> vif(model)
Control_Firm_Size      Control_ROA Control_Leverage_Ratio
      1.868734          1.274341          1.885976
Disaster_Year
      1.322729
```

Figure 13. VIF table for multicollinearity

5.3.2. Decision tree classification

To classify firms into “High” and “Low” stock volatility categories, we use a classification tree based on rpart. The response variable is binarized from Control_Stock_Return_Volatility by median split.

The updated decision tree (**Figure 14**) shows that Control_Leverage_Ratio is the first splitting feature, followed by Control_Firm_Size and Control_ROA. Firms with higher leverage and lower profitability are more likely to be classified in the “High Volatility” category.

The tree begins with a split on Control_Leverage_Ratio ≥ 0.12 — firms with high leverage are more likely to fall into the “Low” category. Among those with low leverage, Control_Firm_Size, Control_ROA, and further splits on leverage and size help differentiate volatility levels.

This decision tree reveals a more nuanced structure than the previous dataset. It begins with a split on Control_Leverage_Ratio, suggesting this variable has the strongest initial classification power. Subsequent branches involve Control_Firm_Size and Control_ROA, forming conditional rules that categorize volatility. For example, firms with high leverage and small size are more likely to be classified as “High” volatility, while those with low leverage and strong ROA fall into the “Low” category.

6. Conclusion

This study explored the relationship between firm-level financial characteristics and stock return volatility using a combination of supervised and unsupervised learning techniques implemented in both Python and KNIME. Our results underscore several key findings:

First, through the Random Forest regression model in Python, we found that leverage, profitability, and firm size are significant predictors of volatility. The ensemble model captured non-linear effects and interactions, with leverage emerging as the most influential factor. However, the moderate R^2 value suggests that while firm fundamentals matter, volatility is also driven by other external factors not included in the current model.

Second, logistic regression analysis indicated that while firm attributes moderately predict whether a firm experiences high volatility, classification performance remains limited with a linear approach. This justifies the future application of more complex classifiers or hybrid models.

Third, the KNIME-based Regression Tree model, though visually interpretable, underperformed relative to the Python implementation. The negative R^2 value reflects the model's inability to effectively capture underlying relationships, highlighting the trade-off between simplicity and predictive strength.

Finally, the unsupervised K-Means clustering (supported by PCA) provided exploratory insights into latent structures within the data. While clustering revealed meaningful groupings, further interpretation is needed to validate economic relevance.

In summary, this project demonstrates the value of integrating machine learning techniques across platforms for financial risk modeling. It highlights both the potential and limitations of current approaches and suggests directions for future research—such as incorporating temporal variables, macroeconomic indices, or alternative firm-level indicators—to enhance predictive power and policy relevance.

Disclosure statement

The author declares no conflict of interest.

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Research on Satisfaction Improvement Strategy of “Songji Ancient Town Research Products” in Yongchuan District under the High-Quality Education System

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Abstract: Songji Ancient Town in Yongchuan District, Chongqing, is a famous historical and cultural town in China and a national AAAA-level tourist attraction. In recent years, combining its unique historical and cultural heritage, the scenic area has developed research travel products themed on intangible cultural heritage and red tourism, attracting students from across the country to experience it. On the other hand, in the context of the deepening of the “double reduction” policy and the concept of a “high-quality education system,” the educational connotation of Songji Ancient Town’s research products is constantly enriching. Based on this, this article will combine the RMP theory to explore strategies for improving satisfaction with Yongchuan District’s “Songji Ancient Town Research Products” under a high-quality education system, to promote the development of the scenic area’s research experience projects and overall tourism service levels.

Keywords: Songji Ancient Town; Satisfaction improvement; High-quality education system; Tourism

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1. Research background

Research travel has a long history in Europe and the United States, but started late in China. In 2013, the General Office of the State Council issued the “Outline of National Tourism and Leisure (2013),” which mentioned the need to “gradually implement research travel for primary and middle school students”^[1]. This is the first time that research travel has appeared in a formal policy document. In 2016, the Ministry of Education, the National Development and Reform Commission, and other departments issued the “Opinions on Promoting Research Travel for Primary and Middle School Students,” which clearly stated that research travel for primary and middle school students should be organized and arranged by education departments and schools in a planned manner, emphasizing the importance of research travel^[2]. On the other hand, Chongqing has also issued multiple policy

measures to support the development of research travel in recent years. For example, in 2017, the Chongqing Education Commission and other departments jointly issued the “Implementation Opinions on Further Deepening the Pilot Work of Research Travel for Primary and Middle School Students” (Chongqing Education Foundation [2017] No. 10), which clearly proposed to “create a number of influential research travel boutique routes and establish a practical classroom for research travel with Chongqing characteristics”^[3]. In 2025, the Chongqing Culture and Tourism Development Committee mentioned in the “Chongqing 2025 Measures to Support Market Entities to Expand Domestic and Foreign Customer Markets” that it is necessary to enrich the supply of research tourism resources, cultivate a group of high-quality research tourism brands and enterprises, and promote the healthy development of travel agency research tourism business^[4]. For Songji Ancient Town, both the 2024 and 2025 Yongchuan District Government Work Reports proposed to enrich its cultural tourism industry and support its construction and development of research projects^[5,6].

2. Research overview

2.1. High-quality education system

The 20th National Congress of the Communist Party of China proposed to “adhere to people-centered education development and accelerate the construction of a high-quality education system.” Searching for “high-quality education system” as the key term on CNKI yields 1,142 relevant documents.

2.1.1. A high-quality education system is a comprehensively coordinated education system

A high-quality education system signifies comprehensive and coordinated development for students, which is a widely mentioned point among scholars. Ruan and Zheng proposed that a high-quality education system is one that fosters comprehensive development in moral, intellectual, physical, aesthetic, and labor education^[7]. Additionally, Liu and Zou suggested that a high-quality education system signifies greater fairness, balance, coordination, and comprehensiveness in education^[8]. These scholars believe that under a high-quality education system, students should develop in a more comprehensive direction, with all aspects of their skills being honed.

2.1.2. A high-quality education system is an interdisciplinary knowledge integration education system

The concept of “interdisciplinary” is not only one of the essential elements of a high-quality education system. The Ministry of Education also mentioned in 2023 that conducting interdisciplinary learning is one of the critical and difficult issues in deepening the reform of curriculum and teaching. Bu *et al.* believed that one of the ways to build a high-quality curriculum system is to integrate disciplinary knowledge into practical and interdisciplinary activities, while taking into account personalized and diversified learning^[9]. In summary, interdisciplinary knowledge learning is one of the effective ways to achieve a comprehensive understanding of knowledge and is also one of the important starting points for building a high-quality education system.

2.1.3. A high-quality education system is an education system that cultivates students’ innovation ability and exploratory spirit

Under a high-quality education system, students’ innovation ability has become the focus of research. Li and Zhou believed that one of the educational theoretical interpretations to meet the needs of high-quality education is to maintain an open perspective and comprehensive innovation^[10]. Meanwhile, Yu believed that a high-quality education system emphasizes the cultivation of educated people’s innovation awareness and creativity, so that they

can learn to actively explore unknown fields ^[11]. In summary, under a high-quality education system, the subject status of students is valued, and active exploration and creativity cultivation have become top priorities.

2.2. RMP theory

RMP theory, also known as Angpu theory, was proposed by Wu Bihu, an expert in the field of tourism in China. This theory aims to plan the development strategy of tourism products in a region by studying the tourism resources (R), market resources (M), and tourism products (P) of that region ^[12]. In terms of research methods, some scholars summarize the existing tourism resources (R), educational resources (M), and research-based learning product programs (P) of the case site to tease out the future optimization and development trends of research-based learning products. This type of research mainly focuses on qualitative analysis.

2.3. Tourist satisfaction

The concept of tourist satisfaction is an extension of customer satisfaction. Li believed that tourist satisfaction is a psychological activity, a sense of pleasure after tourists' needs are met, and the level of satisfaction is a function of the difference between perceived effects and expectations ^[13]. Zhou believed that tourist satisfaction is a comprehensive psychological evaluation of tourists on natural landscapes, infrastructure, management levels, etc. It is a comparison between tourists' expectations and actual perceived effects ^[14].

3. Overview of the study area

Songji Ancient Town is located on the bank of the Yangtze River in the southern part of Yongchuan District, bordering Zhuyang Town in Jiangjin District on the east and Zhutuo Town on the west, about 40 kilometers away from Yongchuan City. In 1593 AD, due to the development of water and land transportation, Songji Ancient Town formed a town with a beginning scale, attracting merchants from neighboring counties and cities such as Lu County, Bishan, Rongchang, and Dazu to trade here. Later, because of the immigration policy of "Huguang filling Sichuan," Songji Ancient Town welcomed many immigrants and became a prosperous trade transit point. In 1747 AD, the town built the Zongya Yamen (a government office in charge of local administration and justice) and the City God Temple. In 1892 AD, a local military officer was established in the ancient town, further maintaining local security and living order. Many famous historical figures emerged during the prosperous history of Songji Ancient Town.

In summary, Songji Ancient Town is a historic and cultural town with a long history and rich talents. For this reason, Songji Ancient Town now has rich historical and cultural tourism resources, attracting tourists from all over the world to visit.

4. Analysis of research and study products in Songji Ancient Town

4.1. Analysis of R (Resources) in Songji Ancient Town's research and study products

4.1.1. Classification of tourism resources in Songji Ancient Town

Songji Ancient Town, located on the banks of the Yangtze River and named after the Songshan irrigation water, is situated at the southern end of Yongchuan District, Chongqing. With over 20 streets and alleys and about 5 kilometers of bluestone paths, it is one of the most well-preserved ancient towns with a thousand-year history in Chongqing. It is also a national AAAA-level tourist attraction, honored with titles such as China's Historical and

Cultural Town, Chongqing's Top Ten Charming Towns, and Chongqing's Ten Most Beautiful Ancient Towns. In terms of natural resources, Songji Ancient Town boasts an approximately eight-kilometer-long riverbank, where the river view and ancient town buildings are well-arranged. Visitors can take a cruise to enjoy the scenery along the riverbank of Songji Ancient Town. Regarding cultural resources, as a famous historical and cultural town in China, Songji Ancient Town was once the lecture site of Chen Pengfei, the emperor's teacher during the Song Gaozong period, and boasts many well-known ancestral halls and other tourist attractions. In 2022, Songji Ancient Town was selected for the "National Intangible Cultural Heritage Tourism Towns" directory. Currently, the scenic area still retains cultural exhibition areas such as the Spark Songji Red Culture Exhibition Hall, Pengfei Academy Ruins, Jade Emperor Temple Ancient Stage Ruins, and the Horse Caravan Council Hall. Meanwhile, it also provides traditional cultural experience projects such as "Songji Ancient Town Nine Bowls" traditional cuisine, bamboo weaving, oil paper umbrella making, and Sichuan Opera face-changing. To further clarify the research logic, the author has categorized and organized the tourist resources of Songji Ancient Town based on the "Classification, Survey, and Evaluation of Tourism Resources" (GB/T18972-2017) issued by the National Tourism Administration (**Table 1**).

Table 1. Classification of tourism resources in Songji Ancient Town

Category	Subcategory	Basic type	Tourism resource
B Water Scenery	BA River Systems	BAA Recreational River Sections	Songji Ancient Town Yangtze River Cruise Scenic Belt
E Buildings & Facilities	EA Cultural Landscape Complexes	EAA Social & Commercial Activity Sites	Mafang Conference Hall (Horse Caravan Meeting Hall)
		EAE Cultural Activity Venues	Spark Songji Red Culture Exhibition, New Life Movement Spinning Mill Exhibition Hall, Yuhuang Taoist Temple Ancient Stage, Ancient Yamen Integrity Exhibition Hall
	EB Functional Buildings & Core Facilities	EBA Characteristic Streets/Quarters	Songji Market
		EBB Characteristic Houses	Luo Family Ancestral Hall, Qin Family Compound
		EBG Dam Sections	Chenggong Weir
		EBH Ports, Ferries & Wharves	Songji Ancient Town Yangtze River Wharf
	EC Landscapes & Ornamental Structures	ECA Image Landmarks/Symbolic Structures	Kuixing Pavilion (Tower of Literary Star), Yuhuang Hall (Jade Emperor Hall)
F Historical Sites	FA Material Cultural Heritage	FAA Architectural Remains	Ten-Mile Old Street & Ming-Qing Dynasty Architecture
	FB Intangible Cultural Heritage	FBB Local Customs	Songji Ancient Town "Nine Bowls" Banquet Culinary Culture
		FBD Traditional Performances	Songji Ancient Town Sichuan Opera Face-Changing (Bian Lian), Waist Drum Performances
G Tourist Shopping	GC Handicrafts	GCG Paper & Lantern Crafts	Songji Handmade Paper Cutting, Songji Oil-Paper Umbrellas
H Human Activities	HA Records of Human Events	HAA Local Figures	History Lectures on Chen Pengfei, Medical Research History of Chen Wengui

4.1.2. Evaluation of tourism resources in Songji Ancient Town

The tourism resources of Songji Ancient Town are relatively rich. According to the “Classification, Investigation, and Evaluation of Tourism Resources” (GB/T18972-2017) by the National Tourism Administration, the tourism resources of Songji Ancient Town are classified into 5 main categories, 8 sub-categories, and 13 basic types. These resources not only have high ornamental value but also carry rich historical and cultural connotations, providing tourists with a comprehensive and unique travel experience.

4.2. Analysis of M (Market) in Songji Ancient Town’s research and study products

4.2.1. Analysis of tourism market in Yongchuan District

In recent years, Yongchuan District has actively promoted the development of the tourism industry, enhancing the hardware facilities and service quality of tourist attractions while creating a variety of festive tourism events during holidays. In 2024, major scenic spots in Yongchuan organized various activities such as the Mid-Autumn Lantern Festival (selected as a typical case of tourism consumption promotion innovation practice by the Ministry of Culture and Tourism), the Animal New Year Carnival, and the traditional slaughter of pigs for the new year, attracting tourists from all over the country. Throughout 2024, Yongchuan District received approximately 35 million tourists, with a total expenditure of about 24.6 billion yuan, representing an increase of 16.2% and 13.6% respectively compared to the previous year (Table 2) [6]. Based on the analysis of the work report of the Yongchuan District People’s Government, it can be seen that the tourism market in Yongchuan has shown continuous development in recent years, and the growth rate of tourism income and the number of tourists received has continued to expand (except during the COVID-19 pandemic control period in 2022).

Table 2. Changes in tourism revenue and the number of tourists received in Yongchuan District in recent years

Year	Tourism revenue (Billion RMB)	Growth rate	Visitor arrivals (10,000 person-times)	Growth rate
2024	246	13.6%	3,500	16.2%
2023	216	10.1%	3,015	11.0%
2022	194	3.5%	2,683	2.4%
2021	187	22.3%	2,619	13.4%

4.2.2. Analysis of educational resources in Chongqing and Yongchuan

Chongqing has strongly supported the development of education in recent years. According to statistics, in 2024, Chongqing added 75,000 new basic education places. As of the beginning of 2025, there were 73 ordinary universities in Chongqing with 1.38 million students, and 9,422 primary and secondary schools and kindergartens with 5.16 million students. The overall level of education development has entered the upper middle ranks in the country and the first tier in the West. On the other hand, according to the website data of the Yongchuan District Education Commission, there were 108 primary and secondary schools in Yongchuan District at the end of 2024, with a total of about 129,900 students. Such a large-scale educational resource provides a market foundation for the development of research travel projects in Songji Ancient Town.

4.2.3. Evaluation of the marketability of study tour products in Songji Ancient Town

Currently, Chongqing is vigorously promoting the improvement and expansion of education quality, aiming to enter the upper-middle ranks nationwide and become a leader in the western region. Therefore, the educational

resources in the greater Chongqing area, which are the main source of tourists for the research and study programs in Songji Ancient Town, are expected to further expand. This provides more potential customers for the research and study programs in Songji Ancient Town. On the other hand, since the post-pandemic era, due to the supportive policies of the cultural and tourism departments and the continuous deepening of online and offline tourism promotion, the tourism development speed in Chongqing and Yongchuan District is accelerating. This has also brought more development opportunities to the research and study programs in Songji Ancient Town to some extent.

4.3. Analysis of P (Product) in Songji Ancient Town's research and study products

4.3.1. Analysis of research and study tourism resources in Songji Ancient Town

Throughout its historical development, Songji Ancient Town has preserved and cultivated abundant tourism resources by leveraging its geographical advantages. In accordance with the Service Specification for Study Travel (LB/T 054-2016) and based on the town's existing tourism resources, the author has developed a classification table for Songji Ancient Town's study tour resources (**Table 3**).

Table 3. Classification of study tour resources in Songji Ancient Town

Product type	Experience projects/Activities
Knowledge popularization	<ul style="list-style-type: none"> • Spark Songji Red Culture Exhibition Hall • Yongchuan Ancient Yamen • Mafang Conference Hall • New Life Movement Spinning Mill Exhibition Hall • Luo Family Ancestral Hall (Architecture)
Nature appreciation	<ul style="list-style-type: none"> • Yangtze River Cruise in Ancient Town • Riverside Teahouses
Experiential investigation	<ul style="list-style-type: none"> • Pengfei Academy (Intangible cultural heritage production: dyeing, oil-paper umbrellas, etc.) • Songji Market (Traditional food making: Zhuerba rice cakes, etc.) • Qin Family Compound • Luo Family Ancestral Hall ("Nine Bowls" banquet)
Cultural wellness	<ul style="list-style-type: none"> • Yuhuang Taoist Temple Ancient Stage (Face-changing appreciation & workshops)

4.3.2. Current composition of research activities in Songji Ancient Town

Since 2023, study tour activities in Songji Ancient Town have gained increasing attention across society. Over the past two years, kindergartens, primary and secondary schools, and higher education institutions from various regions have successively organized study tours in Songji Ancient Town. Consequently, the town's study tour system has continuously developed and matured. According to the categorization in the Service Specification for Study Travel (LB/T 054-2016), the current study tour programs in Songji Ancient Town primarily encompass the following types: Historical Culture, Intangible Cultural Heritage, Local Gastronomy, and Sichuan Opera Face-Changing (**Table 4**).

Table 4. Details of study tour programs in Songji Ancient Town

Study theme	Study location	Study content
Historical Culture	Ancient Town Core Area	<p>Led by instructors, students explore Songji's most representative cultural sites including:</p> <ul style="list-style-type: none"> • Spark Songji Red Culture Exhibition Hall • Yongchuan Ancient Yamen • Pengfei Academy • Yuhuang Taoist Temple • Mafang Conference Hall • Traditional Oil Mill <p>Through storytelling, participants discover the millennium-old town's history and evolution.</p>
Intangible Cultural Heritage	Pengfei Academy	<p>Organizers provide materials and expert guidance for hands-on creation of:</p> <ul style="list-style-type: none"> • Traditional tie-dyeing • Hand-painted oil-paper umbrellas • Paper cutting <p>Students learn heritage craftsmanship techniques through direct practice.</p>
Local Gastronomy	Songji Market	<p>Participants learn to make traditional Zhuerba rice cakes with instructor guidance:</p> <ul style="list-style-type: none"> • Provided with authentic ingredients • Step-by-step production instruction • Option to steam, consume on-site, or take two portions home
Sichuan Opera Face-Changing	Ancient Stage at Yuhuang Taoist Temple	<p>Professional opera artists:</p> <ul style="list-style-type: none"> • Demonstrate face-changing (Bian Lian) techniques • Teach non-classified elements: body postures and stage movements • Provide backstage access and basic opera knowledge • Facilitate appreciation of traditional performance artistry

4.3.3. Evaluation of tourism resources and research tourism resources in Songji Ancient Town

The ancient town of Songji is rich in tourism resources. The town has retained numerous historical and cultural relics as well as festive events. For example, there is the ancient stage of Yuhuang Temple where intangible cultural heritage performances are still held, the intangible cultural heritage craftsmanship experience hall at the Xinyun Spinning Factory, and the nighttime lantern festival activities during holidays. Such projects focus on visitor experience, which can increase visitors' touring time and enhance their willingness to revisit to some extent. In terms of educational tourism resources, based on its unique locational advantages and rich historical and cultural heritage, Songji Ancient Town has nurtured a diverse range of educational tourism resources, covering knowledge popularization, natural observation, experiential exploration, and cultural well-being. Through these educational resources, students can gain a deep understanding of the town's historical culture and the evolution of human life and customs.

On the other hand, the educational tourism resources in Songji Ancient Town carry distinct educational significance. Combining its unique historical and cultural background, Songji Ancient Town has created educational experience programs with profound educational value. For instance, by visiting knowledge-based venues such as the Spark Songji Red Culture Exhibition Hall and the Yongchuan Ancient County Government Office, students can appreciate the greatness of the revolutionary spirit of their ancestors and the importance of integrity. This, in turn, cultivates students' patriotism, cultural confidence, and the correct values of fairness and righteousness. Simultaneously, hands-on activities such as experiencing intangible cultural heritage crafts like tie-dyeing and oil paper umbrellas at Pengfei Academy, and learning traditional food preparation at Songji Market, enable students to develop their creativity and practical skills through hands-on practice. This approach to educational tourism aligns with the concept of quality education, helping to foster students' innovative spirit and

practical abilities, and enhancing their overall comprehensive qualities. In summary, the educational resources of Songji Ancient Town can serve as a valuable complement to school education, and its distinct educational focus contributes to the holistic development of students in terms of morality, intelligence, physical fitness, aesthetics, and labor from a practical perspective.

In conclusion, the educational tourism resources of Songji Ancient Town possess two significant advantages: a rich variety and distinct educational value. This benefits both study tour groups (such as schools) and individual students, allowing them to select educational programs based on their actual needs and thus achieve the educational goals of their study tours.

5. Strategies for improving visitor satisfaction with research-based learning products in Songji Ancient Town

5.1. Student-centered activities to stimulate exploration and innovation

Stimulating students' spirit of exploration and innovation is a key aspect of a "high-quality education system." Songji Ancient Town's research-based learning products should integrate its unique characteristics and advantages to create an excellent learning experience for visitors. The most important aspect is optimizing existing products, emphasizing the student's central role, focusing on cultivating their exploratory spirit through activity details and teacher guidance, attracting their interest, and aligning the curriculum and teaching objectives with the requirements of a "high-quality education system."

5.2. Scientific design of activity processes, emphasizing the integration of knowledge and subjects

The integration of knowledge and subjects is also a crucial requirement of a "high-quality education system." The research-based learning project design in Songji Ancient Town should fully utilize its comprehensive range and broad teaching objectives, highlighting the integration and mutual promotion of various activities. By involving students in activities, they can experience the interconnectedness of knowledge, promoting autonomous learning and improving their ability to transfer knowledge.

5.3. Enhancing mentor teaching abilities to foster students' comprehensive development

Research mentors play a crucial leading role in research-based learning activities. Mentors for Songji Ancient Town's research projects must continuously improve their teaching abilities and knowledge reserves. When guiding students in research activities, they should aim to promote students' comprehensive development in morality, intelligence, physical fitness, aesthetics, and labor, refine teaching steps, choose appropriate teaching methods, and ensure balanced and comprehensive student development.

6. Conclusion

Currently, the study products of Songji Ancient Town have attracted a large number of tourists to participate. To further enhance tourist satisfaction, Songji Ancient Town should optimize product design, improve teacher quality and service levels based on its current situation and cultural heritage, and be guided by a high-quality education system. It should achieve this goal through multiple avenues, including "innovation capability," "knowledge integration," and "improving teaching ability to promote comprehensive development."

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Research on the Integration Development Model of Intangible Cultural Heritage and Tourism Industry in Rongchang District of Chongqing from the Perspective of Cultural and Tourism Integration

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Abstract: Promoting the deep integration of culture and tourism has become an important goal for the development of Rongchang District, Chongqing. With its rich intangible cultural heritage, Rongchang District has a great opportunity to drive the deep fusion of culture and tourism, using culture to promote tourism and vice versa, thereby vigorously developing the cultural tourism economy. From the perspective of all-for-one tourism, this paper takes the integration of “intangible cultural heritage (ICH) +” cultural tourism in Rongchang, Chongqing as an example, analyzes the advantages and disadvantages of the construction of the cultural tourism industry in Rongchang District, Chongqing, and explores the integration development mechanism of rural “ICH +” cultural tourism industry. Using literature research, case analysis, and field investigations, and based on the theories of sustainable development and cultural tourism integration, this paper extracts the achievements and shortcomings of the deep integration of “ICH +” cultural tourism in Rongchang District through data collation and analysis. This provides valuable reference and lessons for realizing the inheritance of ICH and the sustainable development of tourism.

Keywords: Cultural tourism integration; Intangible cultural heritage; Tourism industry

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1. Research background and significance

1.1. Research background

With the release of the “Outline of the 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives Through the Year 2035” of the People’s Republic of China, the integrated development of cultural tourism has been elevated to a national strategic level. The goal of promoting the deep integration of cultural tourism has been clearly stated in the “14th Five-Year Plan,” emphasizing the importance of shaping tourism through culture and valuing the reflection of culture in tourism. Furthermore, the report of the 20th National Congress of

the Communist Party of China puts forward specific requirements on how to advance the high-quality integrated development of culture and tourism, further emphasizing the necessity of deep integration of cultural tourism.

1.2. Research significance

This study focuses on the integrated development model of intangible cultural heritage (ICH) and tourism in Rongchang District, Chongqing. It aims to identify issues in the current model of ICH and tourism integration in Rongchang District, propose improvement suggestions, and facilitate the integration of ICH resources to promote high-quality tourism development and achieve the strategic goal of deep cultural tourism integration.

1.2.1. Theoretical significance

Through field research and interviews with relevant personnel to understand the current situation of the integration of ICH and tourism development in Rongchang District, this paper studies the mode of integration development using case analysis to promote further deep integration. This study can expand the research theory on the implementation mode of the integrated development of ICH and tourism, contributing to the lively and innovative inheritance of ICH and the innovative development of tourism.

1.2.2. Practical significance

By analyzing the specific situation and cases of the “ICH + Tourism” integration mode in Rongchang District, and studying the advantages and disadvantages of the current integration development mode in Rongchang District, this study helps the Rongchang District government better understand the potential and direction of the integration development mode. This promotes better coordinated development between ICH and tourism. This study can provide practical guidance for improving the integrated development model of ICH and tourism in Rongchang District in the future.

1.2.3. Importance

Driven by national strategic planning, the deep integration of culture and tourism has become a popular development direction. By studying the integrated development model of intangible cultural heritage and tourism in Rongchang District, this research can provide research theories and case studies for future related studies, promoting the advancement of research on the deep integration of culture and tourism. In summary, through in-depth research on the integrated development model of intangible cultural heritage and tourism in Rongchang District, this study will provide a certain degree of theoretical support for related cultural and tourism integration development models and offer corresponding practical guidance for specific practices. In terms of theoretical significance, practical significance, and importance, this study has certain research significance.

2. Research status at home and abroad

2.1. Research on intangible cultural heritage

According to the 2003 “Convention for the Protection of the Intangible Cultural Heritage” of the United Nations Educational, Scientific and Cultural Organization (UNESCO), ICH includes social practices, thoughts, expressions, knowledge systems, skills, and their related tools and objects. It is a key part of cultural diversity, reflecting human creativity and transmission, and is crucial for cross-cultural understanding and respect^[1]. After the adoption of the Convention, ICH protection has become a global focus, and scholars have begun to conduct in-depth research on its protection methods.

When the concept of ICH was first introduced to China, research mainly focused on conceptual understanding, classification, and characteristic description, emphasizing knowledge popularization while lacking deep theoretical exploration. As time progressed, scholars began to combine theory with practice, focusing on the practical operation of ICH protection and exploring its integration and sustainable development in society and economy.

The introduction of the concept of cultural and tourism integration has brought new vitality to the development and protection of ICH tourism. Through field investigations, Wu pointed out the challenges faced by the inheritance of ICH skills and advocated that ICH inheritance should adhere to the principles of integrity, regionality, and innovation. She proposed the construction of a symbiotic and win-win relationship between ICH and the tourism industry, emphasizing the importance of government guidance, tourism environment optimization, and civilian participation ^[2].

Zhou analyzed the protection and development of ICH in the renovation of historical blocks, advocating for sustainable development, integration, and authenticity principles, and achieving ICH's live transmission through a multi-level protection system ^[3]. Guo studied the ICH projects in Xinyu City, exploring new development models under the integration of culture and tourism, and opening up new paths for the protection and development of ICH ^[4]. Li and Liang focused on the inheritance, protection, and utilization of intangible cultural heritage in Guangming District. They identified deficiencies in professional talents, capital investment, tourism integration, and technology application, and proposed a protection and tourism integration development strategy from the perspective of cultural and tourism collaboration, aiming to inject new momentum into ICH inheritance ^[5].

2.2. Research on the integration of culture and tourism

The integration of culture and tourism describes the mutual combination of culture and the tourism industry. This combination not only contributes to the preservation and dissemination of cultural resources but also stimulates the growth and innovation of the tourism industry. In the international academic field, especially in English-language research, the focus on the integration of culture and tourism centers on two main aspects: exploring the role of culture in tourism and emphasizing comprehensive research on cultural tourism.

Vergori and Arima analyzed international cultural tourism data from Italy and concluded that developing cultural tourism is one of the key strategies for tourist destinations to cope with seasonal fluctuations ^[6]. Many countries use their rich historical and artistic heritage as a cornerstone to promote cultural tourism. After reviewing international literature, it is evident that foreign academic circles usually do not adopt the concept of “integration of the tourism industry and cultural industry,” but rather focus on cultural tourism phenomena in specific regions, including policy analysis and industrial development. In contrast, domestic academic circles, with policy support, have gradually increased theoretical research on the integration of the cultural and tourism industries, focusing on implementation paths, value significance, systematic frameworks, drivers, and synergies.

Wu and Bai advocated the use of digital technology to strengthen the combination of urban and rural cultural tourism and proposed various practical models. Based on scene theory, they constructed a multi-dimensional analysis framework that includes elements such as integration, creative design, dynamics, global experience, community participation, and sharing. They explored the role of the digital economy in the integration of culture and tourism. These theories provide a model for the cultural and tourism development of Zhanjiang City and help promote high-quality industrial development ^[7].

Scholars such as Ming *et al.* believed that the deep integration of culture and tourism is crucial for promoting industrial division and collaborative evolution. They established a hierarchical and systematic framework and research model aimed at promoting the high-quality development of the cultural and tourism industries. They emphasized the importance of cultural and tourism integration for socialist modernization, enhancing cultural self-

confidence, and building an advanced cultural system. They believed that this helps meet people's pursuit of a better life and promotes national rejuvenation^[8].

Geng and Liu used a systematic framework to explore the integration of culture and tourism, revealing its development dynamics and mechanisms. They analyzed its connotations from the perspectives of happiness and spatial production. Based on China's reality, they proposed an integration path that balances multi-party relationships and establishes a comprehensive tourism concept. They advocated a circular development model that promotes a balance between supply and demand through core attractiveness and unique experiences, enhancing the self-development capabilities of cultural and tourism integration. This perspective provides theoretical and practical guidance for the integration of culture and tourism^[9].

2.3. Research on the integration of intangible cultural heritage and tourism

Research on the combination of "ICH + tourism," both domestically and internationally, generally believes that the integration of ICH and the tourism industry is a mutually beneficial development model. This model can promote cultural inheritance and development while enriching tourism experiences.

Wang and Yuan proposed suggestions for tourism resource planning under a new paradigm for the integration of ICH and cultural tourism in Jiaozuo City. They suggested taking Tai Chi culture as the lead, expanding promotion, cultivating professional talents, improving infrastructure, and utilizing digital technology to enhance the image of ICH tourism and enrich visitor experiences^[10]. Wen analyzed the current situation of Rongchang tourism and proposed promoting the comprehensive development of "culture + education + tourism" with the ICH study travel base as the core. This approach aims to facilitate ICH protection and sustainable tourism while transforming the single tourism model^[11].

Pang focused on the micro level, studying how to stimulate the tourism potential of folk ICH in cultural tourism integration. She established a research framework and activation path model, conducting an in-depth analysis using the example of the Huaiyuan Wanghuo custom and proposing tourism activation strategies^[12]. Yu explored innovative ways to combine ICH with cultural and creative products, promoting innovative development in both ICH and the tourism industry^[13]. Xia and He examined the organizational forms of ICH entering scenic areas, proposing a development model that combines ICH and scenic resources. This provides a new perspective for the integration of ICH and the tourism industry^[14].

2.4. Literature review

By summarizing the referenced literature, it can be observed that scholars both domestically and internationally have studied the integrated development model of ICH and the tourism industry from different perspectives. With the progression of time, researchers have developed various tourism models and mechanisms based on the cultural value of different ICH and tourism experiences, greatly facilitating the integration of ICH and the tourism industry. Most research in China on the integrated development of ICH and the tourism industry involves discussing innovative development models for cultural tourism integration. Many ICH-related tourist attractions across the country are exploring cultural tourism integration models tailored to their unique characteristics.

3. Research design

3.1. Case study location

Firstly, representative integration cases were selected from the integrated development of ICH and tourism in

Rongchang. The Rongchang District fully utilizes its local ICH cultural resources to promote tourism development by establishing the Grass Cloth Town, the Antao Town, and the historically and culturally famous Wanling Ancient Town.

Secondly, using grass cloth as a medium, Rongchang vigorously promotes the development of ICH cultural and creative products. By combining traditional grass cloth with modern design concepts, a series of stylish and practical grass cloth cultural and creative products have been created, which have been well-received in the market. This initiative not only preserves the craftsmanship of grass cloth making but also extends its reach to a broader market.

In addition, Rongchang actively promotes the integrated development of ICH and tourism. ICH experience projects and ICH performance activities are organized in scenic areas, allowing tourists to experience ICH skills and deepen their understanding and knowledge of local culture. Simultaneously, Rongchang encourages local residents to participate in ICH tourism projects, improving their income levels and achieving mutual benefit and win-win results between ICH and tourism.

3.2. Data sources

The data is divided into two parts (**Table 1**). One part consists of field research meeting records. The research team participated in the on-site symposium on “Developing the Cultural Industry to Empower Rural Revitalization” in Rongchang District from April 13 to 14, 2024. They also conducted field research in Rongchang’s Grass Cloth Town and Antao Town to collect relevant information on the integrated development of ICH and tourism, providing detailed first-hand data. The other part comprises interview materials. On April 28, 2024, the research team conducted a focused interview with industry association personnel who have a deep understanding of the Rongchang Grass Cloth Fashion Week. The materials are comprehensive, align with the field research findings, and accurately reflect the current status of ICH and tourism development in Rongchang District, Chongqing.

Table 1. Sources of symposium text materials and interview text data

Data type	Interviewee/Source	Time
Rongchang District Intangible Cultural Heritage & Tourism Symposium Meeting Minutes	Deputy Director, Cultural and Tourism Commission	April 13, 2024
	Chongqing University Career Mentor	
	Head, Chongqing University Research Delegation	
	Head, Chongqing University Alumni Association	
	Representative 1, Corporate Inspection Delegation	
	Representative 2, Corporate Inspection Delegation	
Interview Record	Deputy Secretary-General, Chongqing Garment & Textile Association	April 28, 2024

4. Research on the integrated development model of intangible cultural heritage and tourism in Rongchang District, Chongqing

4.1. Open coding

Open coding was used to annotate and name the relevant raw data content related to the research topic and to extract initial conceptual categories. Based on the research topic, data processing and analysis were conducted on the collected raw data. Key sentences were screened through keywords such as intangible cultural heritage, intangible cultural heritage inheritors, cultural innovation, culture and tourism-related words, government, enterprises, etc. Twenty basic concepts were extracted, including innovation and promotion of cultural heritage,

tourism economy and cultural innovation, cultural tourism and industrial integration, brand and market of the intangible cultural heritage industry, international marketization of intangible cultural heritage, government support and promotion, innovation and comprehensive development of the cultural industry, brand building and market strategy, promotion of intangible cultural heritage, inheritance and value of intangible cultural heritage, artistic promotion of intangible cultural heritage, media drive and industry linkage, industry association supervision and promotion of culture and tourism, market strategy and value growth of intangible cultural heritage products, market adaptability and development of intangible cultural heritage products, integrated promotion and inheritance innovation of intangible cultural heritage, local industrial development driven by the integration of culture and tourism, brand linkage and cultural dissemination, industrial cooperation and creative development, market adaptability and business model innovation (see **Table 3** for details). The coding process is shown in **Table 2**, and only part of it is displayed due to space limitations. Since it is a mixed coding of text materials from symposiums and interviews, during the coding process, the key sentences contained in the collected text materials are summarized for better understanding. The original representative sentences belonging to the cultural tourism symposium are set as a1, a2, ..., and those belonging to the interview record text materials are set as b1, b2, ...

Table 2. Example of open coding

Conceptualization	Primary sources
A1 Heritage Innovation & Promotion	a1. Rongchang was named in 1373... developing the “Millennium Rongchang Historical Culture Week” as a flagship IP event. a2. Planning major projects for the Chengdu-Chongqing Ancient Route, where Rongchang serves as a key node.
A2 Tourism Economy & Cultural Innovation	a3. Xiabu (Grass Cloth) Town is best visited at night for its lantern displays. a4. Antao (Pottery) Town requires enhanced commercial formats... New e-commerce talents are needed to guide online sales.
A3 Cultural-Tourism-Industry Integration	a5. Rongchang integrates culture, sports, and tourism. a6. Rongchang is among China’s first National Model Zones for Public Fitness and the only such district in Chongqing. a7. The Commerce Bureau is establishing a Food E-commerce Industrial Park leveraging influencer economy.
...	...
A6 Government Support & Promotion	b1. Led by Chongqing Municipal Commission of Economy and Informatization. b2. Officials from national cultural authorities, including the Intangible Cultural Heritage Department, conducted inspections in Rongchang.
...	...
A13 Industry Association Oversight & Promotion	b10. Organized by Chongqing Garment & Textile Association (registered with Civil Affairs Bureau), supervised by Chongqing Municipal Commission of Economy and Informatization.
...	...
A17 Cultural-Tourism Driven Local Industry Development	b16. Every cultural-tourism base can establish a national defense education base. a10. Collaborating to build an Industry Integration Training Center and practical training base.
...	...
A20 Market Promotion & Business Model Innovation	b21. Persistently high costs constrain sales channels to traditional models (physical stores/dealers). We aim to catalyze e-commerce adoption.

4.2. Axial coding

Using axial coding methods, the logical relationships between 20 basic concepts were analyzed and categorized into seven areas: innovative development of the intangible cultural heritage industry, integrated development of cultural tourism, brand building and market positioning, industry integration model innovation, government support and policy guarantees, enterprise cooperation and industry synergies, intangible cultural heritage education and industry cooperation, denoted as Cn; this ultimately formed four main categories: industry, culture, governance, and talent, denoted as Fn, as shown in **Table 3**.

Table 3. Axial coding table

Primary category	Sub-category	Initial concepts (from Open Coding)
F1 Industry Sector (ICH Culture & Innovation)	C1 ICH Industry Innovation & Development	A1 Heritage Innovation & Promotion; A2 Tourism Economy & Cultural Innovation; A7 Cultural Industry Innovation & Integrated Development; A9 ICH Cultural Promotion; A10 ICH Inheritance & Value Enhancement; A11 Artistic Promotion of ICH; A17 Integrated ICH Promotion & Innovative Inheritance
F2 Cultural Sector (Cultural-Tourism Industry & Market Positioning)	C2 Cultural Industry Convergence	A3 Cultural-Tourism-Industry Integration
	C3 Brand Building & Market Positioning	A4 Branding & Market Expansion for ICH Industries; A8 Brand Development & Marketing; A14 Market Strategies & Value Growth for ICH Products; A15 Market Adaptability & Development of ICH Products; A18 Brand Synergy & Cultural Dissemination
	C4 Industrial Integration Models	A19 Industrial Collaboration & Creative Development; A20 Market Promotion & Business Model Innovation
F3 Governance Sector (Government Administration & Policy Support)	C5 Government Support & Policy Safeguards	A6 Government Support & Promotion
F4 Talent Sector (ICH Practitioners & Enterprise Engagement)	C6 Enterprise Collaboration & Business Innovation	A12 Media-Driven Industry Linkage; A13 Trade Association Oversight & Promotion
	C7 ICH Education & Industry Partnerships	A17 Cultural-Tourism Driven Local Industry Development

4.3. Selective coding

Using selective coding methods, the “core category” was extracted, resulting in a core concept—the reciprocal symbiosis of intangible cultural heritage and tourism development. This forms a core element model of “intangible cultural heritage + cultural tourism integration development” driven by three core collaborative entities: intangible cultural heritage inheritors, the government, and enterprises, to further integrate intangible cultural heritage and tourism, better attract the tourist market, provide products and services to tourists (consumers), and thus inherit intangible cultural heritage.

4.4. Elements of cultural tourism integration development

- (1) Government: The government’s main interests are to protect and inherit intangible cultural heritage, maintain cultural diversity, promote regional economic development to achieve common prosperity, enhance regional brand image, and strengthen cultural soft power. Therefore, the government formulates

and implements relevant policies, provides governance and policy guarantees, ensures the inheritance of intangible cultural heritage, provides human and financial support, promotes industrial development, and provides policy support and guidance. The goals are to achieve sustainable development in the cultural tourism integration area, promote common prosperity, and drive deep industrial integration.

- (2) Intangible cultural heritage inheritors: By showcasing and inheriting cultural identity and lifestyle, intangible cultural heritage inheritors attract public attention and participation. They provide cultural content for the cultural tourism industry by demonstrating and imparting skills while earning economic benefits.
- (3) Enterprises: Enterprises aim to enhance market competitiveness, achieve benefit growth, and fulfill social responsibilities. To achieve this, they participate in the formulation and coordination of intangible cultural heritage projects, promote industrial development, adjust and improve the industry's momentum to ensure healthy industrial development, provide employment opportunities, and engage in cultural tourism industry development. Their goals are to achieve market positioning and industrial agglomeration, drive industrial innovation and development, and enhance brand value.
- (4) Tourists (consumers): Consumer demand for intangible cultural heritage products drives the formation and development of the market. Consumer feedback helps enterprises and intangible cultural heritage inheritors improve their products and services to better meet market demand.

4.5. Innovative integration development model of culture and tourism

- (1) "Intangible Cultural Heritage + Tourism" utilizes intangible cultural heritage resources to create a full chain. For example, the transformation of intangible cultural heritage into cultural tourism products is achieved through innovative experiences and digital activation in places like Antao Town and Xiabu Town.
- (2) "Scenic Area + Tourism" promotes the transformation of scenic areas. With the help of cultural IP and innovative formats, Wanling Ancient Town and Gufo Mountain Scenic Area extend visitors' stay time and increase secondary consumption.
- (3) "Village + Tourism" constructs a three-industry integration path. Qingsheng Town and Anfu Street rely on intangible cultural heritage and ecological resources to increase farmers' income and rural tourism revenue.
- (4) "Service + Tourism" improves service through intelligence and standardization. Platforms like "One Code Travel Rongchang" and "Intangible Cultural Heritage Service Station" enhance visitor satisfaction and form a high-quality service network.

5. Countermeasures and suggestions for the integrated and innovative development of the cultural tourism industry in Rongchang District

5.1. Strengthening the cultivation of young inheritors

Currently, the inheritance of intangible cultural heritage faces challenges such as the aging of inheritors and a lack of interest among the younger generation, leading to the risk of skill transmission gaps. To address this issue, multiple parties should work together. The government and relevant departments should provide financial support, fund intangible cultural heritage projects, create training bases, and attract young people. Scholarships and vocational training should be provided to young people to stimulate their participation and enthusiasm, injecting vitality into the inheritance. Collaboration with cultural and educational institutions can enhance the knowledge and communication skills of intangible cultural heritage inheritors. Favorable conditions for inheritance should be

created by strengthening talent cultivation and introduction, providing policy and technical support, and facilitating market access. Multiple measures should be taken to create a good atmosphere where the entire society values intangible cultural heritage.

5.2. Promoting the development and innovation of cultural tourism products

Currently, there are issues such as insufficient integration between Chongqing's rural intangible cultural heritage and modern design, a lack of depth and breadth, and high prices for innovative products, which restrict the dissemination and innovation of intangible cultural heritage. To address this, designers and inheritors can be encouraged to collaborate, merging traditional skills with modern aesthetics, promoting cross-border cooperation, organizing design competitions, and developing diverse cultural and creative products. Cultural festivals and activities can enhance the experiential and interactive aspects of intangible cultural heritage. Additionally, digital technology can be utilized to establish an intangible cultural heritage database, develop virtual exhibitions, formulate reasonable pricing strategies, and encourage social forces to participate through public-private partnerships, comprehensively promoting the sustainable development of intangible cultural heritage.

5.3. Strengthening brand building and market positioning

To enhance the brand value of Chongqing's rural "intangible cultural heritage," a multi-pronged approach is necessary. Firstly, a clear brand image and positioning must be established, deeply exploring intangible cultural heritage stories and aligning them with modern aesthetics and market demands. Innovative design of tourism products and experiential activities should be pursued to strengthen emotional connections with consumers and enhance brand influence and market recognition. Simultaneously, expanding sales networks through online e-commerce platforms and offline experience stores is crucial. International cultural exchanges, such as collaborations with foreign museums, should be enhanced, and a cooperation platform between inheritors and enterprises should be established to facilitate resource sharing. Additionally, actively promoting the integration of intangible cultural heritage with industries like tourism, education, and fashion, and developing diversified products and experiences, can comprehensively broaden the dissemination channels of intangible cultural heritage.

5.4. Enhancing the precision and supervision of government support

The government plays a leading role in promoting the integrated development of intangible cultural heritage and the tourism industry. Firstly, the government should establish and improve the evaluation and supervision mechanism for policies related to intangible cultural heritage and tourism. Through in-depth research on the characteristics of intangible cultural heritage and tourism market demands, precise and targeted policies should be formulated and adjusted based on feedback to facilitate deep integration. Secondly, increased financial investment is necessary to provide funding support for the promotion, protection, inheritance, and innovation of intangible cultural heritage projects and the tourism industry. Policy guidance should be utilized to cultivate inheritors of intangible cultural heritage, especially among the younger generation, and encourage cross-industry collaboration. Furthermore, promoting community participation in intangible cultural heritage protection and enhancing public awareness are crucial. Policies should also be leveraged to support the brand building and promotion of intangible cultural heritage, and international exchanges should be conducted to comprehensively promote the sustainable development of intangible cultural heritage and the tourism industry.

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Research on the Behavioral Intention of Health and Wellness Tourism for Elderly People in Chongqing Based on ETPB Theory

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Abstract: This study is based on the Extended Theory of Planned Behavior (ETPB) and focuses on the elderly population in the main urban area of Chongqing to explore their intentions and influencing factors regarding health and wellness tourism behavior. Data was collected through questionnaire surveys and field research, and SPSS 26.0 and Amos 29.0 software were used for reliability, validity analysis, and structural equation modeling testing. The study shows that behavioral attitude, perceived behavior control, and the context of health and wellness tourism have a significant positive impact on the elderly's intentions regarding health and wellness tourism behavior, while the influence of subjective norms is not significant. In addition, subjective norms have a significant positive effect on behavioral attitudes and perceived behavioral control. Based on the research conclusions, suggestions are made to strengthen the behavioral intention of elderly tourists to participate in health and wellness tourism.

Keywords: Health and wellness tourism; Theory of Planned Behavior; Elderly; Behavioral intention

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1. Introduction

With the intensifying aging of the population, health and wellness tourism, as an emerging healthy lifestyle, is receiving increasing attention from the elderly. Health and wellness tourism not only helps improve the physical health of the elderly but also enriches their spiritual and cultural life. However, current research on health and wellness tourism at home and abroad is mostly focused on the supply side, and rarely considers the demand side, especially from the perspective of the elderly as a special group. This study, based on the Extended Theory of Planned Behavior (ETPB) and focusing on the elderly in Chongqing, explores their intentions and influencing factors regarding health and wellness tourism behavior through questionnaire surveys and field research. The aim is to provide theoretical support and practical guidance for the development of the health and wellness tourism market and the improvement of the quality of healthy living for the elderly.

2. Literature review and theoretical basis

Both domestic and foreign research on healthcare tourism started late and has had a short development time. Moreover, there is no unified definition of healthcare tourism in academic circles at home and abroad. Goodrich and Goodrich were the first to propose the concept of “Healthcare Tourism,” defining it as a type of tourism that attracts tourists with health services and facilities ^[1]. Hall proposed the concept of healthcare tourism, believing that it is a general term for activities such as sauna, massage, and recuperation conducted in a casual environment motivated by health ^[2]. Wang first proposed the concept of healthcare tourism in China, stating that it is tourism activities that rely on the cultural, natural ecological, and humanistic environments, and integrate various forms such as viewing, leisure, health, and play to achieve physical and mental health, prolong lifespan, enhance physical fitness, and healthcare ^[3]. Du believed that healthcare tourism refers to specialized tourism activities that promote physical and mental health through various activities during the tourism process, based on superior material and climatic conditions, and cultural environment, and sometimes combined with traditional Chinese medicine and Western medical health technology and equipment ^[4]. Peng defined healthcare tourism as tourism activities based on the excellent natural ecological environment of the tourism destination, equipped with good medical and health equipment, for the purpose of health preservation, recuperation, and healthcare, and finally achieving the harmonious complementarity of tourists’ body and mind through various tourism activities ^[5]. Sun believed that “healthcare” refers to health + wellness + elderly care, and “healthcare tourism” refers to the general term for various tourism activities where tourists travel to different places for more than 24 hours for the purpose of health, wellness, and elderly care, combining the external environment of the tourism destination to bring tourists close to or achieve harmony in physiological, psychological, and spiritual aspects, and be in a better natural state ^[6]. The above research mainly defines healthcare tourism in terms of tourism form and purpose. Healthcare tourism is a cross-regional tourism activity, and its core lies in promoting and achieving human physical and mental health.

Research on healthcare tourism at home and abroad mainly focuses on the following aspects: (1) Research on healthcare tourism destinations, focusing on the development, evaluation, advantages, and development strategies of healthcare tourism destinations. Zhang believed that Guangxi’s unique natural environment, ethnic culture, and dietary characteristics are unique advantages for the development of healthcare tourism ^[7]. Yang and Du innovatively adopted the Random Forest algorithm (RF) model by integrating multi-source information such as geospatial data, network platform data, and socio-economic statistical data, to accurately evaluate the suitability of mountain healthcare tourism in Yunnan Province, and systematically explored its influencing factors ^[8]. (2) Research on health and wellness tourism products focuses on the types of products covered and the development of related products. Zhao and Sun selected Qinhuangdao City in China as the specific target for their research, conducting an analysis of the current development status of the health and wellness tourism industry in Qinhuangdao. They believed that a comprehensive exploration of the characteristics of regional internal resources should be carried out, and new business formats should be developed to achieve continuous innovation and effective development of corresponding products ^[9]. (3) Research on health and wellness tourists mainly revolves around tourist motivations and behavioral intentions. Domestic research on the motivations of health and wellness tourism is relatively limited, focusing primarily on the motivations of forest health and wellness tourists. Han constructed a structural equation model with health accounts and consumer attitudes as intermediary variables based on psychological account theory and the “cognition-attitude-willingness” theory, exploring the influencing factors of forest health and wellness tourism willingness from the perspectives of frugality and cognition ^[10].

In summary, research on health and wellness tourism at home and abroad has started relatively late. From the

perspective of the concept of health and wellness tourism, there is currently no unified and clear definition. In terms of the main research content of health and wellness tourism, it is mainly focused on the supply side, while there is less research on the demand side, especially the health and wellness tourism needs of special groups such as the elderly.

The Theory of Planned Behavior is a cognitive model proposed by Ajzen in 1985 based on the Theory of Reasoned Action, which aims to systematically explain and predict human behavior and decision-making processes. The theory suggests that behavioral attitude, subjective norm, and perceived behavioral control are the core variables that drive individuals' behavioral intentions and ultimately influence actual behavior through the mediating role of intentions^[11]. Behavioral attitude reflects an individual's positive or negative evaluation of a specific behavior, and its strength depends on the assessment of behavioral outcomes and the subjective degree of association between the behavior and the outcomes. For example, if an individual believes that exercise can significantly improve health levels, they will have a stronger willingness to exercise. Subjective norm refers to the social pressure perceived by an individual, namely the expectations of significant others (such as family and friends) or organizations regarding whether they should perform a certain behavior. If the reference group generally supports a certain behavior, individuals will be more inclined to comply due to social pressure. Perceived behavioral control covers individuals' comprehensive judgments on the ease of implementing a behavior, including both internal factors (such as ability, emotions, and willpower) and external conditions (such as time, money, and resources). This variable directly affects behavioral intentions and enhances the feasibility of actual behavior when resources are sufficient. In domestic academic circles, the Theory of Planned Behavior (TPB) has gradually been introduced and applied to specific research to explore the relationship between behavioral intentions and actual behaviors. Currently, this theory has been widely used in various tourism research fields such as eco-tourism, low-carbon tourism, and rural tourism, and it has become a relatively mature research model. Li *et al.* studied virtual tourism experiencers and constructed a structural equation model based on the Theory of Planned Behavior. By introducing dual variables of virtual tourism experience and epidemic effects, they analyzed the driving path for experiencers to transition from virtual scenes to actual tourism behavior^[12]. Xiang studied the historical and cultural block of Nanchang Wanshou Palace, applying the Theory of Planned Behavior to analyze influencing factors, propose research hypotheses, and construct a research framework for tourists' consumption behavior in nighttime cultural tourism^[13]. However, as research on tourism behavior deepens, more scholars are gradually realizing the limitations of the TPB model. Especially in complex and changing tourism scenarios, the applicability of the TPB model is questioned. Therefore, researchers have introduced extended variables such as tourism experience into the TPB model to more comprehensively explain the formation process of tourists' behavioral intentions. Liu studied potential cruise tourists, based on the Theory of Planned Behavior, combined with the actual situation of cruise tourism development, introduced risk perception variables, and established an extended Theory of Planned Behavior model for the formation mechanism of cruise tourism behavioral intentions^[14]. Zheng studied the Qingming Bridge historical and cultural block. Based on the Theory of Planned Behavior (TPB), he introduced tourism experience as an extended variable, constructed an extended TPB model, and systematically explored the influence of subjective norms, perceived behavioral control, tourist attitudes, and tourism experience on tourists' behavioral intentions^[15].

This article focuses on the elderly population in the main urban area of Chongqing, collecting data through questionnaire surveys combined with field research. Under the framework of the Theory of Planned Behavior, the concept of healthcare and wellness tourism is introduced to construct an Extended Theory of Planned Behavior (ETPB) model. This model is used to explore tourists' behavioral intentions and influencing factors in healthcare

and wellness tourism, thus contributing a new perspective to research in related fields.

3. Research hypotheses

(1) Behavioral attitude, subjective norm, and perceived behavioral control, along with behavioral intention, are the main variables of the Theory of Planned Behavior. Previous studies have repeatedly verified the impact of behavioral attitude, subjective norm, and perceived behavioral control on tourists' willingness to participate. According to Zhang's research, there is a significant positive correlation between perceived behavioral control and both revisit intention and recommendation intention ^[16]. Li and Jiang believed that the subjective norm of dark tourists has a significant positive impact on their behavioral attitude and behavioral intention ^[17]. This study suggests that in the field of health and wellness tourism, behavioral attitude, subjective norm, and perceived behavioral control also have a significant impact on the willingness of elderly people to participate in health and wellness tourism. In summary, based on the Theory of Planned Behavior, the following hypotheses are proposed:

H1: Among elderly tourists, behavioral attitude has a significant positive impact on behavioral intention in health and wellness tourism decisions.

H2: Among elderly tourists, subjective norm has a significant positive impact on behavioral intention in health and wellness tourism decisions.

H3: Among elderly tourists, perceived behavioral control has a positive impact on behavioral intention in health and wellness tourism decisions.

(2) Besides the above three independent variable factors, the behavioral intention of elderly tourists to participate in health and wellness tourism is also influenced by other factors. Tourism is an activity that occurs in a specific place, and in the context of health and wellness tourism, the environment can affect tourists' behavioral intentions. The concept of health and wellness tourism scenarios includes the collection of environmental factors such as health and wellness philosophy, industry, and services that can influence the behavioral intentions of health and wellness tourism participants. Therefore, this paper proposes the following hypothesis:

H4: Among elderly tourists, the health and wellness tourism scenario has a significant positive impact on behavioral intention in decision-making.

Subjective norm refers to a kind of social pressure that individuals feel when engaging in specific behaviors. This pressure mainly comes from organizations or individuals who have a significant impact on the behavioral subject, such as peer pressure from family, colleagues, and friends, as well as superior pressure from leaders, parents, teachers, etc. After processing these pressures, the behavioral subject will form different types of attitudes and thinking results ^[18].

Therefore, this paper proposes the following hypotheses:

H5: Among elderly tourists, subjective norm has a significant positive impact on behavioral attitude in health and wellness tourism decisions.

H6: Among elderly tourists, subjective norm has a significant positive impact on perceived behavioral control in health and wellness tourism decisions.

4. Research design

4.1. Variable measurement

The initial questionnaire for this study was designed based on several established questionnaires. It consists of

three parts: the first part introduces the research, mainly elaborating on the purpose of this survey and the definition of health and wellness tourism; the second part collects basic information about the respondents, including gender, age, education, income, etc.; and the third part focuses on five latent variables related to health and wellness tourism, namely behavioral attitude, subjective norms, perceived behavioral control, health and wellness context, and behavioral intention. The five items for behavioral attitude were referenced from the scale designed by Zhang and others, the five items for subjective norms were referenced from the scale designed by Song and others, the three items for perceived behavioral control were referenced from the scale designed by Zhang and others, the four items for health and wellness context were referenced from the scale designed by Wang and Mo, and the three items for behavioral intention were referenced from the scale designed by Ajzen and others. This study uses a Likert scale to measure observed variables, with a positive assignment method where 1 to 5 correspond to “strongly disagree,” “disagree,” “neutral,” “agree,” and “strongly agree,” respectively. Respondents are required to choose based on their actual situation.

4.2. Data collection

The questionnaire was distributed mainly through sampling surveys, using both online and offline methods to collect data. Offline surveys were conducted in places such as universities and travel agencies for the elderly. Online surveys were created and distributed using questionnaire stars. After screening, 443 valid questionnaires were retained.

5. Empirical analysis

5.1. Reliability and validity testing

This study used SPSS 26.0 to analyze the reliability and validity of the sample (**Table 1**). Firstly, the Cronbach's α coefficient of the overall scale was 0.994, indicating extremely high reliability. Further reliability analysis was conducted separately for the five variables of behavioral attitude, subjective norms, perceived behavioral control, wellness context, and behavioral intention. The results showed that the Cronbach's α coefficients of all scales were higher than the standard of 0.7, indicating good reliability of the measurement items. The factor analysis results showed that the KMO value was 0.911, which was far higher than the suitable standard of 0.5, and the significance level of the Bartlett test of sphericity was 0.000 (less than 0.001). The factor loadings of all items were greater than 0.7, indicating that the data were suitable for factor analysis. Additionally, to ensure the convergent validity of the model, the average variance extracted (AVE) ranged from 0.863 to 0.936, all higher than the standard of 0.5; the composite reliability (CR) ranged from 0.954 to 0.983, all higher than the standard of 0.7. These results indicate that all variables have good convergent validity.

Table 1. Results of confirmatory factor analysis

Factor	Measurement item	Standardized factor loading	Cronbach's α	CR	AVE
Behavioral attitude	1. Participating in wellness tourism is pleasant.	0.926	0.980	0.980	0.909
	2. Participating in wellness tourism is beneficial for physical health.	0.966			
	3. Participating in wellness tourism is wise.	0.930			
	4. Participating in wellness tourism is enjoyable.	0.969			
	5. Participating in wellness tourism is relaxing.	0.976			
Subjective norm	1. People important to me (family/friends/colleagues) support my participation.	0.931	0.978	0.969	0.863
	2. People important to me approve of my participation.	0.946			
	3. People important to me recommend I participate.	0.915			
	4. I am more willing to participate if invited by important people.	0.979			
	5. I am more willing to participate if I see social media posts about it.	0.869			
Perceived behavioral control	1. I have sufficient time to participate.	0.958	0.951	0.954	0.873
	2. I have sufficient financial resources to participate.	0.859			
	3. I am physically fit to participate.	0.982			
Wellness context	1. I value abundant wellness resources at the destination.	0.999	0.987	0.983	0.936
	2. I value diverse wellness product offerings.	0.923			
	3. I value well-developed infrastructure.	0.998			
	4. I value mature service management systems.	0.948			
Behavioral intention	1. I am willing to participate in wellness tourism.	0.987	0.984	0.984	0.953
	2. I am willing to recommend wellness tourism to others.	0.983			
	3. I am willing to share my wellness tourism experiences.	0.958			

5.2. Testing of structural model equations

This study tested the hypothetical model using Amos 29.0 software, calculating the standardized path coefficients between various measurement variables in the structural equation model. The test results are shown in **Table 2**.

Table 2. Hypothesis testing table

Hypothesis	Path	Standardized path coefficient	Significance	Conclusion
H1	Behavioral Attitude → Behavioral Intention	0.571	***	Supported
H2	Subjective Norm → Behavioral Intention	-0.078	0.555	Not supported
H3	Perceived Behavioral Control → Behavioral Intention	0.316	***	Supported
H4	Wellness Context → Behavioral Intention	0.187	***	Supported
H5	Subjective Norm → Behavioral Attitude	1.005	***	Supported
H6	Subjective Norm → Perceived Behavioral Control	0.979	***	Supported

Note: * indicates $P < 0.05$, ** indicates $P < 0.01$, and *** indicates $P < 0.001$

6. Research conclusions and suggestions

6.1. Research conclusions

Both behavioral attitude and perceived behavioral control have significant positive effects on older adults' intentions to participate in healthcare tourism, while subjective norms do not significantly affect these intentions. This is consistent with the findings of some scholars^[19]. When elderly tourists recognize that healthcare tourism can not only promote physical health but also bring pleasure and acquire more knowledge about healthy lifestyles, they form a positive impression of healthcare tourism, thereby enhancing their intention to participate. Additionally, if older adults perceive that they have enough time, money, and physical condition to support participation in tourism, they are more likely to form intentions for healthcare tourism. Conversely, a lack of these resources and abilities may inhibit the formation of such intentions.

The healthcare tourism context has a significant positive effect on behavioral intentions. If the healthcare tourism destination has rich resources, diverse product types, well-developed infrastructure, and mature service management, it can enhance older tourists' intentions to participate in healthcare tourism.

Subjective norms have a significant positive effect on behavioral attitudes and perceived behavioral control, which is supported by numerous scholarly studies. When choosing to experience healthcare tourism, the supportive attitudes of surrounding people (such as family and friends) are important considerations for older adults' decision-making. This social support directly affects older adults' behavioral attitudes and perceived behavioral control towards healthcare tourism.

6.2. Research suggestions

Based on the above research conclusions, suggestions for guiding older adults in Chongqing to participate in healthcare tourism focus on three main areas:

- (1) Improving resource suitability for older adults and enhancing perceived behavioral control: Design products suitable for aging, such as developing short-cycle, time-segmented healthcare tourism packages, to lower the time and physical barriers for older tourists to participate in healthcare tourism. Travel agencies in scenic areas should increase emergency response systems, set up emergency stations for the elderly, and provide health management services to enhance safety perceptions.
- (2) Deconstructing traditional concepts of elderly care and building a positive social identity: Increase promotion of healthcare tourism to make more older adults aware of its benefits. For example, create role model communications by inviting "elderly travel enthusiasts" to shoot documentary shorts showcasing the tangible improvements in quality of life brought by healthcare tourism, thereby weakening the "luxury consumption" label and increasing participation intentions. Additionally, incentives for family members can be increased by offering "family group discounts" to encourage children to book travel products for their parents, turning social pressure into supportive motivation.
- (3) Deepening the development of the healthcare tourism context and activating core driving forces: Relevant government departments should integrate resources, establish a regional database of healthcare tourism resources, and develop integrated "medical, health, education, and tourism" products in collaboration with traditional Chinese medicine clinics and forest therapy bases. Upgrade smart services tailored for older adults, utilizing apps with features such as VR-based previews, one-click emergency calls, and health data tracking to improve facilities and services in scenic areas catering to older tourists.

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Research on the Evaluation of Ecosystem Cultural Service Quality in Qu County Congren Valley Forest Park from the Perspective of Tourist Perception

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Abstract: This study focuses on the ecosystem cultural service quality of Qu County Congren Valley Forest Park from the perspective of tourist perception. Using the Importance-Performance Analysis (IPA) questionnaire survey method and SPSS data analysis techniques, we systematically evaluate tourists' cognitive differences and improvement paths regarding the cultural service value of the scenic area. Based on the nonmaterial characteristics of ecosystem cultural services, combined with the unique Congren culture and natural landscape resources of Congren Valley, we designed a five-dimensional scale including natural landscape and ecological protection, cultural display and interpretation services, cultural activity participation and experience, infrastructure and supporting services, and safety management. This covers tourists' evaluations of the importance of elements such as cultural displays, interpretation systems, interactive activities, and facility support, as well as their actual satisfaction feedback. Through descriptive statistical analysis, reliability and validity testing, factor analysis, and IPA matrix analysis, we reveal the core contradictions and improvement directions perceived by tourists. The study found that the convenience of facilities such as signage, rest areas, toilets, roads, and the cleanliness of the scenic area are key areas for improvement. Additionally, different age groups perceive differences in the cultural service quality of the Congren Valley Forest Park ecosystem. The study concludes that tourists have a high level of concern for the convenience of scenic infrastructure and sanitary environment. Improving these facilities can help increase tourist satisfaction and the overall service quality of the scenic area. Simultaneously, meeting the needs of segmented markets and constructing a three-in-one service system of "deep excavation of cultural symbols–digital storytelling–immersive scenes" is recommended.

Keywords: Tourist perception; Ecosystem cultural services; Congren Valley Forest Park

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1. Introduction

With the rise of eco-tourism, tourists' demands for travel destinations have gradually shifted from mere appreciation of natural landscapes to the ecosystem and its cultural connotations. Ecosystem services refer to

all environmental conditions and utilities formed, maintained, and realized by ecosystems and their constituent species for human survival ^[1]. The Millennium Ecosystem Assessment (MA), a global assessment project led by the United Nations Environment Programme (UNEP) in 2005, defines ecosystem cultural services as “the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, entertainment, and aesthetic experiences.” These are further divided into six categories: cultural diversity and identity, cultural landscapes and heritage values, spiritual services, inspiration, recreation and entertainment, and aesthetics ^[2]. In short, these refer to the nonmaterial benefits provided by ecosystems, which are often related to human spirituality, culture, and social well-being. As an essential component of eco-tourism, ecosystem cultural services not only carry the protection and inheritance of natural ecology but also integrate the display and dissemination of regional culture.

Forest ecosystems, as the dominant terrestrial ecosystems, boast rich biodiversity. They serve as a crucial medium for the public to access ecosystem cultural services and enrich their spiritual lives. The function of forest ecosystems in improving people’s quality of life has been widely recognized by various sectors of society. The State Forestry Administration categorizes ecosystem cultural services into aesthetic value, spiritual value, social interaction, cultural heritage, experience and education, leisure and tourism ^[3]. As the largest terrestrial ecosystem ^[4], forest ecosystems not only carry the important task of protecting natural resources and biodiversity but also shoulder the significant mission of inheriting and promoting local culture. By analyzing the relationship between resource use and ecosystem services, scientific evidence is provided for the sustainable management of forest parks, furthering the understanding of the interaction between human activities and the natural environment ^[5]. With the deepening of ecological civilization construction, people’s demand for ecological culture is rapidly increasing, including learning about forest culture, engaging in forest recreation, and conducting nature education.

From the perspective of tourist perception, evaluating the quality of ecosystem cultural services in Congren Valley Forest Park using the Importance-Performance Analysis (IPA) method not only helps to reveal the core contradictions of tourist perception but also provides empirical evidence for optimizing the cultural services of the scenic area. This promotes the transformation of ecotourism from a resource-dependent to a culturally empowered model. This study aims to obtain data on tourists’ perceptions of the cultural service quality of the ecosystem in Congren Valley Forest Park through a questionnaire survey. The IPA method is employed to analyze tourists’ evaluations of the importance of and satisfaction with natural landscapes and ecological protection, cultural display and interpretation services, participation in cultural activities, infrastructure and supporting services, and safety management. This reveals the core contradictions and directions for improvement in tourist perception.

2. Literature review

2.1. Tourist perception and ecosystem cultural services

Tourist perception refers to tourists’ reactions and evaluations to various stimuli in the tourist destination, which affect their satisfaction and loyalty ^[6]. Some scholars believe that tourist perception is a comprehensive reflection of tourists’ feelings about the culture, characteristics, and style of the tourism environment, as well as their cognition of the tourist destination. It represents subjective perception and evaluation of objective things ^[7]. The Millennium Ecosystem Assessment (MA) defines ecosystem cultural services as “the non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, entertainment, and aesthetic experiences” ^[2].

Another scholar defines it as “the products, services, and benefits that human behavioral activities obtain from natural ecosystems, which can effectively meet spiritual and cultural needs”^[8]. There is a complex coupling relationship between ecosystem service value and human well-being, especially the important role of ecosystem cultural services (such as tourism and leisure functions) in improving human well-being^[9]. As an important component of ecotourism, the quality of ecosystem cultural services directly affects tourists’ perception and satisfaction. Scholars at home and abroad have conducted a lot of research in the field of tourist perception and ecosystem cultural services, finding significant differences in tourists’ perception and satisfaction with elements such as cultural display, interpretation systems, and interactive activities^[10,11].

2.2. Application of the IPA method in the tourism field

The IPA method, also known as Importance and Satisfaction Analysis, was proposed by Martilla and James in 1977 and initially applied to analyze the attributes of automotive products^[12]. Through questionnaire surveys, this method obtains tourists’ evaluations of the importance and satisfaction feedback on various elements of a tourist destination, constructing a two-dimensional four-quadrant chart that visually displays the core contradictions and improvement directions perceived by tourists. Due to its intuitive and easy-to-understand characteristics, this method has been widely used in the tourism field. Utilizing data from online reviews and field surveys, Bai and Chen employed the IPA analysis method to quantitatively display public “importance-satisfaction” differences through a four-quadrant chart, thereby promoting sustainable management of city parks^[13].

2.3. Current research status of the Congren Valley Forest Park

Located as a transport hub between Chongqing and Chengdu, Qu County boasts a rich Cong culture and Bashu culture. During the May Day holiday in 2025, Sichuan Dazhou Qu County welcomed approximately 168,700 tourists, with the Congren Valley Forest Park, as a significant tourist attraction in Qu County, accounting for a considerable proportion. This scenic area has a vast tourist market.

The Congren Valley Forest Park, integrating natural landscapes and Cong culture, directly impacts tourist satisfaction and loyalty through the quality of its ecosystem cultural services. This scenic spot boasts abundant tourism resources, including a wide range of natural and cultural landscapes with excellent resource combination and endowment^[14], earning it the nickname “Little Jiuzhaigou” due to its rich natural and cultural landscapes. However, current research on the cultural service quality of the park’s ecosystem is relatively scarce, lacking a systematic evaluation from the perspective of tourist perception. Therefore, this study employs the IPA method to evaluate the cultural service quality of the Congren Valley Forest Park’s ecosystem, carrying significant theoretical and practical implications.

3. Research design and data collection

3.1. Research design

From the perspective of tourist perception, this study focuses on the cultural service quality of the Congren Valley Forest Park’s ecosystem. Utilizing the IPA method combined with SPSS data analysis techniques, it systematically evaluates the cultural service quality of the ecosystem perceived by tourists. The research covers importance evaluations and satisfaction feedback on elements such as natural landscapes and ecological protection, cultural display and interpretation services, participation in cultural activities, infrastructure and supporting services, and safety management.

The questionnaire design is based on literature reviews and field visits, including two parts: basic tourist information and tourists' perceptual evaluation of the cultural service quality of the Congren Valley Forest Park's ecosystem. The perceptual evaluation section adopts a Likert 5-point scale, evaluating relevant elements from two dimensions: importance (1 indicates "extremely unimportant," and 5 indicates "very important") and satisfaction (1 represents "extremely dissatisfied," and 5 represents "very satisfied").

3.2. Data collection

In this study, a stratified sampling method was employed to distribute questionnaires at the entrance, visitor center, and major attractions of the Congren Valley Forest Park. A total of 100 questionnaires were distributed, and 63 valid questionnaires were collected. The sample covered tourists of different ages, genders, education levels, and travel frequencies, ensuring the representativeness and reliability of the data.

4. Data analysis and results

4.1. Descriptive statistical analysis

Descriptive statistical analysis was conducted on the questionnaire data using SPSS 26.0. The results indicated significant differences in tourists' overall perception of the cultural service quality of the ecosystem in Congren Valley Forest Park. Specifically, 87.3% of tourists visited the park based on recommendations from friends, while 28.57% learned about the park through online searches. Additionally, 60.32% of tourists expressed a need for more diverse cultural activities (such as nighttime performances and themed festivals), and 50.79% believed that the park should improve the convenience of its infrastructure (such as adding charging stations and accessibility features) and enhance its digital development.

As shown in **Table 1**, from the overall dimension analysis, the importance score for the cultural activity participation experience element was the highest (mean of 4.38), but the satisfaction score was relatively low (mean of 4.3). The cultural display and interpretation service element also received a high importance score (mean of 4.46), but the satisfaction score was lower (mean of 4.4).

Table 1. Analysis of primary indicator dimensions

Dimension	Satisfaction (P)		Importance (I)		Gap (P-I)	<i>t</i>	<i>P</i>
	Mean	Rank	Mean	Rank			
Natural landscape & ecological conservation	4.41	1	4.52	1	-0.11	-1.507	0.137
Cultural display & interpretation services	4.40	2	4.46	3	-0.05	-0.980	0.331
Cultural activity participation experience	4.30	4	4.38	5	-0.08	-2.122	0.038
Infrastructure & supporting services	4.21	5	4.41	4	-0.21	-3.217	0.002
Safety management	4.37	3	4.48	2	-0.10	-2.140	0.036

As shown in **Table 2**, the clarity and interest of display boards and signs related to Cong people's culture, the professionalism and interactivity of tour guides/commentators on Cong people's culture, the professionalism of folklore performances (such as dance and music), the sense of participation and educational significance of handicraft experience activities (such as weaving and pottery), and the richness and attractiveness of cultural activities (such as exhibitions and performances) all rank higher in importance than satisfaction.

Table 2. Secondary index analysis

Factor	Satisfaction (P)		Importance (I)		Gap (P-I)	t	P
	Mean	Rank	Mean	Rank			
1. Natural environment quality (vegetation coverage, air quality)	4.48	1	4.52	1	-0.048	-0.652	0.517
2. Visibility of conservation measures (waste sorting, wildlife protection signage)	4.33	6	4.51	2	-0.175	-2.024	0.047
3. Clarity & engagement of Cong culture displays (information boards, signs)	4.44	2	4.48	3	-0.032	-0.629	0.531
4. Cultural heritage preservation	4.4	4	4.48	3	-0.079	-1.523	0.133
5. Expertise & interaction of guides (regarding Cong culture)	4.37	5	4.41	9	-0.048	-0.504	0.616
6. Professionalism of folk performances (dance, music)	4.3	9	4.4	11	-0.095	-2.555	0.013
7. Engagement & educational value of handicraft activities (weaving, pottery)	4.27	10	4.37	13	-0.095	-1.624	0.109
8. Diversity & appeal of cultural events (exhibitions, performances)	4.32	8	4.38	12	-0.063	-1.158	0.251
9. Convenience of facilities (signage, rest areas, restrooms, pathways)	4.27	10	4.46	7	-0.19	-2.555	0.013
10. Value & cultural features of F&B/accommodation	4.22	12	4.32	14	-0.095	-1.426	0.159
11. Sanitation conditions	4.16	14	4.46	7	-0.302	-3.609	0.001
12. Clarity of signage systems	4.17	13	4.41	9	-0.238	-2.951	0.004
13. Safety measure implementation (fire prevention, rescue systems)	4.41	3	4.48	3	-0.063	-1.07	0.289
14. Staff responsiveness to safety concerns	4.33	6	4.48	3	-0.143	-2.609	0.011

4.2. Reliability and validity testing

Cronbach's α coefficient was used to test the reliability of the questionnaire. As shown in **Tables 3** and **4**, the overall index and the α coefficients of each dimension are all greater than 0.92, indicating high internal consistency of the questionnaire. The validity of the questionnaire was tested using the KMO value and Bartlett's test of sphericity. As shown in **Table 5**, the KMO value is 0.77, and the significance level of Bartlett's test of sphericity is less than 0.001, indicating high structural validity of the questionnaire.

Table 3. Overall indicators of items

Scale/dimension	Cronbach's alpha	Number of items
Overall satisfaction-importance scale	0.986	28
Satisfaction subscale	0.980	14
Importance subscale	0.973	14

Table 4. Dimension indicators

Dimension	Satisfaction		Importance	
	Cronbach's α	Items	Cronbach's α	Items
Natural landscape & ecological conservation	0.923	2	0.930	2
Cultural display & interpretation services	0.942	3	0.945	3
Cultural activity participation experience	0.960	3	0.945	3
Infrastructure & supporting services	0.961	4	0.957	4
Safety management	0.927	2	0.947	2

Table 5. Validity analysis

KMO and Bartlett's test			
Kaiser-Meyer-Olkin measure of sampling adequacy			0.77
Bartlett's test of sphericity	Approx. chi-square		3445.433
	Degrees of freedom (<i>df</i>)		378
	Significance (<i>P</i>)		< 0.001

4.3. Factor analysis

Factor analysis was used to reduce the dimensionality of the questionnaire data, extracting five common factors: natural landscape and ecological protection, cultural display and interpretation services, cultural activity participation and experience, infrastructure and supporting services, and safety management. The cumulative variance contribution rate reached 78.6%. The factor loads of the internal items of each common factor are all greater than 0.5, indicating high content validity of the questionnaire.

4.4. IPA matrix analysis

IPA matrix analysis was used to analyze tourists' importance evaluation and satisfaction feedback on various elements of the cultural service quality of the Congren Valley Forest Park ecosystem. As shown in **Figure 1**, a two-dimensional four-quadrant graph was constructed using the mean importance (4.45) and mean satisfaction (4.34) as segmentation points. The results show that natural landscape and ecological protection, cultural display and interpretation services, and safety management are located in the first quadrant (continue to maintain area). Cultural activity participation and experience, as well as infrastructure and supporting services, are located in the third quadrant (low priority area), indicating that tourists' demand for participation in cultural activities and related infrastructure and supporting services is relatively insufficient, and the priority is low, which may reflect that resource allocation and management focus are biased towards other aspects.

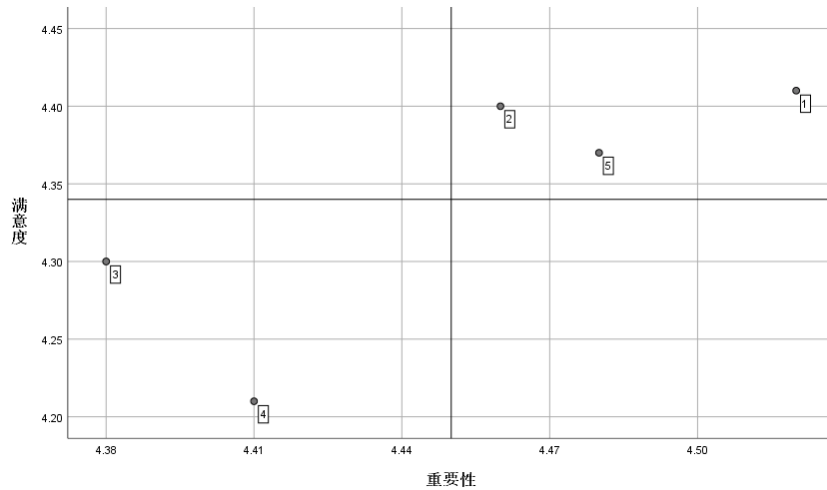


Figure 1. Scatter plot of first-level indicators

As shown in **Figure 2**, the analysis reveals that various aspects such as the quality of the natural environment (A1) including park vegetation coverage and air quality, the visibility of ecological protection measures (A2) like waste sorting and wildlife protection prompts, the clarity and interest of exhibition boards and signs related to the Cong people's culture (B1), the preservation of cultural heritage (B2), the completeness of safety measures such as fire protection and rescue (E1), and the staff's attention and response speed to tourist safety (E2) are all distributed in the “continue to maintain” zone. This suggests that the scenic area has managed these aspects well and only needs to continue its current efforts. The professionalism and interactivity of guides/interpreters regarding the Cong people's culture (B3) are in the “oversupplied” zone. Aspects like the professionalism of folk performances (such as dance and music) (C1), the sense of participation and educational value of handicraft experience activities (such as weaving and pottery) (C2), the richness and attractiveness of cultural activities (such as exhibitions and performances) (C3), the cost-effectiveness and cultural characteristics of commercial services such as dining and accommodation (D2), and the clarity of the signage system (D4) are in the “lower priority” zone. The convenience of facilities such as signboards, rest areas, toilets, and roads (D1), as well as the sanitary conditions of the scenic area (D3), are in the “key areas for improvement” zone.

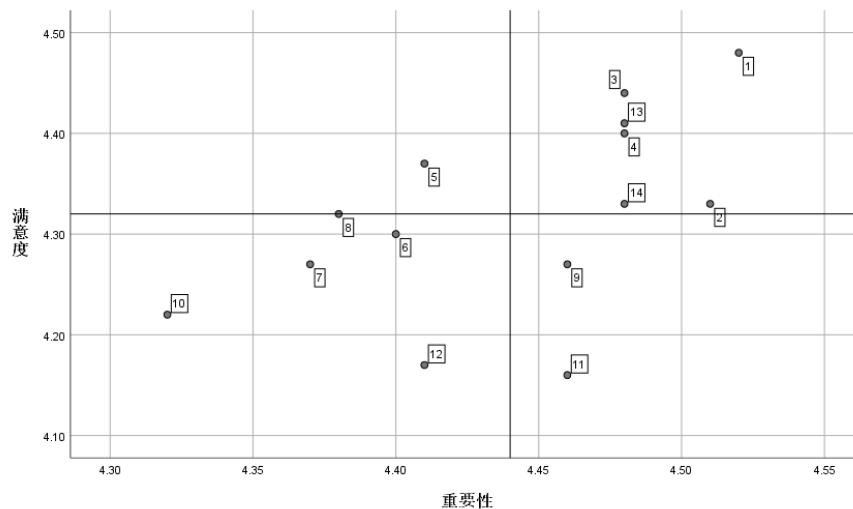


Figure 2. Scatter plot of second-level indicators

4.5. Difference analysis

Using the *t*-test to analyze the perceived differences in the cultural service quality of the Congren Valley Forest Park's ecosystem among different age groups, the results indicate that elderly tourists (>45 years old) have higher demands for the convenience of facilities such as signboards, rest areas, toilets, and roads than young and middle-aged tourists (18–44 years old). Young and middle-aged tourists have significantly higher demands for the professionalism and interactivity of guides/interpreters regarding the Cong people's culture than elderly tourists. The average willingness to use digital interactive devices reaches 4.21, while elderly tourists prefer traditional interpretation methods, with an average of only 3.78.

5. Discussion and suggestions

5.1. Discussion

This study finds significant differences in tourists' perceptions of the cultural service quality of the Congren Valley Forest Park's ecosystem. The convenience of facilities such as signboards, rest areas, toilets, roads, and the sanitary conditions of the scenic area have become key areas for improvement. This suggests that tourists desire a safe, convenient, and comfortable touring environment to enhance their overall experience and satisfaction. Aspects such as the professionalism of folk performances, the sense of participation and educational value of handicraft experience activities, the richness and attractiveness of cultural activities, the cost-effectiveness and cultural characteristics of commercial services, and the clarity of the signage system are in the lower priority zone. Together, these reflect the diverse needs of tourists for cultural experiences and service quality in the scenic area. These issues not only affect the service quality of the scenic area but also influence whether tourists are willing to visit again or recommend it to others. Furthermore, significant differences in the needs of different age groups for the convenience of infrastructure, sanitary environment, and cultural immersion experiences suggest that the scenic area should implement differentiated service strategies.

5.2. Suggestions

5.2.1. Facility convenience improvement project

(1) Smart navigation system upgrade

Plan dynamic pathways and deploy an IoT sensor network to monitor real-time crowd density in various areas. Push optimal routes through electronic signboards and mobile apps, and install interactive ground screens at intersections that trigger voice navigation when stepped on. Use 3D laser scanning technology for terrain modeling and plan barrier-free passageways across the entire area. Set up Braille guidance screens and vibration sensors in restrooms and resting areas, and develop a dedicated navigation mini-program for disabled individuals. Design AR (Augmented Reality) markers for visitors to access 3D spatial navigation by scanning with their phones. Install solar-powered illuminated signboards at key nodes that automatically switch to strobe warning mode at night.

(2) Modular service facility deployment

Build smart resting areas with movable container-style stations equipped with photovoltaic roofing, wireless charging tables, and air quality monitors. Also include smart seats that automatically adjust their tilt angle based on pressure sensors.

Promote microorganism-degrading toilets equipped with a self-processing system for waste.

Install smart induction faucets, negative pressure deodorization devices, and infrared occupancy display systems for toilet stalls.

Set up AED emergency stations and smart first aid kits every 500 meters, allowing visitors to scan and access medical supplies.

5.2.2. Sanitation management system

(1) Smart sanitation management system

Deploy smart trash cans that can automatically classify waste through AI image recognition and send cleaning instructions when they are full. Develop a garbage classification integral game, where tourists can redeem scenic area services by correctly disposing of waste. Establish a monitoring network for PM2.5, temperature and humidity, and odor, with data projected onto an electronic screen in real time. When the air quality exceeds the standard, the fresh air system and the atomization deodorization device will automatically start. Additionally, a micro-sewage treatment station can be built, adopting membrane bioreactor technology to achieve water reuse. Set up ecological floating islands in the landscape water bodies to purify water quality through plants.

(2) Dynamic cleaning mechanism

Implement grid-based cleaning management by dividing the scenic area into 200 m²/unit cleaning grids. Cleaners equipped with positioning bracelets can upload their work trajectories in real time.

Establish a cleaning quality scoring system that allows visitors to rate the area's hygiene by scanning a code.

Deploy automatic patrolling robots that operate at night using a laser radar obstacle avoidance system, and utilize drones for high-altitude cleaning in open areas such as squares.

Develop a pollution source tracking system that uses odor sensors and cameras to locate behaviors like spitting and littering, and automatically generates warning messages pushed to visitors' phones.

5.2.3. Constructing a trinity service system of “deep exploration of cultural symbols–digital storytelling–immersive scenes”

(1) Digital translation of cultural symbols

Establish a cultural gene bank of the Cong people, use 3D modeling technology to conduct high-precision digital collection of cultural relics such as petroglyphs and bronze ware, and develop an AR real-scene navigation system that allows visitors to trigger historical scene reproduction by scanning with their mobile phones. Set up VR immersion pods at key nodes to restore scenes such as Cong people's sacrifices and wars, and achieve multi-sensory interaction with haptic devices. Create a thematic route called the “Time and Space Corridor,” set up interactive light and shadow installations along the way, and project the mythology of the Cong people onto natural landscapes through projection technology. Develop a story-based puzzle-solving game where visitors need to unlock hidden attractions by cracking cultural symbol codes, creating an exploratory touring experience. Deploy AI cultural assistants to answer visitor questions through voice interaction. Set up interactive digital screens in resting areas so that visitors can choose their own cultural storylines for deep learning. Establish a visitor experience database to analyze behavioral data in real time and optimize service routes.

(2) Implementing layered design for all-age services

Empower young visitor groups with technology, develop MR mixed reality script games that integrate Cong people's history into the reasoning plot. Set up a haptic competition area to restore ancient ceremonies such as archery rites through motion capture technology. Launch a digital collection check-in system where visitors can collect virtual cultural fragments to redeem unique cultural creations.

Provide warm services for silver-haired visitor groups and form a team of elderly cultural mentors to provide

dialect interpretation services. Offer aging-friendly experience courses such as morning Tai Chi and traditional tea ceremonies. Design a barrier-free digital navigation system that allows access to information through voice commands. Establish a cultural salon for the elderly, and regularly hold intangible cultural heritage handicraft workshops.

Promote interactive integration for family visitor groups, create a parent-child cultural laboratory with projects such as building ancient architecture with blocks and oracle bone script graffiti. Develop AR parent-child treasure hunt games where parents and children collaborate to complete cultural tasks. Set up a family shared creation area to provide a digital shadow puppetry creation platform.

6. Conclusion and outlook

From the perspective of tourist perception, this study systematically evaluated the cultural service quality of the ecosystem in Qu County's Congren Valley Forest Park using the IPA method and SPSS data analysis techniques. The study found that the display depth of Cong people's cultural symbols and the participation in natural education activities have become the focus of improvement, and there are significant differences in the demand for cultural immersion experiences among different educational groups. The research conclusions provide empirical evidence for optimizing the cultural services of Congren Valley Forest Park and have practical guiding significance for promoting the transformation of eco-tourism from resource-dependent to culturally empowered.

Future research can further expand the perspective of tourist perception, combining multi-source data (such as social media data, tourist comment data) to dynamically monitor and evaluate the cultural service quality of the ecosystem in Congren Valley Forest Park. At the same time, the relationship between cultural service elements, tourist loyalty, and word-of-mouth communication can be explored to provide more comprehensive theoretical support and practical guidance for the continuous optimization of cultural services in scenic areas.

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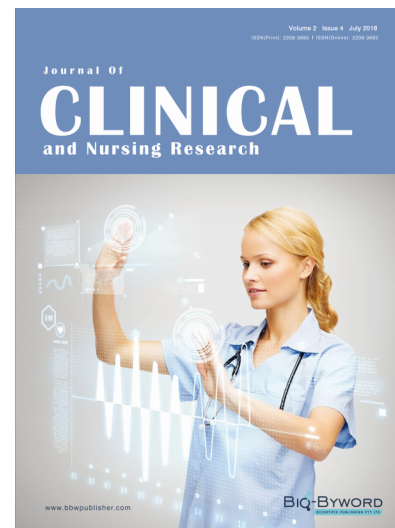
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