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# On C-E Subtitle Translation of New Gods: Nezha Reborn under Skopos Theory

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**Abstract:** Translation plays a vital role in fostering communication and building a bridge for people to get to know a different culture. With the boom of the film industry, films have gradually become a pivotal vehicle in cross-cultural communication. As Chinese films inevitably carry distinctive cultural elements, subtitle quality greatly impacts how well international audiences understand both the narrative and embedded cultural references. This thesis examines the Chinese-to-English subtitles of a Chinese animated film, *New Gods: Nezha Reborn*, analyzing translation strategies and methods through the lens of Skopos Theory. The study reveals that the translation adheres to the Skopos rule through the use of free translation; follows the coherence rule by employing the domestication translation strategy; and respects the fidelity rule by applying the foreignization translation strategy. Under this view, it is effortless for the foreign audience to grasp the film's main plot and the high-context Chinese culture. This study can provide guidance for practical subtitle translation and improve effective cross-cultural interaction.

**Keywords:** Skopos Theory; Subtitle translation; Chinese animation film; Translation strategy

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## 1. Introduction

In today's rapidly developing society, material comfort has largely been achieved, and media such as television dramas and films have become major sources of entertainment. The President of the CPC has repeatedly emphasized the need to strengthen China's international communication capacity, to tell China's stories well, and to present a true, multi-dimensional, and comprehensive image of the country<sup>[1]</sup>. A core requirement for telling China's story effectively is the ability to construct engaging and meaningful narratives.

China, with its profound cultural heritage, has never been short of compelling stories. These rich narrative resources continue to provide strong support for the growth of the Chinese film industry. In recent years, especially between 2020 and 2024, a wave of Chinese films with distinctively Chinese elements rooted in local culture—including the science fiction epic *The Wandering Earth*, the animated feature *New Gods: Nezha Reborn*, the

fantasy blockbuster *Creation of the Gods I: Kingdom of Storms*, and the comedy *Hi, Mom*—have showed up in the international market and received widespread acclaim. This trend illustrates that the film industry is playing an increasingly vital role in sharing Chinese stories with international audiences.

Among these works, many filmmakers, drawing deeply from China's cultural traditions, create works rich in Chinese aesthetics and values. A notable example is *New Gods: Nezha Reborn*, an animated feature by Light Chaser Animation Studios. The film draws inspiration from the 1979 classic *Nezha Conquers the Dragon King* by the Shanghai Animation Film Studio, and is based on the Ming dynasty mythological novel *Investiture of the Gods*. It was featured in the “Work in Progress” section of the 2020 Annecy International Animation Film Festival in France, and also became the first Chinese animated feature acquired by streaming giant Netflix. By reimagining the legendary figure of Nezha in a futuristic setting—where his reincarnation, Li Yunxiang, confronts the East Sea Dragon Clan after 3,000 years—the film achieves a striking blend of tradition and innovation. This setting retains the essence of Chinese mythology while embracing a contemporary aesthetic, resonating strongly with audiences in countries such as Australia, New Zealand, and Singapore <sup>[2]</sup>.

As Chinese films continue to reach broader audiences overseas, the importance of subtitle translation becomes increasingly evident. While global recognition of Chinese films is growing, academic attention to subtitle translation—especially from Chinese to English—remains relatively limited. According to data from the China National Knowledge Infrastructure (CNKI), between 2019 and 2024, a total of 47,425 articles on translation studies were published in China, of which only 871 focused specifically on subtitle translation <sup>[3]</sup>. Most of this existing research centers on translation techniques and practices, particularly in the context of film title translation. The majority of these studies focus on the Chinese subtitles of foreign films, while relatively few examine English subtitle translation of Chinese films, and even fewer target Chinese animated films. Being a representative work that integrates traditional culture with modern innovation, *New Gods: Nezha Reborn* offers a valuable case study that offers useful insights for the broader study of subtitle translation in the context of Chinese cultural exchanges. By analyzing how this film handles cross-cultural communication through subtitles, researchers can gain a better understanding of the challenges and strategies involved in translating culturally embedded content.

Ultimately, the global spread of Chinese culture is a cross-linguistic and cross-cultural endeavor in which translation plays a central role <sup>[4]</sup>. For Chinese culture to step beyond national borders and find resonance in other societies, effective translation is essential. High-quality subtitle translation not only improves the audience's comprehension of the plot and dialogue but also bridges cultural gaps and enhances mutual understanding. In this sense, subtitle translation is not merely a technical task—it is a crucial medium through which China seeks to tell its stories well on the world stage.

## 2. Skopos Theory and its three rules

Skopos Theory, introduced in the 1970s by German scholar Katharina Reiss, later developed by Hans Vermeer, lies at the center of functionalist approaches to translation. The term “skopos”, derived from Greek, means “purpose.” According to Vermeer, more specifically, it refers to the “purpose of translation” <sup>[5]</sup>. The core aim of Skopos Theory, as Venuti summarizes, is to clarify the intention that drives the translation <sup>[6]</sup>. Once the intended purpose is identified, translators can then adopt strategies that best serve this goal. However, this does not imply that translators enjoy unrestricted freedom. Their choices must still align with three fundamental principles: the skopos rule, the coherence rule, and the fidelity rule.

The skopos rule should, according to Vermeer, “translate/interpret/speak/write in a way that enables your



text/translation to function in the situation it is used and with the people who want to use it and precisely in the way they want it to function”<sup>[7]</sup>. Therefore, translators are bound to have a clear mind of the translation’s skopos. As Vermeer further notes, “what the skopos states is that one must translate, consciously and consistently, in accordance with some principle respecting the target text. The theory does not state what the principle is: this must be decided separately in each specific case”<sup>[7]</sup>. In other words, identifying and adhering to the skopos rule is key to ensuring its effectiveness and audience reception.

The second rule, known as the coherence rule or intra-textual coherence, requires that “a translation should be acceptable in a sense that it is coherent with the receivers’ situation”<sup>[7]</sup>. This means that translators must account for the linguistic, social, and cultural background of the target audience, which may differ significantly from that of the source text. Only by doing so can they produce a text that is not only readable and accessible, but also functionally appropriate within its new context.

The third crucial rule is the fidelity rule, also known as inter-textual coherence. This rule requires that “the target text should bear some kind of relationship with the corresponding source text”<sup>[7]</sup>. In other words, although the focus of functionalist translation is on the target text and its intended effect, there should still be a recognizable connection to the source text.

Although these three rules guide the translation process, they do not carry equal weight. As Nord points out, “if the translation skopos requires a change of function, the standard will no longer be inter-textual coherence with the source text. If the translation skopos demands intratextual incoherence (as in the theatre of the absurd), the standard of intratextual coherence is no longer valid”<sup>[7]</sup>. In essence, both the coherence rule and the fidelity rule are subordinate to the skopos rule. The fidelity rule, in turn, ranks below the coherence rule. This hierarchy implies that as long as the translation fulfills its intended skopos, strict loyalty to or equivalence with the source text may not be necessarily required.

This flexible and purpose-oriented approach is particularly relevant to subtitle translation, which differs significantly from literary translation. Film language is inherently auditory, multimodal, instantaneous, accessible, and annotation-free<sup>[8]</sup>. As a result, subtitle translation is constrained by factors such as time, space, culture, and discourse. In addition to adhering to the coherence rule and the fidelity rule, subtitle translation must also align with the visual content of the film. Its ultimate aim is to assist viewers in better appreciating foreign films, understanding plot and dialogue, and gaining insight into other cultures.

### **3. Analysis from the view of Skopos Theory**

Subtitle translation inevitably involves the interaction between two languages and their underlying cultures. To ensure that the target audience can comprehend the plot and dialogue while also sparking interest in the source culture, subtitle translators frequently employ a mix of free translation and the translation strategies of domestication and foreignization. These methods aim to produce subtitles that are both faithful to the original and linguistically coherent. As the second animated feature by Light Chaser Animation, *New Gods: Nezha Reborn* relies heavily on subtitle translation to facilitate its global reach. The following section will present how the subtitle translation of this film meets Skopos Theory’s three rules.

#### **3.1. Free translation method to achieve the skopos rule**

Translation is a goal-oriented activity. As previously noted, the skopos rule takes precedence over the other two rules, implying that violations of the coherence rule and the fidelity rule are acceptable, provided the translation



fulfills the requirements of the skopos rule. In the context of a film—particularly a commercial one—the primary skopos is to ensure that the audience comprehends and enjoys the storyline, which promises a box-office success. To accomplish this skopos, the translator has employed the translation method of free translation and the translation technique of generalization.

The free translation method translates the meaning of the source text instead of its literal meaning. The following two examples well illustrate this approach.

**Example 1:**

Source Text: 德老板：这条鱼我看着眼熟。

孙悟空：熟了，其他地方也熟了。尝尝？

Target Text: De: There's something fishy here.

Sun Wukong: It's fishy all over. Try some?

This dialogue employs the free translation method rather than literal translation. A literal version, such as “This fish is familiar to me” and “The whole fish is already done. Try some?” would be disjointed and confusing for the target audience, failing to capture the underlying joke and conversational logic.

In fact, the line involves a pun that is essential to the humor of the scene. The English phrase “fishy” is cleverly chosen here for its polysemy. As the Cambridge English Dictionary explains, “fishy” has two primary meanings: (1) seeming dishonest or false; and (2) smelling or tasting like fish<sup>[9]</sup>. This dual meaning aligns well with the original Chinese pun, where “熟” can mean both “familiar” and “cooked.” In the scene, De—who is the East Sea Dragon King—inspects the roasted “fish”, which is actually one of his subordinates. Sun Wukong uses this pun to dodge suspicion. By leveraging “fishy” in its dual senses, the translation maintains the pun and preserves the humor that arises from wordplay. This example demonstrates how a single word can fulfill the translator's skopos—to make the audience understand and enjoy culturally embedded humor.

**Example 2:**

Source Text: 我跟他都是女娲补天留下的一块石头。

Target Text: We're stones leftover when the First Goddess patched the sky.

The translation employs a free translation method, aligning with the skopos rule by prioritizing the target audience's comprehension over strict fidelity to the source text. The original line, “我跟他都是女娲补天留下的一块石头”, references the Chinese myth of “女娲补天 (literal translation: Nvwa Mends the Heavens)”. While this story is readily well known by Chinese audiences, it may be obscure to Anglophone viewers unfamiliar with traditional Chinese mythology. Given the constraints of subtitle translation—particularly its limitations in space and time—adding explanatory footnotes is not an option. Therefore, the translator opts for “the First Goddess”, a culturally adapted expression that signals divinity while retaining the referential function of the original. The capitalized letters further reinforce that this is a proper noun. This translation ensures the audience can follow the plot and access the cultural context without confusion.

### **3.2. Domestication translation strategy to achieve the coherence rule**

According to the coherence rule, a translation should be acceptable in the sense that it is coherent with the receiver's situation<sup>[7]</sup>. Guided by this rule, translators need to account for the difference in linguistic and cultural

background between the source text and the target text. Only by considering it can the target audience accept and understand the translation. As a result, the domestication translation strategy is frequently employed. This approach involves turning an exotic source language into a much more familiar one with the target audience. The following two examples illustrate this strategy in practice.

**Example 3:**

Source Text: 德老板：你没看出来那是哪吒吗？

孙悟空：用火的又不只有他。比如，葫芦老四也用火对不对？

Target Text: De: You couldn't tell it was Nezha?

Sun Wukong: Others use fire too, you know. Take the Fire Imp, right?

This subtitle employs the domestication translation strategy, directly illustrating Skopos Theory's coherence rule. “葫芦娃”，as known as “Calabash Brothers”，is one of the most famous Chinese animations, presenting a story of how seven Calabash Brothers with different magical powers defeated two demons to save their grandfather. The fourth one, as mentioned by Sun Wukong, holds the power to create and control fire. However, this character is likely unknown to English-speaking viewers or those unfamiliar with Chinese animation. To solve this, the translator substitutes the original cultural reference with the Fire Imp from the widely played game Terraria—a well-known fire-themed character—to convey the same conceptual meaning in a more accessible way. The Fire Imp is a character found in Terraria's Underworld, recognizable for its fiery attacks and teleportation abilities<sup>[10]</sup>. Since both figures are associated with fire, the substitution maintains thematic equivalence. Using the domestication translation strategy not only enhances comprehension for the target audience but also preserves the humor and relational dynamics of the original dialogue. Consequently, it increases viewer engagement and helps the film's international impact—demonstrating how effective translation can adapt cultural elements without sacrificing coherence or fidelity.

**Example 4:**

Source Text: 丁三配二四。至尊宝啊笨。

Target Text: Dead Man's Hand. Joker. Dumbo.

This example employs the domestication translation strategy aligned with Skopos Theory's coherence rule, translating obscure Chinese cultural references into expressions that hold meaning in the target culture. In the original, Sun Wukong mentions “Pai Gow”，a traditional Chinese gambling game. The phrase he mentioned, “丁三配二四 (Ding San with Er Si)” represents a powerful hand combination, also known as “至尊宝” (Supreme Gee Joon), suggesting a high chance of winning<sup>[11]</sup>. However, this traditional Chinese domino game is unlikely to be recognized by Western audiences. To bridge this cultural gap, the translator thus replaces the reference with two storied poker hands, Dead Man's Hand and Joker.

The Dead Man's Hand refers to a two-pair consisting of two black aces and two black eights. In poker games, a two-pair hand is solid—far from unbeatable, but often strong enough to win several pots, which offers a sense of near victory<sup>[12]</sup>.

The Joker acts as a wildcard in many poker variants, capable of substituting for any other card, thus increasing the player's flexibility and potential for winning. Together, these terms echo the source text's message: Sun Wukong sees a strong hand with promising winning potential. This creative use of familiar card game terminology allows the subtitles to bridge the cultural gap, improve narrative understanding, and maintain coherence and

relatability for target audiences.

### 3.3. Foreignization translation strategy to achieve the fidelity rule

The fidelity rule, also referred to as intertextual coherence, emphasizes that a translation should remain as faithful as possible to the source text, striving to preserve its original meaning to the greatest extent. However, fidelity does not imply a rigid word-for-word translation. As long as the translation maintains the intent and content of the source text, it can still be regarded as an attempt to follow the fidelity rule. The foreignization translation strategy, which seeks to retain the original cultural and informational elements of the source text, is often employed to remain loyal to the original text. The following example illustrates a typical application of this approach.

#### Example 5:

Source Text: 德老板：这些不成敬意。还请公子高抬贵手，不计前嫌。

哥：德老板，您这也太客气。

Target Text: De: Here's a small token of respect. Hope you can kindly accept this and let us move on.

Brother: Boss, this is so...

This subtitle adopts the foreignization translation strategy, effectively conveying the original meaning while preserving cultural nuance. The use of “Boss” to translate “德老板” reflects China's high powerdistance culture, where addressing someone by title signifies respect and acknowledgment of hierarchy—unlike Western norms, which typically soften such distinctions by using “Mr. De.” Individuals from high-power distance cultures accept power as part of society<sup>[13]</sup>. Addressing that guy as Boss indicates that the speaker's full respect for him. Moreover, the phrase “您这也太客气” (You are being too polite) is only partially translated (“this is so...”), with an intentional ellipsis. This unfinished sentence reflects high-context communication typical in Chinese culture, where meanings are often implied rather than explicitly stated. As Hall's concept of highcontext cultures goes, a high context communication or message is one in which most of the information is already in the person, while very little is in the coded, explicitly transmitted part of the message<sup>[13]</sup>. The unfinished sentence, combined with the context, already shows that the utterer wants to accept Boss De's money by showing some appreciation for his “good deeds.”

By combining foreignized address with an unfinished utterance, the translation recreates the original's structural and cultural subtleties, and allows meaning to be inferred from the surrounding context—such as the characters' body language or previous interactions—thereby preserving the communicative style of the original dialogue. This translation strategy successfully preserves both coherence and fidelity, allowing non-Chinese audiences to experience the culturally specific mode of discourse.

Nevertheless, subpar subtitle quality can significantly damage audience reception and even obstruct cross-cultural communication. In analyzing this film, the author identifies several examples of flawed subtitle translation, which may confuse the target audience and thus need correcting. One of those is presented below.

#### Example 6:

Source Text: 三姐，穿得这么漂亮。说不定被董事长一眼看中可就乌鸦变凤凰了。

Target Text: Miss San, you look so pretty. You might catch the boss's eye and go from crow to phoenix.

In this instance, a literal translation method is adopted to achieve the fidelity rule. Literal translation refers to preserving the source language's lexical choices, structures, and stylistic norms, enabling the target audience to experience the text similarly to the source audience. However, the cultural connotations of “crow” and “phoenix” differ markedly between Chinese and Western cultures. In Chinese culture, birds such as crows are considered ordinary and unimpressive. The phoenix, while also a bird, is richly adorned with multicolored feathers and regarded as noble and auspicious. It has long been a symbol of harmony, prosperity, and high status, and is deeply rooted in Chinese cultural traditions. This Chinese phrase, “乌鸦变凤凰 (go from crow to phoenix)”, implies that an ordinary woman might attain wealth or social elevation through a fateful opportunity.

In contrast, the crow in the Western tradition carries mixed symbolism. For example, in the Bible, the crow (or raven) plays contradictory roles: in the *Book of Kings*, it serves as a loyal messenger helping Elijah survive, while in *Genesis*, it is portrayed as an unreliable one, failing to bring news of the flood's end to Noah <sup>[14]</sup>. Moreover, the English term “phoenix” refers to the mythical firebird known for its resurrection and immortality—ideas that are not entirely equivalent to the Chinese concept of “凤凰 (fenghuang)”. Although some overlap between the Chinese “fenghuang” and the Western “phoenix” exists—partly due to cultural blending influenced by works like Guo Moruo's *The Nirvana of the Phoenix*—the two are not functionally equivalent <sup>[15]</sup>. While a literal translation may satisfy the fidelity rule, it may fail to convey the intended meaning to the target audience, who might struggle to understand the metaphor, in that it is clear that there is no inherent or direct link between the crow and the phoenix in Western cultural frameworks.

According to Skopos theory, the Skopos rule is paramount. To ensure the message is accessible and meaningful to the audience, the phrase could instead be rendered as: “...here comes the story of Cinderella.” The tale of Cinderella is a classic and widely recognized Western example of an ordinary girl ascending to nobility, which closely mirrors the Chinese metaphor of a common bird transforming into a phoenix. This use of the domestication translation strategy takes into account cultural differences and background knowledge, significantly improving both the readability and acceptability of the translated text.

## 4. Conclusion

Chinese films released in international markets often receive less favorable reception compared to their domestic success, highlighting persistent challenges in the global communication of Chinese culture. Two primary obstacles contribute to this disparity: cultural unfamiliarity and linguistic barriers. As a crucial medium for cross-cultural communication, subtitle translation plays a pivotal role in addressing these challenges and advancing the broader objective of effectively “telling China's story.”

Skopos Theory offers valuable guidance by focusing on the intended skopos of the translation, thereby enabling translators to make contextually appropriate and audience-oriented decisions. Through subtitles, international audiences can better understand the narrative and engage with Chinese culture, thereby fostering cross-cultural dialogue and amplifying China's cultural voice on the global stage.

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# Transformational Leadership and Employee's Innovative Behavior: A Moderated Mediation Model

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**Abstract:** This study investigates how transformational leadership facilitates employees' innovative behavior. Survey data from 415 employees were analyzed using SPSS and AMOS. Results demonstrate that transformational leadership significantly enhances employee innovative behavior via psychological capital, with perceived organizational support positively moderating the relationship. For human resources practices, transformational leaders foster innovation by developing employees' psychological resources and are reinforced by perceived organizational support.

**Keywords:** Transformational leadership; Psychological capital; Innovative behavior; Perceived organizational support

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## 1. Introduction

Under the backdrop of promoting innovation as the core driving force of socialist modernization through the Mass Entrepreneurship and Innovation policy, enterprises, as the primary entities of innovation, face intensifying market competition challenges. Leaders, acting as helmsmen, significantly promote innovative behavior by reshaping employee values through transformational leadership<sup>[1]</sup>. Employees exhibit higher innovation initiative when perceiving stronger organizational support. However, existing research predominantly focuses on the direct link between transformational leadership and innovative behavior, with insufficient exploration of its underlying mechanisms: on the one hand, mediating variables often emphasize self-efficacy or intrinsic motivation, neglecting the crucial role of psychological capital as an intrinsic driver; on the other hand, the moderating effect of perceived organizational support lacks systematic examination within a moderated mediation model<sup>[2]</sup>. Consequently, precisely stimulating employee innovative behavior has become a key academic focus. From the perspective of individual factors, this study examines the impact mechanism of transformational leadership on employee innovative behavior by introducing psychological capital as a mediating variable and perceived organizational support as a moderating variable<sup>[3]</sup>. Transformational leadership empowers employees and enhances their psychological capital, thereby driving innovative behavior. Perceived organizational support moderates this

mediating pathway, with the level of environmental support influencing employees' psychological safety and innovation output <sup>[4]</sup>. Based on social exchange theory, this study constructs a model to examine the influence mechanism and boundary conditions between transformational leadership and innovative behavior.

## **2. Theoretical analysis and research hypotheses**

### **2.1. Transformational leadership and employee innovative behaviors**

Based on the context in which leadership style guides employee behavior, transformational leadership enhances employee confidence, thereby encouraging innovative behavior through personal charisma, such as leading by example to break conventions, providing emotional support, and offering intellectual stimulation <sup>[1]</sup>. Such behaviors alleviate employees' fear of change and foster the generation of new ideas; simultaneously, intellectual stimulation provides employees with space for dialectical thinking, thereby strengthening critical thinking and confidence in innovation. Unlike authoritarian leadership's inclination to interrogate, transformational leadership fosters an environment of equality and trust <sup>[5]</sup>. Its open and inclusive stance creates a psychologically safe environment, empowering employees to proactively embrace innovation. According to social exchange theory, leadership behavior strengthens employees' motivation to emulate, forming a synergy between individual and organizational values that drives innovation. Therefore, the authors propose the following hypothesis.

H1: Transformational leadership positively influences employee innovative behavior.

### **2.2. The mediating role of psychological capital**

Psychological capital is an individual's positive psychological resource encompassing four dimensions: hope, resilience, optimism, and self-efficacy. Transformational leadership enhances employees' psychological capital through charismatic exemplification, intellectual stimulation, and individualized consideration, thereby strengthening their willingness to innovate. Specifically, leaders' role modeling cultivates employees' resilience against setbacks, visionary inspiration reinforces goal-oriented hope, and decision-making inclusiveness bolsters confidence in innovation <sup>[6]</sup>. This positive mindset encourages employees to pursue challenging tasks and fosters innovative behaviors through the mechanism of socio-emotional resource exchange. According to social exchange theory, the essence of mutual trust, care, and cultivation between individuals constitutes an exchange of socio-emotional resources. When employees perceive organizational support and encouragement, their innovative behaviors achieve significantly enhanced success through organizational recognition <sup>[6]</sup>. Therefore, the following hypothesis is proposed.

H2: Psychological capital mediates the relationship between transformational leadership and employee innovative behavior.

### **2.3. The regulatory role of perceived organizational support**

Perceived organizational support refers to employees' overall assessment of the multidimensional organizational support they receive, including remuneration benefits, life care, and spiritual encouragement. It possesses dual moderating functions: enhancing work motivation while simultaneously promoting innovative behavior through boosting psychological capital levels. Organizational justice significantly strengthens employees' perceptions of organizational support, whereas a positive work climate directly fosters willingness to innovate <sup>[2]</sup>. Material support and spiritual encouragement enhance job satisfaction and perceived competence, respectively. When employees simultaneously perceive both types of resources, their sense of belonging and perceived obligation to

reciprocate intensify, thereby integrating individual goals with organizational development under transformational leadership <sup>[6]</sup>. Based on social exchange theory, in contexts of high perceived organizational support, the affective/status resources transmitted by leaders complement institutional organizational support, increasing the efficiency with which psychological capital translates into innovative behaviors, such as actively exploring new methods and setting high-performance standards. Conversely, low perceived organizational support weakens resource reception efficacy, leading to diminished psychological safety, erosion of psychological capital, and suppression of innovation investment, as manifested through reduced frequency and quality of creative output <sup>[3]</sup>. Therefore, we propose the following hypothesis.

H3: Perceived organizational support moderates the effect of transformational leadership on employee innovative behavior through psychological capital, such that the effect is stronger when perceived organizational support is high than low.

### **3. Data and variables**

#### **3.1. Research sample**

This study selected five enterprises operating across multiple provinces (covering real estate, energy, and pharmaceutical industries) and implemented stratified sampling via an electronic questionnaire platform. The questionnaires were distributed in November 2022. A total of 457 responses were collected. After excluding invalid and incomplete questionnaires, 415 valid samples were ultimately obtained, yielding an effective response rate of 90.6%.

#### **3.2. Measurement**

All scales used in this study were derived from established instruments. A five-point Likert scale was employed for each construct, with scores ranging from 1 (“strongly disagree”) to 5 (“strongly agree”).

Transformational leadership (TL): The scale developed by Li & Shi was adopted, comprising 26 items such as “My leader shows concern about employees’ work, life, and personal growth, and sincerely provides suggestions for their development” <sup>[3]</sup>. The Cronbach’s  $\alpha$  for this scale was 0.95.

Innovative behavior (IB): The scale developed by was used, including items like “I frequently experiment with new approaches to solve work-related problems” <sup>[2]</sup>. The Cronbach’s  $\alpha$  coefficient was 0.86.

Psychological capital (PC): The 24-item scale developed by Luthans was employed, featuring items such as “When facing work difficulties, I can generate multiple solutions to overcome them” <sup>[4]</sup>. The Cronbach’s  $\alpha$  coefficient was 0.84.

Perceived organizational support (POS): The scale developed by Liu, containing 6 items (e.g., “The organization respects my goals and values”), was utilized, with a Cronbach’s  $\alpha$  of 0.86 <sup>[7]</sup>.

Control variables: Gender, age, education level, and organizational tenure.

### **4. Research results**

#### **4.1. Descriptive statistics and correlation analysis**

This study collected 415 valid samples. Among the respondents, 268 were male (64.60%) and 147 were female (35.40%), indicating a predominance of male participants. In terms of age: 112 participants (27%) were aged 12–30, 203 (48.9%) aged 31–40, 72 (17.4%) aged 41–50, and 28 (6.7%) aged 51 or above, revealing the highest



concentration within the 31–40 age group. Regarding education level, 254 held junior college diplomas (64.4%), 151 held bachelor's degrees (36.4%), 4 held master's degrees (1%), and 6 held doctoral degrees (1.4%). Regarding organizational tenure, 392 participants (94.5%) had 0–10 years of experience, 21 (5%) had 11–20 years, and 2 (0.5%) had 21–30 years. The results of the correlation analysis are shown in **Table 1**.

**Table 1.** Correlation analysis

	Variable	1	2	3	4
1	TL	-			
2	PC	0.59**	-		
3	IB	0.47**	0.73**	-	
4	POS	0.49**	0.63**	0.61**	-

N=415; \* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ .

## 4.2. Hypothesis test

As shown in **Table 2**, Model 1 indicates that, after controlling for gender, education, age, and tenure, transformational leadership has a significant positive effect on employee innovative behavior ( $\beta = 0.47$ ,  $P < 0.001$ ). Hypothesis 1 was thus supported. Model 3 demonstrates that after introducing psychological capital, the standardized coefficient  $\beta$  of transformational leadership on employee innovative behavior decreased from 0.47 to 0.06, while the positive relationship remained significant ( $P < 0.01$ ). Hypothesis 2 was therefore supported. Model 6 reveals a significant positive effect of the interaction term between transformational leadership and perceived organizational support on psychological capital ( $\beta = 0.01$ ,  $P < 0.001$ ), confirming Hypothesis 3.

**Table 2.** Regression analysis results

IB	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Gender	-0.12	0.21	-0.05	0.21	0.01	-0.10*
Education	0.04	0.08	-0.01	0.08	0.7	0.02
Age	0.03	0.53	0.02	0.52	0.86	0
Work time	0.08	0.17	-0.03	0.16	0.23	0.01
TL	0.47***	0.68***	0.06**		0.30**	0.31**
PC			0.69***			
POS					0.52***	0.52**
TL*POS						0.01**
R <sup>2</sup>	0.25	0.55	0.54	0.65	0.32	0.52
ADJ-R <sup>2</sup>	0.24	0.55	0.54	0.65	0.31	0.31
F	26.62***	44.96***	83.37***	83.37***	32.28**	9.48**

N=415; \* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ .

## 5. Conclusion

This study investigated the relationship between transformational leadership and employee innovative behavior

through paired surveys of 415 employees. First, a significant positive correlation exists between transformational leadership and employee innovative behavior; Second, psychological capital mediates this relationship; Third, POS moderates the mediating effect, specifically, high POS amplifies the indirect impact of transformational leadership on innovative behavior through psychological capital.

The moderated mediation model empirically confirms that transformational leadership has a positive influence on innovation. Organizations should implement transformational leadership styles to establish trust through charismatic influence and moral modeling; Develop systematic training programs integrating domestic and international expertise; Enhance employee' psychological capital through tiered interventions targeting optimism, hope, and resilience; Foster leader-employee interaction cycles where role modeling reduces innovation risk perception; Provide resource support, innovation fault-tolerance mechanisms, and holistic care to strengthen leader-organization synergy. These evidence-based practices catalyze employee innovation, converting psychological resources into sustainable competitive advantages.

## Disclosure statement

The authors declare no conflict of interest.

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# The Basic Dimension and Innovative Path of Chinese-Style Modernization Leading the High-Quality Development of the Sports Tourism Industry

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**Abstract:** Sports is an important carrier of modernization, tourism is a “bridge” for world communication, and it is “the right thing to do” to lead the high-quality development of the sports and tourism industry with Chinese-style modernization in an all-round way. This paper analyzes the high-quality development of the sports tourism industry from five dimensions: practical foundation, development goal, value orientation, development concept, and development direction. The paper reveals that modernization oriented toward a large population is the basic feature, common prosperity is the fundamental goal, the coordination of material and spiritual civilization is the intrinsic pursuit, harmonious coexistence with nature is the guiding principle, and peaceful development is the defining value of this era. Despite these advantages, China’s sports tourism industry still faces challenges such as mismatched supply and demand, obstacles to achieving common prosperity, insufficient coordination of material and spiritual development, limited ecological benefits, and a lack of international influence. To address these issues, this paper proposes building a people-oriented modernization system, fostering innovation and coordinated development, emphasizing cultural heritage, promoting green development, and constructing platforms for multilateral cooperation and mutual understanding.

**Keywords:** Chinese-style modernization; Sports tourism industry; High-quality development

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## 1. Introduction

The report of the 20th National Congress of the Communist Party of China (CPC) set out a comprehensive blueprint for national rejuvenation through Chinese-style modernization <sup>[1]</sup>. The President of the CPC emphasized that high-quality development is the central task in building a modern socialist country <sup>[2]</sup>. High-quality development is not only the core requirement of Chinese-style modernization but also the practical path to achieving it. As a new integration of the sports and tourism industries, the sports tourism industry is reshaping consumption, driving industrial restructuring, and supporting socioeconomic modernization <sup>[3]</sup>. To

meet the demands of this new era, the sports tourism industry must integrate with the broader goals of Chinese modernization and pursue high-quality, innovative development.

While recent academic interest in “Chinese-style modernization” has grown, systematic studies focusing specifically on its essential implications for the high-quality development of the sports tourism industry remain limited. Current research mainly addresses the new development paradigm, new quality productive forces, digital economy, consumption upgrading, and rural revitalization <sup>[4-8]</sup>. This is to address the practical challenges in this process, aiming to provide useful recommendations for China’s sports tourism sector. Based on this, this paper explains the background, connotation and basic dimensions of the era of Chinese-style modernization to lead the high-quality development of sports tourism industry, and further puts forward innovative paths to address the reality of the stagnation faced by the sports tourism industry in the process of advancing the Chinese-style modernization, with a view to providing advice for the high-quality development of China’s sports tourism industry.

## **2. Reality foundation of the high-quality development of the sports tourism industry led by Chinese-style modernization**

### **2.1. The basic connotation of Chinese-style modernization**

Chinese-style modernization refers to modernization with Chinese socialist characteristics, guided by the leadership of the Communist Party of China (CPC), and is rich in meaning. First, it is rooted in the reality of China’s large population, which brings both significant challenges and abundant human resources as well as broad market potential. Second, a core objective is the achievement of common prosperity, which not only seeks material abundance but also ensures equitable access to education, healthcare, sports, culture, and tourism—making shared prosperity a core feature of China’s development <sup>[10]</sup>. Third, Chinese-style modernization stresses the balance between material and spiritual civilization. Economic growth is supported by cultural construction and the cultivation of core socialist values, enhancing citizens’ moral and scientific qualities. Fourth, harmonious coexistence between humanity and nature is essential; China upholds green development, practices environmentally responsible growth, and seeks synergy between economic progress and ecological protection. Finally, the path of peaceful development is a key attribute: China emphasizes an independent foreign policy of peace, multilateral cooperation, and actively contributes to global governance, advocating the building of a community with a shared future for mankind while offering Chinese wisdom and solutions to global challenges <sup>[11]</sup>.

### **2.2. The basic interpretation of the high-quality development of the sports tourism industry**

The sports tourism industry is a social and economic sector that develops through the deep integration of sports and tourism, creating a unique industry chain distinguished from other tourism types <sup>[12]</sup>. It is characterized by attributes such as regional specificity, openness, inclusivity, attractiveness, and seasonality. The industry includes high-end sports clubs, theme parks, sports tourism towns, competitive sporting events, and leisure festivals, and operates through the interaction of markets, enterprises, consumers, and resources. Typical manifestations involve stadium tours, sports event tourism, and outdoor sports and leisure activities <sup>[13]</sup>.

At the macro level, China’s sports tourism industry has shifted from a phase of rapid growth to one of high-quality development. The sector now aims to support the building of a strong sports nation and the broader task of socialist modernization. This requires addressing the evolving consumption demands of the population, deepening supply-side reforms, upgrading industrial structure, and ensuring simultaneous improvements in economic, social, and ecological benefits. On a micro level, the emphasis is on supplying high-quality products and services to

stimulate domestic consumption and create a virtuous cycle of production and consumption.

In adapting to the new development landscape, China's sports tourism industry is working to align with international standards by participating in global rule-making and international sports event cooperation. By fostering international competitiveness, enhancing infrastructure, developing resources, and advancing policy frameworks, the industry seeks not only to strengthen its position in the global market but also to stimulate domestic industry growth and open a new chapter in high-quality sports tourism development.

### **2.3. Connotation of Chinese-style modernization leading the high-quality development of the sports tourism industry**

Chinese-style modernization has provided both the foundation and direction for the high-quality development of the sports tourism industry. The large population offers a robust market base, requiring a continued focus on people-centered approaches that enhance public health and increase citizens' sense of gain, happiness, and participation. Since the 18th CPC National Congress, the sports tourism industry in China has achieved significant milestones, notably in poverty alleviation and rural revitalization, which underscore the industry's role in improving livelihoods and ensuring that development outcomes are widely shared. For instance, rural sports tourism projects such as the Liupanshui Noyu Hai International Mountain Tourism Resort in Guizhou have greatly expanded local economic benefits and raised incomes, with the industry now comprising a substantial share of the local economy. Furthermore, integrating sports tourism with culture is crucial for advancing both industry modernization and the promotion of socialist values, thereby strengthening the spiritual vitality of society. The sports tourism industry also serves as a key area for energy conservation and emission reduction, fostering green, low-carbon, and environmentally friendly development. This encourages environmental awareness, helps protect natural resources, and supports the creation of an ecological society. Additionally, the industry contributes to national diplomacy by showcasing China's openness, confidence, and inclusiveness. Major events such as the 2022 Beijing Winter Olympics have enhanced international exchange, strengthening understanding and cooperation between Chinese civilization and the rest of the world through the platform of sports tourism.

## **3. Chinese modernization to lead the sports tourism industry high-quality development of the reality of obstacles**

Based on the basic dimension of Chinese-style modernization leading the high-quality development of the industry, and taking "problem-oriented" as the analytical paradigm, the high-quality sports tourism industry is still facing the problems of poor matching of the industry's supply and demand structure in the process of Chinese-style modernization, obstacles to driving the common prosperity of the whole people, insufficient coordination of the development of material and spiritual civilization, insufficient ecological benefits, and low carbon emissions. The quality of the sports tourism industry still faces such practical difficulties as the lack of matching of the industry's supply and demand structure, the obstacle of promoting the common prosperity of all people, the lack of a coordinated development system to promote material and spiritual civilization, the lack of ecological benefits and the risk of low-carbon transformation, and the lack of the right to speak out for peaceful development.

### **3.1. Inadequate matching of industry supply and demand structure**

First, the scale and quantity of sports tourism supply are insufficient. (1) Industrial development and operational efficiency remain low, with many projects showing strong seasonality. Off-peak periods often result in resource



waste and increased costs <sup>[15]</sup>. For example, ski resorts in northeastern China typically operate only around 100 days during the snow season, with most closing in summer; fewer than 10% remain active off-season, reflecting weak year-round utilization. (2) Sports tourism products are overly uniform and lack diversity. Most offerings focus on performance or viewing experiences, while experiential products remain underdeveloped. For instance, only 10% of Qinghai's tourism resources have been developed—mainly for sightseeing. Participatory activities like rock climbing, rafting, and outdoor adventures target mainly young people, limiting audience reach and market growth. Second, the quality of sports tourism products and services needs improvement <sup>[16]</sup>. (1) The industry lacks innovative momentum and quality-oriented growth. Development still emphasizes quantity over quality, superficial form over substantive content, and short-term gains over long-term planning. These issues contribute to product homogenization, lagging innovation, and weak market influence. (2) Service quality is insufficient, with outdated government mindsets, low managerial standards, and poor service attitudes still prevalent. For example, in western China, departments related to sports, culture, and tourism maintain traditional service concepts. Although the region possesses unique tourism resources, the limited service awareness of personnel has significantly constrained the development of the local sports tourism industry.

### **3.2. Industry to drive the common prosperity of all people still faces obstacles**

Firstly, the development foundation of the sports tourism industry is relatively weak. Factors such as improper policy management, outdated development concepts, and external environmental pressures have significantly affected this environmentally sensitive and crowded industry, revealing structural fragility and limiting its ability to meet the public's growing demand for health and leisure tourism <sup>[17]</sup>. Although high-end products should drive industry growth, the current model still relies on extensive, low-end development—positioned at the bottom of the “smile curve.” Growth depends mainly on traditional factors like labor, land, and capital, while technological innovation remains insufficient, making it difficult to support the vision of common prosperity. Secondly, regional development is uneven. (1) China's sports tourism is mostly concentrated in areas rich in natural resources, such as mountains for marathons, hiking, and rock climbing; coasts for surfing and diving; and snow regions for skiing and skating <sup>[18]</sup>. However, in places with strong cultural or red-revolutionary heritage, local governments and enterprises have yet to effectively explore the potential of sports tourism. (2) Infrastructural limitations and underdeveloped transportation networks in central and western regions hinder activity expansion. For example, although Yunnan boasts vast mountain resources suitable for diverse sports tourism projects, it has only one national demonstration base, and poor connectivity between sites makes access difficult. Thirdly, the supply of public products for sports tourism is inadequate. Public products are vital for ensuring social welfare and promoting shared prosperity, yet the supply remains insufficient given China's population size <sup>[19]</sup>. Medical, educational, and health-related services related to sports tourism are limited, failing to meet tourist needs. Moreover, tourism and sports departments often operate in isolation, lacking integration with land use, transportation, environmental protection, and health systems. This disconnect results in low-quality public service provision across the sector.

### **3.3. Poor industrial material and spiritual civilization development system**

First, lack of cultural roots. Although China strongly supports sports tourism at the policy level and massive capital input provides short-term momentum, overreliance on policy and capital without gradual cultural cultivation leads to a “distorted” industry lacking cultural depth. For example, red sports tourism, despite efforts to revive old revolutionary areas through historical storytelling, revolutionary spirit learning, and military sports experiences,

suffers from insufficient cultural excavation, weak transformation of sports and cultural resources, limited revitalization of revolutionary culture, stereotypical educational promotion, and monotonous military sports programs<sup>[20]</sup>. Second, a lack of humanistic heritage. While themed towns such as “soccer town”, “ice town”, and “marathon town” flourished briefly, they often focused solely on natural resource development under the “sports town” banner, neglecting integration with local traditions, customs, and cultural identity. For instance, marathons across regions show little variation beyond geography; course design, marketing, activities, and event culture remain homogeneous, failing to incorporate local landscapes or historical heritage. As a result, marathon tourism struggles to reflect distinctive cultural traits, falling short in combining the spiritual experience of “running” with the material culture of “watching.”

### **3.4. Insufficient industrial eco-efficiency and the risk of low-carbon transformation**

First, the ecological benefits of the industry are insufficient. Sports tourism relies heavily on the natural environment—such as coastal, mountain, and ice-snow ecosystems—yet enterprises often fail to manage ecological impacts effectively. Overdevelopment, pollution, and industrial waste have damaged ecosystems, while weak environmental awareness and poor implementation of ecological protection have delayed the sector’s ecological advancement, resulting in a clear imbalance between economic gains and ecological sustainability. Secondly, the transformation toward low-carbon development faces significant obstacles. (1) The industry lacks a sound low-carbon development system. As a green health sector, sports tourism still struggles with product R&D, market building, consumer education, and technology application. A comprehensive low-carbon chain—spanning the market, enterprises, consumers, and society—has yet to be established. (2) There is also a lack of consensus on low-carbon development. Key areas fail to adopt an ecological economics perspective in analyzing industry trends. Enterprises, markets, and governments show limited awareness of low-carbon principles, and mechanisms such as market incentives, enterprise innovation, and government coordination remain underdeveloped. This hinders the industry’s ability to align with ecological civilization goals and limits progress toward sustainable, low-carbon transformation.

### **3.5. Lack of discourse power of the industry to promote peaceful development**

First, affected by public health events, the development of sports tourism came to a standstill. In particular, the COVID-19 outbreak disrupted the global sports tourism market chain. International tourism was severely impacted by health control measures such as border screenings, travel restrictions, goods circulation limitations, and public venue closures. International dialogue and exchanges in the sports tourism industry were also suspended. In the face of such emergencies, China’s sports tourism safety system still faces uncertainty and instability. How to ensure smoother, broader, and more convenient international exchanges and how to play a pivotal role in global tourism cooperation have become key issues for the high-quality development of the industry.

Secondly, there remains a gap between the scale of China’s sports tourism industry and the international tourism market. In 2021, China’s sports tourism market reached nearly 1.3 trillion yuan with a 30% annual growth rate, showing a “blowout” trend. However, it accounted for just over 5% of the total tourism market, compared to about 25% in developed countries<sup>[21]</sup>. This reflects the limited scale of China’s sports tourism relative to global standards. Although China actively promotes initiatives like the “Bilateral Tourism Year” and the “Belt and Road” sports tourism program to encourage cultural exchange and cooperation, there is still significant room for improvement in international engagement—particularly in participation, rule-making, cooperation in international sports events, alignment with global market demands, and the cultivation of international competitiveness in the sports tourism sector.

## **4. Innovative path of Chinese modernization to lead the sports tourism industry to high quality**

### **4.1. Put people first and build a modernized development system with humanistic care**

First, a people-centered approach should guide the rational structuring of supply and demand in the sports tourism industry to expand product quantity and scale. The government should promote scientific planning, institutional innovation, and market-driven mechanisms to optimize resource allocation, integrate related sectors, and foster industrial clustering. Emphasizing the synergy of sports, tourism, industry, and culture, efforts should align with digital economy trends by using big data to analyze consumer preferences, segment the market, and offer diversified, personalized services. Second, product quality must be improved through humanistic care by developing distinctive, high-end brands and enhancing service professionalism. Enterprises should adopt a “consumer-centered” philosophy, build strong service teams through training and incentives, and establish systems that support recruitment, empowerment, and brand cultivation, ensuring the industry’s high-quality and sustainable development.

### **4.2. Construct a development mechanism of innovation, coordination, and solidarity with the core of promoting common prosperity**

First, innovation and openness drive high-quality development of the sports tourism industry. Guided by the “14th Five-Year” Digital Economy Development Plan, the industry should pursue digitization and tech-driven transformation. Integrating Internet technologies into products and services reshapes the value chain based on resource attributes, functions, and market positioning. Digital tools analyzing consumer needs enable differentiated production, flexible marketing, and personalized services<sup>[22]</sup>. Leveraging big data, IoT, AI, cloud, and edge computing further boosts innovation. For example, Beijing Olympic Park uses digital tech for access control, parking, navigation, and data collection to enhance the tourist experience.

Second, coordination and sharing optimize the industrial structure. A multi-level collaboration mechanism should attract social capital via PPP models and investment-return systems, fostering integration, clustering, and regional growth through a “point-to-surface” strategy. Prioritizing infrastructure upgrades—transportation, roads, water, and power—is essential. Technological tools should improve supply-demand coordination by enhancing monitoring, early warning, and resource allocation. Efficient transportation and storage networks enable cross-regional and cross-industry resource sharing, promoting market development.

Third, unity and dedication enhance public product quality. The government should relax controls on relevant social organizations and encourage their participation in public product supply through service procurement and cultivation. A “co-construction and sharing” model involving governments, enterprises, and residents should ensure equitable involvement and benefits. A management committee of officials, organizations, and residents should oversee governance, safeguard public welfare, and continuously improve product quality.

### **4.3. Based on highlighting the cultural heritage to satisfy the inner yearning of spiritual civilization**

First, efforts should be made to fully develop red sports resources, highlight cultural heritage, and leverage these resources to promote old revolutionary areas. This includes strategic planning of red sports tourism images, integrating national red sports resources, selecting key scenic spots, and introducing curated routes. The connotation of red sports tourism products should be enriched by emphasizing historical heritage, local traits, and contemporary characteristics to vividly convey the revolutionary spirit to consumers. Additionally, old revolutionary areas should actively transform red sports tourism resources into industrial and economic advantages



by developing the industry, collecting revolutionary culture, restoring memorial halls and war sites, and achieving coordinated social and economic benefits. Second, promote the integration of social, humanistic heritage, and sports tourism resources. The government should guide enterprises to deepen their understanding of humanistic heritage by tapping into regional traditional sports culture, festivals, and fitness resources to highlight distinctive living heritage. Leveraging local human resources, these cultural elements should synergize with modern development needs to shape the characteristics of contemporary sports tourism. Moreover, respecting ethnic cultural customs and protecting ethnic traits, sports projects should combine ethnic culture with modern elements, ensuring both cultural preservation and reasonable development.

#### **4.4. Practice ecological civilization construction with a solid green development concept as synergy**

First, government, enterprises, markets, and consumers must embrace a strong green development concept. High-quality sports tourism development depends on ecological protection, optimized industry structure, cohesion, and improved ecological efficiency<sup>[23]</sup>. Governments should strengthen green cooperation, guide sustainable policies, and research market trends. Enterprises need to embed green values, invest in low-carbon R&D, promote resources, and foster healthy competition via exchange platforms. Markets should establish low-carbon regulations that monitor emissions through tracking and compensation, reducing emissions across all stages. Consumers should follow green consumption guidelines, supported by incentive systems to boost engagement and awareness.

Second, national and local authorities should advance ecological civilization in sports tourism by innovating low-carbon technologies to break technical barriers. Top-level design must develop aligned regulations, standards, and certification systems. Local governments should conduct expert eco-efficiency assessments for targeted improvements. Science and technology integration with sports tourism enterprises should accelerate green innovation and adoption of technologies like carbon reduction and sequestration, enabling low-energy, low-carbon development.

#### **4.5. Build a multilateral exchange and mutual understanding platform with the purpose of promoting common construction and sharing**

The high-quality development of the sports tourism industry should serve as a global link for interconnection, promoting shared construction and mutual benefits. Deepening the “Belt and Road” strategy and advancing “bilateral tourism cooperation” will build a multilateral exchange and cooperation system, contributing to China’s strength, offering Chinese solutions, and enhancing international sports and cultural exchanges. Firstly, China should leverage its “double-cycle” development pattern to coordinate domestic and international sports tourism resources, orderly restoring tourism flows. Government agencies must relax restrictions on international participation while managing public health risks, providing benefits such as visa-free transit, safety guidance, tour assistance, and cultural explanations. Secondly, “Chinese characteristic” sports tourism products should be expanded internationally to form a high-quality development pattern, fostering domestic and global industry growth.

Second, China should provide solutions for global sports tourism sharing. Embracing the community of human destiny concept, China’s sports tourism must establish multilateral platforms to foster cooperation and exchange. Efforts should focus on promoting distinctive sports tourism brands and deepening collaboration with countries along the “Belt and Road”, APEC, BRICS, and others, facilitating passenger exchanges, resource

sharing, and market integration. Leading tourism enterprises should build international sports tourism consulting and sharing platforms to expand market scale and influence <sup>[24]</sup>. The government should also unite countries to integrate regional resources, accelerate infrastructure development, and create convenient transport networks, including high-speed rail, flights, taxis, and bicycles. Additionally, inbound tourism safety mechanisms must comply with consulate laws, strengthening safety information sharing, monitoring, early warning, rescue, and legal assistance to ensure the security of international tourists engaging in sports tourism in China.

## 5. Conclusion

Chinese-style modernization combines global modernization traits with China's unique national conditions. This paper explains the connotation of Chinese-style modernization guiding the high-quality development of the sports tourism industry, revealing five fundamental dimensions: practical foundation, development goals, value orientation, development concepts, and direction. Facing multiple challenges, it proposes a people-centered modern development system emphasizing humanistic care; an innovation-driven, coordinated, and unified mechanism focused on common prosperity; a cultural heritage platform supporting spiritual civilization; a solid green development synergy fostering ecological civilization; and a multilateral exchange platform promoting shared construction and cooperation. The goal is to provide theoretical guidance and wisdom support for China's sports tourism high-quality development, bridging Chinese modernization with a stronger industrial future.

## Disclosure statement

The authors declare no conflict of interest.

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# Research on the Impact of Digital Inclusive Finance on Rural Revitalization

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**Abstract:** As a region that started early in the development of the digital economy, Zhejiang's digital inclusive finance has effectively promoted rural revitalization by alleviating rural financing difficulties, promoting industrial integration, and effectively promoting rural revitalization. This article uses panel data from Zhejiang Province from 2014 to 2022 to empirically explore the impact and mechanism of digital inclusive finance on rural revitalization in Zhejiang Province. The study uses the entropy weight method to build a comprehensive evaluation index for rural revitalization, and combines it with Peking University's digital inclusive finance index to construct a fixed effects model for regression analysis. Multiple collinearity tests, heteroscedasticity tests, and other analyses are used to ensure the reliability of the model. Research has found that: (1) Digital inclusive finance has a significant promoting effect on rural revitalization; (2) The income gap between urban and rural areas shows a significant negative correlation, and as an important prerequisite for rural revitalization, it is necessary to narrow the urban-rural gap; (3) Although fiscal intervention has shown positive effects, it demonstrates policy synergy with digital finance and needs to enhance resource allocation efficiency. This article provides theoretical support and practical reference for Zhejiang Province to deepen the reform of digital inclusive finance and improve rural revitalization policies. It is suggested to achieve the coordinated promotion of digital finance penetration, precise fiscal investment, and regional differentiated policies, and create a model of digital empowerment for rural revitalization.

**Keywords:** Digital inclusive finance; Rural revitalization; Fixed effects model

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## 1. Introduction

The research on the relationship between digital inclusive finance and rural revitalization is based on the real contradiction of imbalanced allocation of financial resources under the dual structure of urban and rural areas in China, and the historical opportunity brought by the digital technology revolution. Rural areas are plagued by the narrow coverage of traditional financial institutions, the continuous rise of service costs, and the incomplete credit evaluation system. A large number of farmers and small and micro business entities are trapped in the dilemma

of difficult and expensive financing. This financial exclusion situation has seriously constrained the development of rural industries and the improvement of people's livelihoods. With the comprehensive implementation of the rural revitalization strategy, the national policy scope has intensively issued documents such as the Plan for Promoting the Development of Inclusive Finance and the Outline of the Digital Rural Development Strategy, which require financial institutions to adopt digital means to innovate service models, break through the obstacles of the last mile of rural finance, and mature the application of technologies such as mobile payment, big data risk control, and blockchain, so that financial services can break through the constraints of geographical space and extend to rural fields with the help of intelligent terminals. This not only reduces operating costs but also achieves multidimensional dynamic evaluation of farmers' credit risks. This technology empowerment not only deeply aligns with the goals of the rural revitalization strategy of prosperous industries, livable ecology, and prosperous life, just like supply chain finance revitalizing characteristic agriculture and digital insurance improving risk resistance, but also has unique value in narrowing the urban-rural digital divide and promoting public service equality. This article takes Zhejiang Province as an example to explore in depth the impact and effects of digital inclusive finance on promoting rural revitalization.

## **2. Literature review**

### **2.1. Research on digital inclusive finance**

With the innovation of digital technology, digital inclusive finance has gradually become a new stage of its evolution. Compared to traditional financial models, digital inclusive finance has shown unique advantages in poverty reduction. Research has shown that digital finance helps households enhance their risk resilience by providing convenient payment, savings, and credit services, especially in rural areas where the widespread use of digital payment tools directly promotes smooth consumption and income growth <sup>[1]</sup>. The latest research further reveals that digital financial platforms, by integrating agricultural production data, provide precise credit support for returning entrepreneurial groups, significantly improving the entrepreneurial activity and employment quality in rural areas <sup>[2]</sup>.

### **2.2. Research on rural industrial revitalization**

Due to the heterogeneity of agricultural development both domestically and internationally, China and other countries have different models of rural industrial development. Under the promotion of agricultural policies in various countries, rural industries are diversifying towards high-value industries. However, there are still problems such as small business entities, fragmented management, and lagging development of industry organizations. Therefore, in the process of revitalizing rural industries, the government needs to formulate relevant industrial policies reasonably to achieve industrial organization <sup>[3]</sup>. Secondly, the subjectivity of farmers in the process of rural industrial revitalization cannot be ignored. Farmers are the foundation of rural social development, and rural industrial revitalization cannot be separated from farmers' rural production, rural culture, and rural governance <sup>[4]</sup>.

### **2.3. The impact of digital inclusive finance on rural industrial revitalization**

Existing research indicates that there is an interactive development mechanism between the digital economy and rural industrial revitalization. The main content includes that digital inclusive finance can alleviate financing constraints in the process of rural industrial revitalization, and rural industrial revitalization provides a broad development space for the digital inclusive finance market <sup>[5]</sup>. Digital inclusive finance has the advantages of



reducing financial supply costs, usage costs, providing convenient insurance services, and transaction methods, which can alleviate rural industrial financing constraints, improve the availability of industrial funds, provide industrial risk protection, and alleviate rural agricultural product transaction constraints. While various rural agricultural business entities generally face different degrees of financial exclusion when seeking financial services, digital inclusive finance based on Internet platform and digital technology has greatly filled the funding gap of various rural industries <sup>[6]</sup>. At the same time, digital inclusive finance integrates emerging financial technology into all aspects of rural industrial production and operation activities, greatly extending the agricultural industry chain and improving agricultural added value <sup>[7]</sup>. At the same time, existing research also points out that digital inclusive finance has a spatial spillover effect on rural industry development. Digital support for digital inclusive finance can make financial services more convenient and practical. With the universality, timeliness, and inclusiveness of Internet information technology, it can overcome geographical barriers, break the barrier boundary of traditional financial constraints, drive financial deepening and agglomeration in surrounding areas, improve the matching of elements required for rural industry development, and promote rural industry development <sup>[8]</sup>.

### **3. Definition and related concepts**

#### **3.1. Digital inclusive finance**

The inclusive financial system is an important innovative model in modern financial development, originating from the inclusive financial framework proposed during the International Year of Microcredit in 2005. Its core is to create a multi-level and inclusive financial environment that covers a wide range, addressing the exclusion of socially and economically vulnerable groups, such as small and micro enterprises, rural residents, and low-income groups, from the traditional financial system. The Blue Book on Inclusive Financial Systems, released by the United Nations in 2006, systematically established its theoretical framework, emphasizing the need to establish innovative mechanisms with flexible systems, differentiated services, and sustainable supply. Through flexible adjustment of financial products and services, the 28 rules of traditional finance can be changed. This system not only includes innovative tools such as digital inclusion and micro credit, but also includes the construction of financial infrastructure networks and the optimization of policy support systems. By lowering the threshold for financial entry and expanding the scope of services, a dynamic balance between accessibility and sustainability of financial services can be achieved <sup>[9]</sup>.

The inclusive financial system has important value in multiple dimensions: at the micro level, it can make it easier for households to obtain financing and stimulate internal development momentum; At the meso level, enhance the financial adaptability of small and medium-sized enterprises throughout their entire lifecycle <sup>[10]</sup>. At the macro level, there is a non-linear transmission relationship between the inclusive finance development index and the poverty reduction effect. As a way to achieve sustainable development goals, inclusive finance alleviates the problem of capital misallocation and reconstructs the mechanism of economic resource allocation. The multifaceted benefits it brings are not only helpful in preventing intergenerational poverty but also reflected in the dual enhancement of inclusive growth and financial ethical values, becoming an important institutional arrangement for promoting balanced socio-economic development.

#### **3.2. Rural revitalization**

Rural industrial revitalization is a complex and important concept that involves various aspects of the rural economy, aiming to increase agricultural output value, optimize industrial structure, enhance rural economic

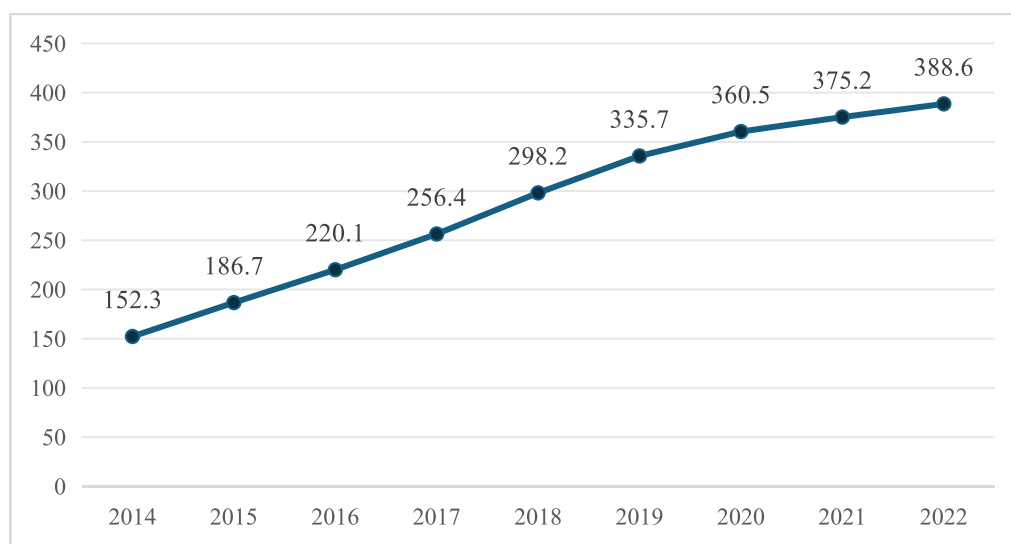
development vitality, and improve the living standards of farmers. Firstly, the revitalization of rural industries emphasizes the development of industries, which means that people must not only focus on the development of the primary industry, namely agriculture, but also pay attention to the development of rural industries and service industries. In terms of agriculture, the revitalization of rural industries requires the promotion of advanced agricultural technologies in rural areas to improve agricultural production efficiency and the added value of agricultural products. In terms of rural industry, the revitalization of rural industries requires guiding and cultivating rural enterprises, developing industries such as agricultural product processing and handicraft manufacturing, and promoting the transformation and upgrading of rural industry.

In terms of the rural service industry, the revitalization of rural industries requires the development of emerging service industries such as rural tourism, e-commerce, and logistics distribution, providing new growth points for the rural economy. Secondly, the core goal of rural industrial revitalization is revitalization, which means optimizing industrial structure, improving industrial quality, and enhancing industrial competitiveness to promote the sustainable development of the rural economy. At the same time, it is necessary to strengthen scientific and technological innovation, brand building, market development, and other aspects to jointly promote and enhance the comprehensive strength and competitiveness of rural industries. Finally, the core of rural industrial revitalization lies in farmers, emphasizing that the interests of farmers should always be given top priority in rural development, and truly benefiting farmers in the process of rural industrial revitalization.

## 4. Current situation and research

### 4.1. The development status of digital inclusive finance in Zhejiang Province

The Peking University Digital Financial Inclusion Index (DFII) is jointly developed by the Peking University Digital Finance Research Center and Ant Group Research Institute to measure the popularity and inclusiveness of digital financial services in various regions of China. This article calculates the Digital Inclusive Finance Index of Zhejiang Province from 2014 to 2022 (**Figure 1**).



**Figure 1.** Zhejiang province digital inclusive finance index from 2014 to 2022

As shown in **Figure 1**, from 2014 to 2022, the digital inclusive finance index in Zhejiang Province showed a continuous and rapid growth trend, rising significantly from 152.3 points in 2014 to 388.6 points in 2022, with an overall cumulative growth rate of 155.1%. The compound annual growth rate is 12.4%, reflecting Zhejiang Province's leading development strength in the field of digital finance. In terms of the trend of change, the growth of this index can be divided into three stages: from 2014 to 2016, it was in a high-speed growth stage, mainly benefiting from the rapid popularization of mobile payments; The period from 2017 to 2019 is a gradual improvement stage, reflecting the transition of digital financial services towards deep application; Entering a mature development stage after 2020 indicates that digital inclusive finance has achieved a high level of coverage. It is worth noting that there is a significant synergistic effect between the growth of the index and the increase in rural residents' income, especially after the index broke through the key point of 250 in 2017; its marginal driving effect on the rural economy has become increasingly apparent. From a structural perspective, the contribution of digitalization indicators (such as mobile payment penetration rate) has shown a continuous upward trend, rising from 42% in 2014 to 58% in 2022, becoming the core force driving the index to rise. Regional differences still exist, and the growth rate gap shows a tendency to widen, which points out the starting point for precise policy formulation in the next step. These findings not only indicate the support effectiveness of digital inclusive finance for rural revitalization, but also reveal the structural contradictions that need to be noted in its development stage.

## 4.2. The development status of rural revitalization in Zhejiang Province

According to data from the National Bureau of Statistics, since 2012, the total output value of agriculture, forestry, animal husbandry, and fishery in Zhejiang Province, as well as the segmented agricultural output value, forestry output value, and fishery output value, have continued to grow positively (**Table 1**). However, the total output value of animal husbandry has fluctuated significantly, showing an overall trend of first decreasing and then increasing.

**Table 1.** Subdivision of agricultural, forestry, animal husbandry, and fishery output in Zhejiang Province from 2014 to 2022

Segmented output value of agriculture, forestry, animal husbandry, and fishery in Zhejiang Province (unit: billion yuan)

	Total fishery output value	Total output value of animal husbandry	Total forestry output value	Total agricultural output value
2014	779.36	472.23	147.00	1385.96
2015	855.85	426.18	151.63	1434.71
2016	899.07	455.6	158.15	1455.29
2017	979.28	371.29	170.16	1494.49
2018	1043.27	331.8	177.01	1517.96
2019	1080.93	395.16	185.48	1594.96
2020	1130.63	472.63	189.56	1593.96
2021	1188.32	402.74	168.25	1697.86
2022	1261.18	405.66	183.01	1769.83

From **Table 1**, Zhejiang Province's agriculture, forestry, animal husbandry, and fishery industries have shown significant structural evolution, with fishery output value increasing from 77.936 billion yuan in 2014 to



126.118 billion yuan in 2022, with an average annual growth rate of 5.3%. The experience of animal husbandry first declined and then stabilized (with a low of 33.18 billion yuan in 2018 and a rebound to 40.566 billion yuan in 2022), reflecting the hedging effect of environmental protection production restrictions and ecological breeding policies; Agriculture has always been a pillar industry (accounting for 45% in 2022), benefiting from the promotion of digital facility agriculture, and the growth rate has accelerated to 6.5% after 2021; Forestry is slowly growing supported by the resilience of the industrial chain, and will rebound to 18.301 billion yuan in 2022. The unique economic role of the Anji bamboo industry and other industries is significant.

### 4.3. Empirical analysis of the impact of digital inclusive finance on rural revitalization

This article takes 90 counties (districts, cities) under the jurisdiction of 11 prefecture-level cities in Zhejiang Province as the research object, selects panel data from 2014 to 2022, and constructs an empirical analysis model of digital inclusive finance and rural revitalization.

The data of digital inclusive finance mainly comes from the county-level digital inclusive finance index released by the Digital Finance Research Center of Peking University, which involves three dimensions: coverage breadth, usage depth, and digitalization degree; At the same time, the regional financial statistics of Hangzhou Central Branch of the People's Bank of China are integrated, including the number of rural mobile payment transactions and the scale of agricultural digital credit. The data on rural revitalization comes from the "Zhejiang Statistical Yearbook", the rural revitalization evaluation report of the Zhejiang Provincial Department of Agriculture and Rural Affairs, and the statistical bulletins of various counties and districts, covering five dimensions of specific indicators: industrial prosperity, ecological livability, rural civilization, effective governance, and affluent living. The control variables (such as per capita GDP, financial support for agriculture, overall level of infrastructure, etc.) are mainly obtained from official channels such as the Zhejiang Provincial and municipal statistical yearbooks, financial settlement reports, and communication management bureaus.

In order to further explore the impact of digital inclusive finance on rural revitalization, this article constructs the following regression model between digital inclusive finance and rural revitalization:

$$RDI_t = a_0 + a_1 DFII_t + a_2 X_t + \varepsilon_t$$

In the formula,  $t$  is the year of investigation;  $a_0$  is the intercept term;  $RDI$  stands for Rural Revitalization Index, which measures the development level of rural revitalization in Zhejiang Province;  $DFII$  stands for Digital Inclusive Finance Index, which is used to measure the development of digital inclusive finance in Zhejiang Province over the years;  $X$  represents two control variables, namely fiscal intervention and urban-rural income gap;  $\varepsilon$  represents the influence of other factors that the model did not consider.

Before conducting analysis and modeling, descriptive statistics should be conducted on the variables studied to comprehensively grasp the overall situation of the variables (**Table 2**).

**Table 2.** Descriptive statistical results

Variable	Sample size	Average value	Standard error	Min	Max
RDI	9	0.586	0.119	0.412	0.761
DFII	9	285.967	86.319	152.3	388.6
FI	9	0.164	0.011	0.146	0.178
URgap	9	2.013	0.066	1.9	2.09

According to **Table 2**, the average rural revitalization index is 0.586, indicating significant differences in the level of rural revitalization among different regions. The maximum value (0.761) is about 1.85 times the minimum value (0.412), indicating an uneven development of rural revitalization in Zhejiang Province. The digital inclusive finance index fluctuates greatly (standard deviation 86.32), with the highest value (388.6) being 2.55 times the lowest value (152.3), reflecting significant regional differentiation in the depth of digital financial service coverage within the province. The ratio of fiscal intervention is relatively stable (with a standard deviation of only 0.011), indicating that there is little difference in the proportion of fiscal expenditure among different regions ( $16.4\% \pm 1.1\%$ ). The average income gap between urban and rural areas is 2.013, which means that the income of urban residents is about twice that of rural residents, which is in line with the current characteristics of the urban-rural income gap.

Benchmark regression analysis is a core method in empirical research that constructs a basic model, controls for core explanatory variables and covariates, and tests the basic relationships and statistical significance between variables (**Table 3**). Its purpose is to verify theoretical hypotheses (such as variable influence direction, significance level), provide a benchmark for subsequent model extensions (such as instrumental variables, panel data), and evaluate the explanatory power of the model through indicators such as  $R^2$  and t-value.

**Table 3.** Results of benchmark regression analysis

Variable	Coefficient	Standard error	<i>t</i>	<i>P</i>
DFII	0.907**	0.032	28.34	0.000
FI	0.309*	0.125	2.47	0.047
URgap	-0.106*	0.038	-2.79	0.028
Constant	-0.521*	0.112	-4.65	0.003

Note: \*\*\*  $P < 0.01$ , \*\*  $P < 0.05$ , \*  $P < 0.1$

Through **Table 3**, it can be seen that digital Inclusive Finance has a significant role in promoting rural revitalization, the elasticity coefficient is 0.91, and the interpretation is as high as 99.4%, which proves that digital finance has become the core driving force to promote rural progress in Zhejiang Province by alleviating financing constraints and driving rural e-commerce. The income gap between urban and rural areas shows obvious negative effects ( $\beta = -0.106$ ,  $P$  less than 0.05), which confirms that urban and rural integration is the key basis for Rural Revitalization. Although fiscal intervention has positive effects, it overlaps with digital finance in terms of policies, and the efficiency of resource allocation should be improved.

## 5. Conclusion and recommendations

### 5.1. Conclusion

Based on the provincial panel data of Zhejiang Province from 2014 to 2022, this paper empirically explores the impact and mechanism of digital Inclusive Finance in Zhejiang Province on Rural Revitalization, and finds that digital Inclusive Finance in Zhejiang Province has a significant positive impact on Rural Revitalization. This finding provides strong evidence support for policymakers, indicating that in the process of promoting rural revitalization, people should pay attention to the development of digital Inclusive Finance and promote the prosperity and development of the rural economy by improving the popularization and convenience of financial

services. At the same time, people should also pay attention to the impact of fiscal intervention and the gap between urban and rural areas on Rural Revitalization in order to achieve more comprehensive and sustainable development.

## 5.2. Recommendations

On the one hand, Zhejiang needs to establish a policy effectiveness evaluation system: monitor the overlapping scope of fiscal subsidies and digital financial services with the help of big data platform, and dynamically adjust the field of fiscal capital investment; Comprehensively deepen the cooperation mode of government, bank and insurance: set up a risk compensation fund for rural revitalization, implement up to 30% risk sharing for agricultural digital loans issued by financial institutions, and enhance the driving force for the sinking of small and medium-sized bank services; Implement and promote the mechanism of Green Finance and ecological compensation: pilot implement the value accounting system of ecological products in ecological functional areas such as Anji and Chun'an, and study relevant tools such as pledge loans of carbon sink income rights and special bonds for GEP transformation. On the other hand, cities need to improve the level of county digital infrastructure, the key is to improve the coverage of 5g base stations and cold chain logistics cloud platforms in mountainous and island areas of southern Zhejiang, arrange special funds to support the digital transformation of rural e-commerce industrial parks, and smooth out the trouble of Regional Digital divide; Build an innovative financial product system with characteristic industrial chains, set up a block chain and supply chain financing platform for characteristic industries such as tea and fishery, establish a quality traceability pledge loan mechanism for agricultural products based on the Internet of things, and realize the precise fit between financial resources and rural industries; The government should build a supporting carrier for industrial and financial synergy, promote the adoption of the mode of Digital Economy Industrial Park and inclusive financial service station, guide financial institutions to support new industrial formats such as smart agriculture and rural tourism with financial discount, and create an interconnected ecology of digital technology financial resources industrial clusters.

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# Research on the Credit Risk of Private Real Estate Enterprise Bonds under the Background of Real Estate Regulation

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**Abstract:** Adhering to the positioning of “no speculation in real estate and housing”, China has successively promulgated “345” new regulations, loan concentration management and other real estate industry regulatory policies, further tightened the industry’s financing environment, gradually exposed the credit risks of real estate enterprises under high leverage operation, and bond default events have occurred frequently since 2018. In this context, the article divides the period from 2018 to 2021 into three concentrated default stages in combination with the real estate regulatory policy, explores the factors that cause the bond default of real estate enterprises, and explains the credit risk changes of private enterprises by quantitative analysis. The results show that the credit risk of the real estate industry is deteriorating, and the default risk of private enterprises is greater than that of state-owned enterprises. Finally, some referential suggestions are put forward for the steady and healthy development of the industry.

**Keywords:** Real estate industry; Credit risk; Bond default; Private enterprise

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## 1. Introduction

The real estate industry is an important industry related to the country and people’s lives, and has a strong driving effect on the macro-economy. In the face of excessively fast-rising house prices, China first proposed “no speculation in real estate and housing” in 2016. Since then, the regulatory policies for the real estate industry have been intensively introduced, and the financing channels of real estate enterprises have been gradually tightened. Since the first domestic real estate enterprise defaulted on its bonds in 2018, credit risk events have occurred in the industry. Not only has the credit status of small and medium-sized real estate enterprises deteriorated, but also the credit status of some large real estate enterprises has attracted market attention. At the meeting of the Political Bureau of the CPC Central Committee in 2022, it was clearly pointed out that “it is necessary to effectively control key risks and maintain the bottom line of no systemic risks.” Under the orientation of “no speculation in housing



and housing”, it is particularly important to reduce the credit risk of real estate enterprises and maintain the healthy development of the industry.

The bond market is an important financing channel for the real estate industry. Since 2015, the issuance of domestic bonds by real estate enterprises has exploded, and the amount of overseas bonds has increased year by year. In 2021, the bond repayment period began. However, in the downward cycle of the industry, factors such as the impact of the epidemic and the shortage of funds within the company have been superimposed, resulting in bond defaults by many real estate enterprises, of which private enterprises account for a large proportion. In addition, some credit rating agencies do not directly consider the impact of the domestic macro environment and industry background; their risk early warning ability is weak, and there is information asymmetry in the capital market. Therefore, it is necessary to analyze the factors that lead to the default of real estate companies in order to identify and prevent the occurrence of bond credit risks.

In view of this, this paper summarizes the overall situation of bond defaults of real estate enterprises in combination with real estate regulatory policies, divides 2018–2021 into three concentrated default periods, inspects the main risk factors of defaulting real estate enterprises from a qualitative perspective, and measures the default risks of different types of corporate bonds by combining quantitative means. Finally, it provides some suggestions for the steady development of the real estate industry.

## 2. Literature review

Nowadays, there is a lot of literature about the default risk of corporate bonds. This paper will mainly sort out the relevant literature from two aspects: one is about the factors affecting bond default, and the second is about the measurement of credit risk.

In terms of the influencing factors of bond default, Kay Giesecke et al. found that GDP growth rate has a warning effect on bond default. When the economic situation is bad, the probability of bond default is relatively high <sup>[1]</sup>. Ben Zion et al. studied the relationship between the company’s own qualifications, debt structure, and the company’s credit risk. The research results show that enterprises with better qualifications are more likely to issue bonds, but at the same time, companies with worse qualifications have a higher debt ratio compared with enterprises in the same industry <sup>[2]</sup>. Similarly, domestic researchers also conducted research from the perspective of industry and macro-economy <sup>[3–4]</sup>. In addition, Zhang Qiang and Sui Xueshen conducted a statistical analysis of the bond default problem. The research results show that the internal reasons of the company are the main reasons, and the external reasons play an inducing role <sup>[5]</sup>. Lan Faqin et al. conducted research from the perspective of industry sensitivity, and found that the default rate of real estate and other industries has increased in recent years, and the aggregation area of default subjects has moved to the south <sup>[6]</sup>.

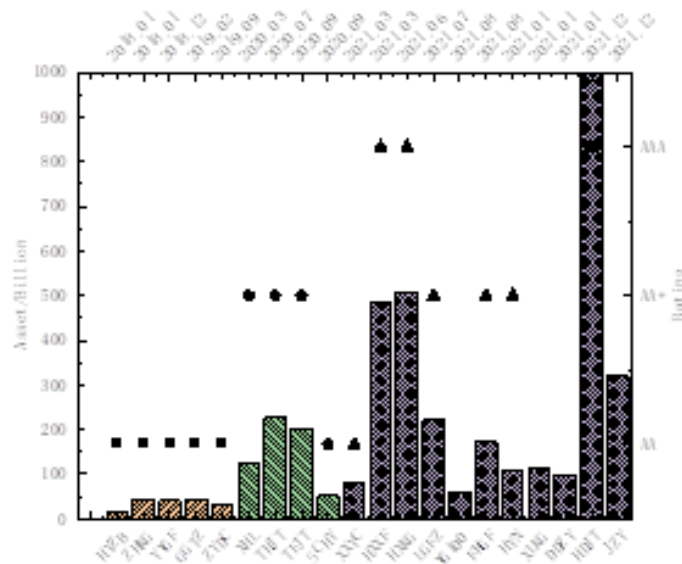
In terms of default risk measurement, foreign scholars’ research on bond risk has been relatively mature. Altman screened 22 financial indicators and finally constructed the classical financial risk measurement model Z-score Model <sup>[7]</sup>. In 1997, KMV company developed the KMV model based on the model established by Merton (1974), which can reflect the market expectation and the default risk of enterprises in time by calculating the default distance <sup>[8]</sup>. On the basis of the above research, domestic scholars continue to deepen. Yang Xiuyun et al. believe that the comprehensive use of the KMV model and financial data of financial companies will make the results more reliable in credit rating based on qualitative and quantitative analysis. In recent years, some scholars have begun to use machine learning methods to predict and measure the possibility of credit risk <sup>[9]</sup>. Xiao Jiayi

combined a BP neural network with the KMV model to estimate the data of unlisted companies when measuring the default risk of unlisted company bonds <sup>[10]</sup>.

### 3. Default in the real estate industry

As listed in **Table 1**, according to the real estate control policy and the company's default situation, the defaulting real estate enterprises in 2018–2021 are generally divided into three centralized defaults. In the first centralized default, due to the loose financing environment of the industry in the early stage, house prices rose rapidly. At the central economic conference at the end of 2016, it was proposed for the first time that “housing and housing should not be speculated”. Subsequently, differentiated credit policies were implemented one after another, and a housing system combining rent and purchase was built to limit demand; At the same time, check the trust business carried out in violation of regulations, prohibit bank financing and trust funds from flowing into the real estate market in violation of regulations through banking and credit business, and restrict the inflow of funds from the supply side. The simultaneous efforts of both supply and demand have gradually exposed the risks accumulated by some companies under the rapid expansion. It can be seen from **Figure 1** that the ratings of the five default real estate enterprises from 2018 to 2019 are all AA, and the asset scale at the time of default is not much different, all of which belong to small private real estate enterprises.

In the second centralized breach of contract, China reiterated that “no speculation in housing” and stressed that the economic policy was relatively loose due to the impact of COVID-19 in 2020. However, the operating conditions of real estate enterprises are still poor, and the sales at the demand side have fallen more than expected, which has hindered some companies from collecting money. On the supply side, the production stoppage and shutdown led to the slow development progress of the company’s stock projects, the reduction of the inventory removal rate, and the breakage of the capital chain.



**Figure 1.** Asset scale and credit rating of default enterprises

In addition, compared with the companies that defaulted before, these real estate enterprises have a larger volume. Three of them have an asset scale of more than 100 billion yuan, a higher main rating, and an increase in

the default balance.

Due to the corresponding economic stimulus policies during the epidemic, the price of commercial housing in some regions rose rapidly, and then the real estate regulation policy was further intensified. In 2020, the state put forward the “three red lines” and the real estate loan concentration management policy, which were implemented in 2021. The real estate market has taken a sharp turn for the worse, and the credit risks of the industry have been exposed and worsened, resulting in the third concentrated default. In 2021 alone, there were as many as 11 defaulting real estate enterprises, almost all of which were listed private enterprises, and the company’s asset scale increased significantly. In addition, in terms of corporate ratings, the domestic main ratings of the three companies when issuing bonds were all AAA, and the overall ratings were also significantly higher than the previous two stages.

**Table 1.** Overview of the default of domestic real estate companies in 2018–2021

	First default	Debt issuer	Enterprise type	Whether to list
The first centralized default (Real estate regulation tightens)	2018.01	HYZB	Private	NO
	2018.01	ZHKG	Private	NO
	2018.12	YYGF	Private	YES
	2019.02	GGTZ	Private	NO
	2019.09	ZYDC	Private	NO
The Second centralized default (COVID-19 pandemic shock)	2020.03	XHL	Private	NO
	2020.07	THJT	Private	YES
	2020.09	TFJT	State-owned	NO
	2020.09	SCHY	Private	NO
The Third centralized default (“Three red lines”, real estate loan concentration management, etc.)	2021.03	XXYC	Private	NO
	2021.03	HXXF	Private	YES
	2021.06	HXKG	Private	NO
	2021.07	LGFZ	Private	YES
	2021.08	YG100	Private	YES
	2021.08	FHGF	Private	YES
	2021.01	HYN	Private	YES
	2021.01	XLKG	Private	YES
	2021.01	DDZY	Private	YES
	2021.12	HDJT	Private	YES
	2021.12	JZY	Private	YES

## 4. Analysis of default factors of enterprise bonds

### 4.1. Macro and industry level analysis

At present, China’s economy has entered the “new normal.” The real estate industry has a typical pro-cyclical nature, which is bound to be affected by the macroeconomy. In terms of demand, the sluggish willingness of residents to buy houses has led to a larger-than-expected decline in real estate sales. On the supply side, enterprises are suffering from epidemic prevention and control. The original projects are slow to start. Under the influence of both sides of supply

and demand, the debt repayment pressure of real estate enterprises has posed a great test to cash flow.

The financing of the real estate industry has been under policy constraints and faced with greater policy risks. It can be seen from **Table 2** that since 2016, the growth rate of funds has obviously shown a downward trend. Although there are abundant financing channels, the actual funds have grown slowly. It is likely that low-cost financing methods, such as standardized bonds in the industry, are not enough to cope with the huge debt repayment pressure.

**Table 2.** Funds and growth rate of the real estate industry in 2015–2020

Time	2015	2016	2017	2018	2019	2020	2021
Funds	12.52	14.42	15.61	16.64	17.86	19.31	12.52
YOY	2.6%	15.18%	8.21%	6.64%	7.33%	8.12%	2.6%

## 4.2. Summary of default factors of real estate enterprises

This paper summarizes the characteristics of four aspects by combining the defaulting real estate enterprises.

- 1) In the stage of rapid development of real estate, some companies will rely on huge profit space to diversify into other industries, and some companies will accelerate the layout of national businesses. However, due to the rapid investment pace of real estate enterprises, a large amount of cash of the company was consumed, and even a large loss of investment projects occurred, resulting in their own capital shortage and debt crisis.
- 2) Real estate enterprises generally adopt the high-leverage operation strategy to make up for the funds needed for the early-stage project development. However, if the project development link is blocked or the real estate sales decline, it may lead to a large amount of funds being deposited in the existing projects, which may lead to a debt crisis. At the beginning of the outbreak of COVID-19 in 2020, many real estate project development was suspended for a time, and the project decentralization rate plummeted. Some companies could not bear the short-term pressure of funds, resulting in default.
- 3) In order to obtain non-standard financing from trust companies and other institutions, enterprises have mortgaged a large amount of the company's assets, but when it is difficult to cash bonds, they cannot sell the mortgaged assets. In addition, the location of real estate projects of some real estate enterprises has sunk to lower-tier cities, with accumulated inventories and low liquidity. Some companies have limited monetary capital, because many regions limit the scope of use of pre-sale funds, which is limited to the development of related projects, so that companies cannot arrange to repay debts at will. Therefore, when the company is faced with debt repayment demands, even if the company has more cash on its books, most of it has been restricted and cannot repay the debts when they become due.
- 4) In order to meet the needs of debt index supervision, many enterprises have taken part of their debts off the balance sheet or modified them into equity, and the hidden debt problem is relatively serious. Nominally, minority shareholders' rights in companies often come from joint development projects with other companies, but at the end of the project, the enterprise must buy back these minority shareholders' rights with capital contributions. In addition, the debt of the project company controlled by the real estate enterprise is not directly reflected in the consolidated report of the company, and the debt is listed. Once these off-balance sheet liabilities mature, it is easy to lead to a large amount of cash expenditure of the company and trigger a liquidity crisis.

## 5. Default analysis and evaluation based on the Z-Score model and the KMV model

### 5.1. Credit risk analysis based on the Z-score model

The Z-score model was proposed by economist Altman in 1968. By selecting important financial ratio indicators and giving them certain weights, a comprehensive score value is calculated to measure the financial health of enterprises.

Its model expression is:

$$Z = 0.012X_1 + 0.014X_2 + 0.033X_3 + 0.006X_4 + 0.999X_5$$

Where:

$X_1$  = working capital / total assets

$X_2$  = retained earnings / total assets

$X_3$  = profit before interest and tax / total assets

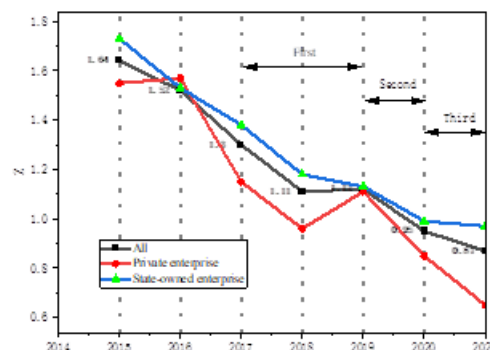
$X_4$  = owner's equity / total liabilities

$X_5$  = operating income / total assets

Generally speaking, the higher the Z value, the better the overall financial performance of the enterprise, and the less likely the corresponding credit risk will occur. When the Z value is less than or equal to 1.81, the financial situation is worrying, and the possibility of bond default is also high; When the Z value is between 1.81 and 2.675, the financial situation of the enterprise needs to be paid attention to; the financial situation is unstable, and credit risk may occur; When the Z value is greater than 2.675, it can be inferred that the company's financial condition is good and the probability of default is low.

This paper selects real estate development enterprises in the Shen-wan industry and A-share listed companies with existing bonds by the end of 2021. The total number of enterprises is 66, including 40 state-owned enterprises and 17 private enterprises, accounting for nearly 25% of the total. Other types include 9 collective and foreign-funded enterprises.

As shown in **Figure 2**, the Z-value of the sample companies has been in the range of a worrying financial situation since 2015, and the credit situation has been deteriorating. Since 2017, the real estate regulatory policy has become stricter. In 2018, the first company defaulted, which triggered the first centralized default. It can be seen that the Z-value of private enterprises fluctuates significantly. Although the Z-value of state-owned enterprises has decreased, the change is not large, and is generally higher than the industry average, reflecting the credit risk resistance of state-owned real estate enterprises. Under the influence of regulatory policies and other factors, in 2019, the financial leverage ratio of real estate enterprises decreased, the short-term solvency was strengthened, and the financial situation of the whole industry was improved, among which private real estate enterprises performed significantly.



**Figure 2.** Changes in the Z value of the real estate industry from 2015 to 2021



In the second stage, private enterprises reacted more violently to the impact of the epidemic, and the Z value fell from 1.24 in 2019 to 0.85 in 2020. In the third centralized default, with the implementation of the “three red lines” and other policies, it was also at the peak of domestic credit debt repayment, and the pressure on bond financing enterprises to repay their funds was huge. The financial risks of private enterprises and state-owned enterprises were further differentiated, and the financial situation of state-owned enterprises was relatively stable. However, 11 companies of private real estate enterprises defaulted in 2021, and their financial situation further deteriorated.

In order to further investigate the distribution of the company's Z-value, the article counts the number of specific sample companies in the three segments of the Z-value. It can be found from **Table 3** that the number of companies with  $Z > 2.675$  has significantly decreased year by year, and many enterprises have experienced thunderstorms from 2018 to 2021. The number of companies with  $1.81 < Z < 2.675$  also showed a downward trend. The proportion of companies with  $Z < 1.81$  continued to increase from 2015 to 2021. At the end of 2021, nearly 94% of the companies had high financial risks. In addition, the number of state-owned companies with  $Z > 1.81$  is mostly, and some of these state-owned enterprises are directly or indirectly held by the City Investment Corporation.

**Table 3.** Distribution of the Z-value interval of the sample companies

Z value	2015	2016	2017	2018	2019	2020	2021
$Z < 1.81$	52	52	55	61	61	64	62
$1.81 < Z < 2.675$	7	8	10	5	4	2	4
$Z > 2.675$	7	6	1	0	1	0	0

Based on the above analysis, this paper selects 10 listed companies with a city investment background. As shown in **Table 4**, the shareholding of City Investment Corporation will have a positive impact on the credit of real estate companies.

**Table 4.** Average Z-value of the urban investment background company and City Investment background company

Average Z value	2015	2016	2017	2018	2019	2020	2021
State-owned	1.73	1.53	1.38	1.18	1.13	0.99	0.97
City Investment Company holding	2.08	1.84	1.64	1.46	1.50	1.27	1.18

## 5.2. Credit risk analysis based on the KMV model

Although the Z-score model can explain the increase in the overall credit risk of the real estate industry, and can also reflect the financial changes of real estate companies in each concentrated default period. However, companies with  $Z < 1.81$  account for the vast majority, which is slightly different from the actual situation. Moreover, the model performs poorly in identifying the credit risk differences between private real estate enterprises and state-owned real estate enterprises. In order to further measure the credit risk of the company and reflect the gap between the credit risk of private and state-owned real estate enterprises, the article excludes 10 listed real estate companies held by CIC from the existing sample. At this time, the sample companies include 17 private enterprises and 30 state-owned enterprises. The KMV model is adopted to measure the default distance between private real estate enterprises and state-owned real estate enterprises and estimate the default probability.

This model is based on the Black Scholes Merton option pricing model, and takes the debt value (D) as the

agreed price of European call options. When the company's asset value ( $V$ ) is lower than the agreed price ( $D$ ), it will default. This model calculates the probability of default (EDF) at the maturity of debt, that is,  $P(VT \leq D)$ , and defines the default distance (DD) as the distance between the company's asset value and debt value. The smaller the default distance, the greater the probability of default, indicating that the company's credit risk is greater.

The steps for calculating the expected default probability of the company under the KMV model mainly include:

- 1) According to the closing price of the company's shares, this paper calculates the volatility of the company's equity value according to the historical volatility method, takes the one-year lump sum deposit and withdrawal interest rate of the central bank as the risk-free interest rate, and derives the formula of the company's asset value  $V$  and Volatility ( $\sigma_v$ ) according to the B-S-M model and the relationship between the volatility of the equity value ( $\sigma_E$ ) and the volatility of the company's asset value ( $\sigma_v$ ).

$$E = VN(d_1) - De^{-r(T-t)}N(d_2) \quad (1)$$

Wherein,

$$\begin{cases} d_1 = \frac{\ln(\frac{V}{D}) + (r + \frac{\sigma_v^2}{2})(T-t)}{\sigma_v \sqrt{T-t}} \\ d_2 = d_1 - \sigma_v \sqrt{T-t} \end{cases} \quad (2)$$

According to the fact that equity value ( $E$ ) is a function of asset value ( $V$ ) and time ( $t$ ), and asset value ( $V$ ) obeys geometric Brownian motion, it can be concluded that equity value ( $E$ ) also obeys geometric Brownian motion. The relationship between the volatility of equity value ( $\sigma_E$ ) and the volatility of the company's asset value ( $\sigma_v$ ) is as follows:

$$\frac{\sigma_E}{\sigma_v} = \frac{V}{E} N(d_1) \quad (3)$$

- 2) Calculate the default point (DP) and the default distance (DD) according to the corporate liabilities, where the default point = short-term debt + 0.5 \* long-term debt, and the default distance (DD) refers to the distance between the expected asset value of the company and the default point, which has nothing to do with the size of the company. It is a standardized indicator. The calculation formula is as follows:

$$DD = \frac{E(V) - DP}{E(V) \sigma_v} \quad (4)$$

- 3) If it is assumed that the asset value of the enterprise follows a normal distribution, it represents the standard deviation of the company's default distance. Therefore, the expected theoretical default probability (EDF) of the enterprise can be obtained as follows:

$$EDF = N(-DD) \quad (5)$$

Due to the late start of China's corporate bond market and the large-scale outbreak of default, it is impossible to establish a default database and obtain the one-to-one correspondence between default distance and expected default rate. Therefore, this paper takes the distance to default (DD) as an indicator to measure the company's credit risk. As shown in **Table 5**, according to the statistical description of the default distance of sample companies in different groups from 2015 to 2021, it is found that the default distance plays a more accurate and significant role in distinguishing the default risk of bonds of listed real estate companies of different natures.

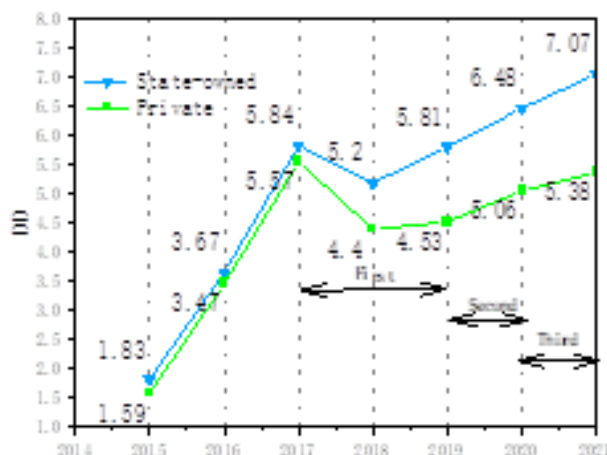
**Table 5.** Sample companies default distance statistical analysis table

	Time	Group	Average value	Standard deviation
Before the centralized bond default	2015	Private	1.59	0.56
		State-owned	1.83	0.51
	2016	Private	3.47	1.08
		State-owned	3.64	1.29
	2017	Private	5.57	1.90
		State-owned	5.84	2.61
First centralized bond default	2018	Private	4.40	1.45
		State-owned	5.20	2.15
	2019	Private	4.53	1.03
		State-owned	5.81	2.63
Second centralized bond default	2020	Private	5.06	1.45
		State-owned	6.48	3.96
Third centralized bond default	2021	Private	5.38	2.34
		State-owned	7.07	4.39

From the perspective of the mean and standard deviation, there was little difference between the mean and standard deviation of the default distance between private and state-owned enterprises from 2015 to 2017. In the three concentrated default periods, the standard deviation of state-owned enterprises is significantly higher than that of private enterprises, which indicates that the default distance of private real estate enterprises is relatively concentrated. And because the average default distance of private real estate enterprises is smaller than that of state-owned real estate enterprises, it indicates that the possibility of concentrated default of private enterprise bonds is higher. The dispersion of the default distance of state-owned enterprise bonds is large, which indicates that the default probability of some state-owned enterprise bonds is still relatively high, which deserves attention.

In order to more intuitively reflect the change of credit risk gap, this paper draws the average change of default distance of different enterprise types from 2015 to 2021. As shown in **Figure 3**, the default distance of state-owned enterprises and private enterprises has increased in volatility, and the average difference between the default distance of state-owned enterprises and private enterprises is not large between 2015 and 2017. However, since 2018, the average default distance has decreased significantly, and private enterprises have decreased significantly. Although the average default distance has increased from 2019 to 2021, the gap between the two has become wider and wider, which indicates that after 2018, the credit risks of state-owned real estate companies and private real estate companies have been seriously differentiated, and the probability of default of private real estate

enterprises is greater.



**Figure 3.** The average value of the default distance (2015–2021)

## 6. Conclusions and suggestions

The article summarizes 20 default cases that occurred from 2018 to 2021, and divides this period into three concentrated default periods. It is found that the vast majority of defaulting companies are private enterprises. The Z-score Model found that: (1) under the period of three concentrated defaults, the overall financial situation of the industry gradually deteriorates; (2) There is a gap in credit risk between state-owned real estate enterprises and private real estate enterprises; (3) The financial performance of real estate enterprises held by CIC is better than that of state-owned real estate enterprises. Further, the KMV model can more accurately depict that the gap between the default distance of private real estate enterprises and state-owned real estate enterprises is growing, which confirms that the possibility of credit risk of private real estate enterprises is higher than that of state-owned real estate enterprises in recent years. In order to prevent and resolve the occurrence of credit risks in the real estate industry, the article puts forward relevant countermeasures and suggestions from the following aspects.

Real estate companies are currently in the phase of elimination, and the possibility of credit risk of private real estate enterprises with weak qualifications is increasing. In the face of debt repayment pressure, real estate companies can first extend the bonds and exchange the bonds that are about to expire through an offer to avoid default. Secondly, the company can introduce state-owned assets and strategic investments to obtain credit endorsement, so as to enhance liquidity. Finally, the company can quickly obtain cash flow, reduce its own burden, and reduce the probability of credit risk by selling project equity and selling diversified businesses.

In order to stabilize the real estate market and to adhere to the positioning of “live without speculation”, government departments should formulate more reasonable counter-cyclical control policies for real estate. Under the urgent requirements of stabilizing house prices, land prices, and expectations, the government should make full use of the policy portfolio tools in the toolbox. The demand side can reduce the mortgage interest rate and the down payment ratio to stimulate residents’ demand for house purchase. The supply side can formulate corresponding real estate financial policies to support the reasonable financing needs of the company. In addition, rating agencies should also improve their rating indicators in combination with the characteristics of the current

domestic real estate market.

## Disclosure statement

The author declares no conflict of interest.

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# Innovations in Enamelled Porcelain Materials and Techniques from the Perspective of Cultural Integration in Southeast Chongqing

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**Abstract:** Enamelled porcelain represents a distinctive category of overglaze decoration that emerged from the fusion of Chinese porcelain body techniques with European low-fusing enamel pigments. This study provides a comprehensive review of the historical evolution of enamelled porcelain and examines its unique artistic language. Particular emphasis is placed on recent innovations in lead-free boron–lithium frit formulations, low-temperature firing processes, and contemporary painting techniques. Through comparative material analysis and firing experiments, the study verifies the energy efficiency, environmental sustainability, and enhanced visual quality of these updated methods. The objective is to offer both technical support and theoretical insights for the sustainable industrial development and cultural revitalization of enamelled porcelain in the contemporary context. Moreover, drawing on traditional ceramic and decorative arts practices in Southeast Chongqing, the paper explores the potential for integrating enamelled porcelain into intangible cultural heritage revitalization and creative cultural industries. This research highlights the aesthetic expression and cultural reinterpretation of this traditional craft from a design-oriented perspective.

**Keywords:** Enamelled porcelain; Porcelain-body painted enamels; Lead-free frit; Low-temperature firing; Artistic language; Intangible heritage revitalization

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## 1. History of enamelled porcelain

Enamelled porcelain originated from the integration of Chinese high-fired white porcelain with Western glass-based colorants, with early prototypes dating back to the Tang and Song dynasties <sup>[1]</sup>. In the 35th year of Emperor Kangxi's reign (1696), the Qing court established the Falangzuo (Enamel Workshop), marking the formal institutionalization of this craft <sup>[2]</sup>. Emperor Kangxi commissioned Jingdezhen kilns to produce plain porcelain

bodies, which were then decorated using imported lead-borosilicate pigments. Court painters collaborated with Jesuit missionaries to execute the polychrome designs, followed by low-temperature refiring, thereby initiating the distinctive technique of “porcelain-body painted enamels”<sup>[3]</sup>. This method, originally derived from European metal-based enamel painting, reached its zenith in the Qing imperial court. During the reigns of Kangxi, Yongzheng, and Qianlong, enamelled porcelain was celebrated for its brilliant colors and meticulous craftsmanship.

The Qing court placed great emphasis on the production of enamelled porcelain, achieving significant advancements between the Kangxi and Qianlong periods<sup>[4]</sup>. However, due to the high production costs, the technique experienced a decline during the mid-Qianlong era. Initial scholarly inquiry emerged during the Republican era, with Yang Xinggu conducting preliminary studies. After the founding of the People’s Republic of China, scientific investigations into enamelled porcelain materials and techniques gained momentum. In the 1970s, Zhang Fukang and colleagues identified the presence of boron in the glaze formulation. Subsequent research by institutions such as the Palace Museum revealed compositional distinctions between various enamelled wares. Although the original technique was lost following the Qing dynasty, efforts to revive it were undertaken in the 20th century, particularly in Jingdezhen. Since the 1980s, advances in material science and manufacturing technology have enabled the batch reproduction of enamelled porcelain. In 2011, it was inscribed on the National List of Intangible Cultural Heritage<sup>[5]</sup>. In recent years, new materials and technologies have further propelled its innovation, positioning enamelled porcelain toward cultural and creative industries and the high-end design market.

In parallel with imperial enamelled porcelain, regional traditions of polychrome ceramics and decorative painting also continued to evolve. Although the southeastern Chongqing region—including areas such as Youyang (酉陽)—was not a historical center of porcelain production, it preserved its own ceramic and decorative traditions. The region is home to diverse forms of folk art, such as Tujia brocade (西蘭卡普), Miao embroidery, and batik, which demonstrate strong visual aesthetics and symbolic motifs. These regional crafts share aesthetic affinities with Qing court enamelling in their vibrant color schemes and auspicious symbolism. Today, the folk arts of southeastern Chongqing provide valuable cultural inspiration for contemporary enamelled porcelain design, enriching its visual language and thematic range. This perspective of craft and cultural integration adds a new historical dimension and humanistic value to the modernization of enamelled porcelain as it transitions from a royal artifact to an object of contemporary cultural significance.

## **2. Artistic expression of enamelled porcelain**

### **2.1. Visual language and material tactility**

The distinctive visual language of enamelled porcelain arises from the interplay between material properties and craftsmanship. The low-melting-point glass pigments, when subjected to secondary high-temperature firing, produce a lustrous, gem-like glaze. Slight fusion of the pigment layer preserves the subtle grooves and diffusion marks left by brushstrokes, combining the textural richness of oil painting with the tonal fluidity of Chinese ink wash. For example, a Qianlong-period imperial yellow-ground porcelain wall vase with landscape motifs exemplifies this synthesis. The bright yellow glaze is punctuated by a reserved white medallion, within which blue pigments depict an impressionistic landscape. The composition blends high-saturation hues with expressive brushwork, embodying the imperial court’s pursuit of both glaze brilliance and painterly refinement. Owing to

its translucent glaze and meticulous execution, enamelled porcelain merges the aesthetics of Chinese ink painting with Western pictorial techniques, culminating in a unique and hybrid visual style.

## 2.2. Evolution of themes and motifs

In the Qing dynasty, falangcai porcelain embodied imperial authority and refined aesthetics, with design and firing tightly coordinated between the Imperial Kiln and Enamel Workshop. Common motifs included auspicious flora, feathers, and imperial inscriptions. During Kangxi's reign, the introduction of rouge-red ground with white reserves became a signature style. The Rouge-red Ground Enamelled Dish (**Figure 1**), decorated with peonies and marked "Made by Imperial Order of Kangxi", symbolizes prosperity and imperial blessings. In the Qianlong era, influenced by European Rococo, court artisans developed yangcai enamels. The Enamelled Vase with Western Figures (**Figure 2**) features gilt scrolls and baroque florals framing European pastoral scenes, reflecting the fusion of Chinese and Western decorative arts.



**Figure 1.** Rouge-red Ground Enamelled Dish with Floral Design, Qing Dynasty, Kangxi period (Collection of the Palace Museum)



**Figure 2.** Enamelled Vase with Gilt Handles and Western Figures in Reserves on a Brocade

### 2.3. Scale and application expansion of enamelled porcelain artifacts

Traditionally, enamelled porcelain artifacts were primarily small-scale ornamental objects, prized for their intricate craftsmanship and ornate beauty, and intended for interior display and appreciation. Contemporary design, however, has extended the scope and scale of enamelled decoration, applying its techniques to a broader range of mediums and functional contexts—including lighting fixtures, wristwatches, and even architectural panels. A notable example is the “Origin” cloisonné enamel wristwatch launched by the Swiss brand Halcyon. On a 43 mm white porcelain dial, intricate cloud-dragon patterns are rendered using cloisonné wirework and subjected to secondary low-temperature firing. The resulting surface retains a jewel-like luster while meeting practical requirements for wear resistance and chemical durability. This innovation exemplifies the potential of enamelled porcelain techniques in wearable design. In the fields of architecture and environmental art, enamel decoration has also begun to appear in the form of porcelain wall murals and surface panels. These applications preserve the vivid coloration and durability of traditional glazes while imbuing architectural spaces with a distinct cultural and aesthetic character. Collectively, these developments signal a transformation of enamelled porcelain from its origins as imperial display ware to a material integrated into contemporary lifestyles. This evolution not only bridges traditional craftsmanship with modern design demands but also repositions enamelled porcelain as a culturally resonant medium within diverse functional and artistic domains.

## 3. Materials and processing technologies for contemporary enamelled porcelain

### 3.1. Porcelain body and biscuit preparation

Modern enamelled porcelain uses high-whiteness bodies for color purity. The base clay primarily consists of low-iron kaolin, with quartz and feldspar additives to control shrinkage and thermal expansion. A typical formulation is about 38% kaolin, 25% potassium feldspar, 23% quartz, and 4% talc. These materials are wet ball-milled and vacuum pugged for a dense ceramic body. After forming and drying, green bodies undergo rapid bisque firing at 1250–1280°C with a 30-minute ramp and 15-minute hold, ensuring  $\leq 1\%$  water absorption and stabilizing thermal expansion at  $\sim 5.6 \times 10^{-6} \text{K}^{-1}$ . This strengthens the body and relieves stress, minimizing glaze cracking risks. Post-bisque firing, a 0.5–1 mm transparent white glaze is applied as a painting substrate and bonding layer. The glaze, composed of potassium feldspar, quartz, and kaolin for thermal compatibility, is ball-milled and aged for improved properties. After firing at  $\sim 780^\circ\text{C}$ , it fuses for a smooth surface, enabling enamel painting.

### 3.2. Formulation of enamel pigments

Enamel pigments are composed of finely ground colored glass powders obtained by fusing silicate-based vitreous materials with coloring agents and opacifiers, followed by rapid quenching and pulverization. Traditional imperial enamel pigments employed high-lead borosilicate frits as the glassy matrix, incorporating metal ions such as gold, copper, cobalt, iron, and tin to achieve various hues—e.g., cobalt and iron for blue-black, gold for rose red, and copper for green. However, the use of lead-based frits poses significant risks due to heavy metal toxicity and environmental emissions. To address these concerns, modern enamel technology has developed lead-free boron–lithium-based frit systems as substitutes for traditional leaded fluxes. In this study, the lead-free frit composition adopted includes  $\text{SiO}_2$  (54%),  $\text{B}_2\text{O}_3$  (18%),  $\text{Li}_2\text{O}$  (10%),  $\text{Na}_2\text{O}$  (8%),  $\text{K}_2\text{O}$  (5%), and  $\text{Al}_2\text{O}_3$  (5%). This formulation has a softening point of approximately  $540^\circ\text{C}$ , which is well-suited to the low firing range of  $\sim 780^\circ\text{C}$ . Upon



application to the porcelain surface, the frit forms a dense and transparent glassy phase, providing an excellent optical base for pigments while eliminating the hazards associated with lead volatilization, thereby improving the process's environmental and occupational safety. In terms of coloring agents, various metal oxides such as CuO, Co<sub>3</sub>O<sub>4</sub>, Fe<sub>2</sub>O<sub>3</sub>, and MnO<sub>2</sub> are added in proportions ranging from 1% to 8% to produce a spectrum of hues, including emerald green, deep blue, reddish-brown, and violet. Opacifiers such as SnO<sub>2</sub> and Sb<sub>2</sub>O<sub>3</sub> are introduced to enhance opacity and color brightness.

The enamel glass powder is ground by ball milling to an average particle size of approximately 4 μm, then mixed with turpentine and clove oil in a volume ratio of 1:0.85 to create an oil-based enamel slurry. This medium exhibits a viscosity of 28–32 Pa·s at 25 °C, offering smooth application, controllable flow, and resistance to pinholes and sagging. It is compatible with both traditional brushwork and modern spraying techniques.

The improved boron–lithium-based enamel system demonstrates no detectable emission of volatile heavy metals, and post-firing exhaust emissions consistently comply with the Special Emission Limits of the *Emission Standard of Pollutants for Ceramic Industry*. Furthermore, the coefficient of thermal expansion (CTE) mismatch between the enamel pigment and the porcelain glaze system remains within  $\pm 0.2 \times 10^{-6} \text{K}^{-1}$ , ensuring crack-free surfaces and vivid, stable coloration. These results confirm the material's green and sustainable performance advantages.

### 3.3. Enamel painting procedure

Enamel decoration requires pre-fired porcelain bodies. Workflow involves three steps: flat brush for background color, pointed brush for linework, and transparent overglaze coating. Place the piece on a ~50°C platform; a flat brush applies paste evenly, heat-reducing viscosity for smooth coverage. Semi-dry, pointed brush outlines motifs, forming raised “line grooves” to enhance relief. After air-drying, apply a thin colorless overglaze. Fire at 780–800°C for ~15 min, sintering glossy film for luster and resistance. The scheme must align with pigment properties and firing for optimal performance and adhesion. Variables affect saturation and adhesion, making it art and engineering, requiring iterative optimization.

Contemporary enamelled porcelain incorporates several classic decorative techniques that have evolved from Qing dynasty traditions. The most prevalent forms include:

- (1) Reserved white panels on colored grounds: The entire vessel is coated with a single-color enamel glaze, while reserved white medallions or cartouches are left unglazed for painted scenes—such as figures, landscapes, or flora and fauna—to be rendered within (**Figure 3**).
- (2) Overpainting on colored grounds: This technique involves first applying a colored enamel glaze across the porcelain surface, followed by additional overpainting in contrasting hues (**Figure 4**).
- (3) Polychrome painting on white porcelain: This literati-oriented technique leaves the white-glazed porcelain body entirely exposed, with floral patterns applied using the *mogu* (boneless) painting method—blending colors directly without outlines (**Figure 5**).
- (4) Cloisonné-style partitioned enamelling: Emulating the metal-wire cloisonné technique, this method outlines motifs in gold or imitation cloisonné lines on the porcelain surface, then fills each segment with enamel colors. Each layer is fired separately at low temperatures to fix the pigments.
- (5) Allover brocade patterning with multicolor overlays: Representative of the highly ornate late-Qianlong style, this technique involves densely tracing brocade-like scrollwork grids across the vessel using glass-white lines, followed by the meticulous filling of each cell with saturated colors such as imperial yellow,



carmine, and emerald blue. Multiple firings (three to four rounds at 700–750 °C) are required to set the colors.

The core decorative styles of enamelled porcelain—reserved medallions, overpainting, minimalist polychrome, cloisonné, and brocade patterns—constitute its traditional aesthetic vocabulary. Using layered pigments or separated motifs, these techniques employ low-temperature overglaze firing (700–800 °C) to achieve jewel-like brilliance and durability. Systematic analysis of these methods offers valuable models for contemporary innovation in form, technique, and aesthetics.



**Figure 3.** Kangxi yellow earth radiant enamel flower bowl



**Figure 4.** Kangxi radiant enamel-colored peony cup in crimson ground



**Figure 5.** Yongzheng enamel colored pheasant peony pattern bowl

### 3.4. Low-temperature firing process

The final enamelled porcelain firing uses a low-temperature overglaze procedure (700–800°C) to melt and fix the enamel layer while protecting the porcelain body. The three-stage sequence includes: first, bisque firing in oxidizing atmosphere at 800°C for 6–8 hours to remove water and strengthen the body; second, high-temperature glaze firing with multi-stage heating to 1300°C, using reducing atmosphere above 1080°C for fusion; third, low-temperature enamel firing, gradually heating to 400°C to eliminate solvents, then to 780°C held for 15 minutes to set pigments, followed by cooling. Oxygen regulation is critical, with concentration maintained at 19.5%–20.5% to prevent discoloration and ensure color fidelity. This study optimized the protocol to balance durability, brilliance, and vibrancy, supporting reliable one-step firing of lead-free boron-lithium enamel while reducing energy use. Results showed firm enamel bonding, rich colors without defects, meeting aesthetic and performance goals.

## 4. Experimental evaluation of enamel-painting materials and processes

### 4.1. Porcelain body compatibility tests

To mitigate thermal stress induced by low-temperature overglaze firing, two types of pre-fired porcelain bodies were selected for comparative testing:

- i. High-density glazed porcelain body: Fired at 1300 °C in a reducing atmosphere, this body exhibits high density with a water absorption rate of less than 0.5%. A smooth, white glaze layer is applied to the surface, making it suitable for refined decorative techniques such as reserved white panels and gold detailing.
- ii. Porous bisque-fired body: Rapidly fired at 1180 °C in an oxidizing atmosphere, this type shows water absorption of 10%–15%. Although unglazed, its sufficient mechanical strength and porous structure facilitate the absorption of oil-based enamel pastes, making it ideal for large-area color application.

Acoustic tapping tests were performed to assess internal integrity. Both types of bodies produced clear, resonant sounds, indicating structural robustness and the capacity to endure subsequent low-temperature firing at 700–750°C. Post-firing inspections confirmed that neither body exhibited glaze cracking, demonstrating that the enhanced glaze-body formulations and firing procedures successfully achieved thermal compatibility across various porcelain substrates.

## 4.2. Preparation experiments of lead-free boron-lithium-based enamel pigments

To address the drawbacks of traditional lead-based frits—which require high melting temperatures (850–900 °C), entail substantial energy consumption, and pose environmental risks due to PbO emissions—this experiment adopted a lead-free frit system based on  $B_2O_3$ – $Li_2O$  as a substitute. The enamel formulation consisted of 90%–95% frit and 5%–10% colorants. The selected pigments included copper oxide (CuO), cobalt oxide ( $Co_3O_4$ ), iron(III) oxide ( $Fe_2O_3$ ), manganese dioxide ( $MnO_2$ ), and several zirconium-based composite stains, ensuring stable chromatic performance. The pigments were subjected to wet ball milling for 48–60 hours using a material-to-ball-to-water ratio of 1:2:0.6. The resulting slurry was refined to a fineness where residue on a 10,000-mesh sieve was limited to 0.01%–0.02%, and the specific gravity of the paste was controlled at 1.50–1.65 g/cm<sup>3</sup>. After milling, the pigment slurry was screened through a 120-mesh sieve to remove ferrous impurities, then naturally dried and low-temperature baked to achieve a moisture content of 5%–8%. The final enamel pigment retained excellent rheological properties even after six months of ambient storage. When applied to ceramic test pieces and fired once at low temperature, the pigment layers exhibited uniform coloration, good adhesion, and no signs of bubbling or sagging. These results verify that the boron-lithium-based lead-free frit system is technically feasible for multi-pigment compatibility and stable low-temperature chromogenic performance.

## 4.3. Performance testing of painting and firing

Using the aforementioned improved process, eight representative enamel color systems were trial-produced on a series of test cups. The testing procedure involved adjusting the specific gravity of the enamel slurry to approximately 1.55 g/cm<sup>3</sup>. A broad base layer was applied using a flat brush, followed by the use of a fine brush loaded with white enamel to outline raised contour lines. Different colors were then filled into designated zones. After air-drying at room temperature, the test pieces were fired once in an electric kiln at 700–750 °C under an oxidizing atmosphere, with a holding time of 15 minutes to ensure complete fusion and solidification. Post-firing results revealed that the enamel layers fused seamlessly with the underlying glaze and exhibited a slightly raised, three-dimensional surface texture. The hues appeared vivid and pure, confirming the reliability of the boron-lithium lead-free pigment system under single low-temperature firing. Further environmental durability testing included thermal cycling between –20 °C and 80 °C, as well as 24-hour immersion in 5% hydrochloric acid. The enamel surfaces showed no signs of blistering, cracking, or noticeable discoloration, indicating excellent weather resistance and chemical stability. These results demonstrate that the newly developed enamel system possesses strong environmental robustness, making it suitable for long-term service applications.

## 4.4. Validation results

Based on the experimental studies, key findings include: using both high-density white-glazed and porous bisque bodies meets differing artistic needs—fine gold detailing and large-area coloring. The  $B_2O_3$ – $Li_2O$  lead-free frit combined with 700–750 °C firing reduces energy use by ~20% versus traditional methods, while improving

color saturation, adhesion, and environmental safety. As shown in **Figure 6**, single-fired samples across eight color families achieved the desired gloss and color purity, with firmly bonded layers. These innovations enhance enamelled porcelain's sustainability and artistry, supporting future large-scale applications.

## 5. Contemporary transmission of craftsmanship and cultural-creative practice

In the 21st century, the revival of enamelled porcelain is marked not only by technological innovation but also by the integration of cultural inheritance and creative transformation. The revitalization and industrialization of intangible cultural heritage (ICH) in the Wuling Mountains region of southeastern Chongqing offer valuable inspiration for contemporary enamelled porcelain design. In 2014, the region was officially designated as a National Cultural and Ecological Protection Zone. Under this framework, local governments have adopted a “ICH+” development model to promote the integration of traditional craftsmanship into modern life, such as “ICH + tourism”, “ICH + poverty alleviation”, and “ICH + industry.”

For instance, the Taohuayuan Scenic Area in Youyang County has introduced heritage crafts like Miao embroidery, creating both cultural enrichment and employment opportunities. Similar initiatives have emerged in Shizhu and Pengshui, where heritage workshops ( 非遗工坊 ) have become catalysts for local employment. By 2023, Chongqing had established 85 such workshops, with Miao embroidery practices from Youyang and Pengshui selected as national exemplary cases. The revitalization of intangible heritage has reinvigorated traditional crafts and opened new directions for the design and cultural significance of enamelled porcelain.

Contemporary designers can draw on innovations in ethnic minority craftsmanship, integrating them into enamelled porcelain production to foster a dialogue between tradition and modernity. For example, the high-saturation color palettes and diamond motifs found in Tujia brocade can be translated into geometric or border decorations on enamelled porcelain. Similarly, auspicious floral and animal patterns in Miao embroidery can enrich the iconographic repertoire of enamelled designs. Some ceramic artists have already experimented with incorporating Xilan Kapu brocade patterns through overglaze enameling on ceramic panels and vessels, achieving striking visual effects. This form of cross-disciplinary fusion demonstrates that enamelled porcelain can successfully integrate ethnic artistic elements to develop culturally rooted creative products.

Furthermore, the “design intervention” model observed in the industrialization of ICH in southeastern Chongqing merits attention. By involving professional designers to extract and reinterpret traditional motifs and techniques, these crafts can be better adapted to contemporary market demands. In the field of enamelled porcelain, design-driven innovation could take the form of culturally themed products inspired by Tujia and Miao traditions, or the use of digital tools to parameterize traditional patterns that are then hand-painted onto porcelain surfaces—balancing mass production with bespoke customization. Such exploratory practices are already emerging within the cultural and creative industries of Chongqing and its neighboring regions, suggesting promising future developments.

The successful integration of intangible heritage and creative industry practices in southeastern Chongqing provides a meaningful reference for the revitalization of enamelled porcelain. On one hand, the protection and innovation of regional craftsmanship revitalize traditional Chinese aesthetics in contemporary contexts. On the other hand, the incorporation of local cultural elements into the historically imperial medium of enamelled porcelain expands its design vocabulary and enriches its cultural depth. This model of “dual empowerment” demonstrates that traditional craftsmanship must be embedded within contemporary discourses—balancing cultural and practical values—to achieve sustainable development. For enamelled porcelain in particular,

embracing regional culture, diverse aesthetics, and emerging technologies will be essential to shaping its future trajectory.

## 6. Conclusions

Falangcai porcelain emerged in the late 17th century from Chinese-European fusion, peaking in the Qing Dynasty. Despite its brilliance, it faces bottlenecks like health risks and high energy consumption.

PbO-based fluxes pose health and environmental hazards.

High firing temperatures (850–900°C) cause elevated energy use, conflicting with conservation goals.

This study, reviewing history and characteristics, innovated with lead-free boron-lithium frits and lower temperatures (700–750°C), validating key conclusions.

- (1) Enhanced safety: Boron-lithium lead-free frit eliminates lead toxicity, with low-temperature firing emissions meeting national standards, improving workplace safety and artisan health.
- (2) Energy efficiency: Low-temperature firing at 700–750°C reduces energy by 18–22% vs. conventional methods, lowering carbon footprint.
- (3) Decorative quality: Boron-lithium frit with controlled firing curve yields saturated colors, smooth finishes, and acid resistance. Falangcai surfaces show vivid colors and strong adhesion; raised lines enhance depth and expression.
- (4) Cultural innovation: Regional ethnic crafts revitalize falangcai, incorporating Tujia and Miao patterns to enrich its scope. Fusion with imperial traditions makes it a culturally resonant medium in contemporary art.

Lead-free frit formulation and precise temperature control are key technologies for the green development of enamelled porcelain. These innovations reduce energy consumption, eliminate pollution, and ensure product quality, laying a solid foundation for its revitalization. In the future, advanced technologies like digital glaze spraying may further decrease energy use, enhance pattern rendering, and broaden application domains. Continued research into long-term weather resistance and refinement of standards remains essential. By preserving traditional craftsmanship while meeting modern demands, enamelled porcelain is poised for high-quality, sustainable development.

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## Disclosure statement

The authors declare no conflict of interest.

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# Intergroup Contact Theory: Theoretical Evolution and Application in the Chinese Context

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**Abstract:** Intergroup Contact Theory (IGCT) has evolved as a foundational framework in social psychology for understanding and improving interactions between diverse groups. This study traces the theoretical development of IGCT, from its early origins in addressing intergroup tensions in post-WWII societies to its formalization by Gordon Allport, who emphasized the “optimal conditions” for positive contact (equal status, common goals, cooperation, and institutional support). Subsequent advancements expanded the theory’s scope, including extensions to indirect contact (e.g., imagined or extended contact) and refined mechanisms (cognitive, affective, and behavioral pathways). The paper also examines the adaptation and application of IGCT in the Chinese context, where scholars have progressively integrated the theory with local realities, particularly in educational settings. Early introductions focused on theoretical translation, while recent studies explore its relevance in culturally diverse classrooms, campus environments, and community interactions, highlighting the role of institutional support and contextualized practices in fostering constructive intergroup relations. This analysis underscores IGCT’s adaptability across cultural contexts and its utility for promoting inclusive interactions, offering insights for researchers and practitioners working in diverse societies.

**Keywords:** Intergroup Contact Theory; Optimal conditions; Prejudice reduction; Cultural adaptation; Chinese education

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## 1. Introduction

Intergroup Contact Theory (IGCT), as a core framework in social psychology for explaining group interaction and relationship improvement, has consistently centered on the proposition: “How can intergroup contact alleviate conflict and promote inclusion?” Originating from Western societies’ practical needs to resolve racial conflicts, IGCT has evolved through decades of theoretical refinement and cross-cultural practice into a comprehensive system encompassing contact conditions, mechanisms, and effect generalization. With the prominence of cultural diversity in globalization, IGCT’s explanatory power and practical value have gradually extended to broader social domains. In China, the social landscape of multicultural coexistence provides a unique setting for the localized application of IGCT. This paper systematically examines the evolutionary trajectory of IGCT, from

empirical explorations in its embryonic stage to theoretical expansions after formal establishment, analyzing its core connotations. Simultaneously, it focuses on the theory's introduction, adaptation, and practice in China, particularly its application forms in education and group interactions, aiming to provide theoretical references for understanding group relations in cross-cultural contexts and practical insights for promoting inclusive societal development.

## **2. Theoretical evolution of Intergroup Contact Theory**

Intergroup Contact Theory originated in Western social psychology, primarily studying how groups interact and how such interactions affect intergroup relations, with the aim of resolving intergroup conflicts.

### **2.1. Embryonic stage**

After World War II, having experienced national consciousness and ethnic conflicts, many multi-ethnic countries realized that idealized nation-states might not necessarily promote social development, thus actively seeking ways to foster harmonious coexistence among different races. Initial social case studies laid the foundation for this theory. Sherif M., a renowned psychologist, further demonstrated through extensive experiments that intergroup contact plays a crucial role in the social environment <sup>[1]</sup>. Zelig R. and Hendrickson G., building on theoretical foundations, conducted in-depth studies of 39 ethnic groups and found that people's expressed awareness and familiarity with groups significantly influence their behavior <sup>[2]</sup>. Smith F.T. designed a series of social contact and intellectual activity experiments conducted on weekends, with participants being white students from Columbia University and leaders from New York's Black community. This study found that college students engaged in interracial communication showed significant shifts in attitudes toward Black people, while those without cross-racial contact maintained their original attitudes <sup>[3]</sup>. Additionally, sociologist Williams R. made outstanding contributions to pioneering this theory. In 1947, he constructed a series of relevant hypotheses and evidential bases to study and analyze group relationships, extensively covering topics such as intergroup interactions, cooperation, and social equity <sup>[4]</sup>. In summary, during the embryonic stage, researchers recognized that individuals from different ethnic groups perceived intergroup contact as promoting improved intergroup relations through actual contact processes. However, such theoretical understanding was vague, fragmented, and unsystematic, lacking practical guidance. Although the theory was incomplete, its emergence prepared the groundwork for future formalization.

### **2.2. Formalization period**

The eminent American social psychologist Gordon Allport contributed significantly to the formal establishment of IGCT. His seminal work, *The Nature of Prejudice*, built upon prior research. Its publication in 1954 marked the formal establishment of IGCT. In this book, Allport emphasized cognition's influence on prejudice. His second core argument posited that if the causes of prejudice were understood, actions would be taken to reduce widespread prejudice, thereby diminishing discriminatory behavior. Furthermore, Allport deeply analyzed the relationship between intergroup contact and intergroup relations: intergroup contact does not necessarily improve relations and may even worsen them. Positive contact effects require four conditions, as he proposed: "If majority and minority groups interact under conditions of equal status, pursuing common goals, prejudice may be reduced. If institutional support (i.e., laws, customs, or local atmosphere) is present and promotes mutual understanding of shared interests and attributes, the effectiveness of intergroup contact is greatly enhanced" <sup>[5]</sup>. Unlike the

vague theoretical understanding during the embryonic stage—where people held simplistic, linear views about the relationship between contact and relations—Allport’s optimal conditions revolutionized this perception. Pioneeringly, Allport shifted focus beyond contact itself to contact conditions and contexts. Under his framework, the Contact Hypothesis generated significant influence, prompting extensive empirical research using field studies, laboratory experiments, and longitudinal studies to test and expand its principles. These investigations not only explored the types and mechanisms of intergroup contact in depth but ultimately solidified IGCT. Through scholarly exploration, it has become one of the few scientific theories providing effective foundations for policymaking and implementation.

### **2.3. Subsequent development period**

For decades after its formation, scholars have conducted extensive research on IGCT using diverse methodologies, including experimental, survey, field, and archival studies. Research subjects have evolved from racial groups to intergenerational groups, people with differing physical health characteristics, and groups with different sexual orientations. Scholars have continuously deepened theoretical exploration, systematically studying contact methods, types, outcomes, and pathways, providing robust evidence for establishing a scientifically structured theoretical system. Theoretical development has driven practical advances: IGCT research has expanded from direct dyadic relationships to indirect relationships involving mediating variables—a significant step forward. However, direct group contact studies face limitations, as many influential relationships lack control for external environments and group characteristics, undermining the persuasiveness of conclusions. Consequently, scholars proposed four new hypotheses based on existing methods and perspectives: imagined contact, extended contact, vicarious contact, and simulated contact. Originally focused on racial and ethnic relations, IGCT’s explanatory scope has recently expanded to other intergroup relationships, further extending Allport’s foundational hypotheses. Today, IGCT constitutes a comprehensive theoretical system for addressing intergroup contact issues and improving intergroup relations.

## **3. Core connotations of intergroup contact theory**

The core value of IGCT lies in revealing the principle of “how effective contact promotes improved intergroup relations.” Its essence can be systematically explained through three dimensions: contact conditions, mechanisms of action, and effect generalization.

### **3.1. “Optimal conditions” for intergroup contact**

Regarding how to effectively promote positive group contact effects, Allport summarized four optimal conditions: Equal status: IGCT advocates an equal and mutually beneficial relational model, where interactions stem from genuine communicative purposes rather than individual interests, ensuring relative equality in social status and creating favorable environments for group contact. Common goals: All social interactions are goal-oriented; shared objectives are essential for motivating positive engagement. Institutional support: Many intergroup contact issues arise not from unwillingness but from constraints imposed by institutions, laws, or culture, preventing normal interaction. Cooperative relationships: Intergroup contact inherently involves negotiation, with cooperation representing its highest form. Groups should establish cooperative relationships driven by shared goals and collective interests, reducing divisions and extending contact types and methods toward diversity.

### **3.2. Mechanisms of intergroup contact**

The relationship between intergroup contact and intergroup relations is not merely linear causality; positive outcomes require mediating mechanisms: Cognitive dimension: Deepening understanding. Pettigrew posits that knowing and understanding outgroups forms the basis for building intergroup relations <sup>[6]</sup>. Contact increases willingness to learn about outgroups; increased knowledge reduces prejudice. Affective dimension: Anxiety reduction and empathy. Emotions are crucial in social networks and irreplaceable in establishing intergroup relations. Initial contact triggers subconscious cognitive and emotional rejection, causing discomfort. However, successful positive intergroup interactions significantly reduce anxiety and increase willingness for future contact. Empathizing with outgroup members' experiences reduces contact anxiety and transforms prejudicial attitudes. Behavioral dimension: Changing prejudiced behaviors. Establishing positive intergroup interactions in contact environments constitutes optimal contact. This process facilitates mutual psychological acceptance, creating new forms of group interaction. Optimal contact enhances mutual familiarity, resolves information asymmetry, and reduces prejudiced behaviors. Encouraging or rewarding positive individual behaviors further amplifies contact effects.

### **3.3. Effect generalization of IGCT**

Categorization is a natural tendency developed for survival. Facing complex social environments, people seek stability by classifying new experiences into existing categories using the “principle of least effort.” Building on Allport's work, Pettigrew proposed a theoretical model for the IGCT effect generalization <sup>[7]</sup>. This model establishes safeguard mechanisms for theoretical realization: intergroup contact is not predetermined but requires specific conditions (equal status, common goals, cooperation, institutional support) as foundational guarantees for positive effects. Since its proposal, this model has sustained academic interest, with research expanding from sociology to education and management, perspectives shifting from contact effects to contact types/methods/outcomes, and research subjects diversifying.

## **4. Introduction and application of IGCT in the Chinese context**

The localization of IGCT in China is a process evolving from theoretical introduction to innovative integration with local practices. Its application focuses on multicultural interactions, generating rich practical experience, especially in education.

### **4.1. Theoretical introduction and early exploration (Early 21st Century–2010)**

Domestic research indicates that scholar Wang Yapeng first introduced contact theory to China <sup>[8]</sup>. He initially reviewed developments in the Contact Hypothesis. Subsequently, the theory gained recognition in Chinese academia, spurring research and achievements. However, pre-2010 studies were scarce, often derivative of Western perspectives with limited scope and application. Later, researchers integrated IGCT with China's realities, exploring its manifestations in specific social contexts. Gradually, IGCT became a vibrant academic focus in psychology and ethnology. Early efforts involved introducing Western theoretical achievements and contextualizing Western practices, laying the groundwork for Sinicization. Later, scholars applied IGCT to ethnic education and inter-ethnic student relations.



## 4.2. Application and development in education (2010–Present)

With China's emphasis on multicultural integration in education, IGCT became vital for analyzing student interactions and improving campus relations, yielding localized outcomes: Ethnic education applications: Hong Yun pioneered applying IGCT to China's ethnic education <sup>[9]</sup>. Hao Yaming explored alignments between China's ethnic characteristics and IGCT's logic <sup>[10]</sup>. He advocated treating IGCT as an inter-ethnic contact theory applicable to diverse ethnic interactions. Zhang Dawei integrated IGCT with China's practical issues <sup>[11]</sup>. Empirical Studies on student interactions: Scholars extended IGCT to student groups. Yi Li proposed stage-specific contact strategies to improve inter-ethnic student relations <sup>[12]</sup>. Su Guangzheng et al. studied Han-Tibetan interactions in integrated schools <sup>[13]</sup>. Gu Jianjie et al. demonstrated that mixed-ethnic dormitories in Xinjiang universities reduce cognitive conflicts and enhance collaboration <sup>[14]</sup>. Duan Zheze et al. examined interactions between Taiwanese youth and mainland students <sup>[15]</sup>.

## 4.3. Localization characteristics and implications

IGCT's application in China transcends “theoretical transplantation”, deeply integrating with socio-cultural and institutional environments, forming distinct localized features that demonstrate theoretical adaptability and provide unique insights for multicultural societies: Value alignment: Resonance with “Pluralistic unity” (多元一体). China's cultural framework inherently aligns with IGCT's core values. Fei Xiaotong's philosophy—“Appreciate one's own beauty; appreciate others' beauty; unite all beauties; achieve global harmony” (各美其美, 美人之美, 美美与共, 天下大同)—emphasizes coexistence through respecting cultural uniqueness, mirroring IGCT's logic of “promoting understanding through contact, seeking consensus amid differences.” Practically, this manifests not as homogenization but as “harmony in diversity” (和而不同). Contextual focus: Education as core venue. Unlike Western applications across communities/workplaces, China's IGCT implementation concentrates on education (K–12 and higher education). Schools function as “primary sites for cultural transmission/innovation”, and education's long-term impact on intergroup relations makes it strategic. Educational settings offer unique advantages: 1) Students are at critical stages of value formation, where positive contact experiences shape lifelong intergroup attitudes; 2) Schools' semi-closed environments enable active creation of “optimal contact conditions” through curricula and activities. This focus spurred innovation—researchers integrated IGCT with China's fundamental education goal of “fostering virtue through education” (立德树人), proposing “contact as education”: respect, tolerance, and collaboration learned through contact become core competencies for multicultural societies.

China's IGCT practice demonstrates that cross-cultural theory localization is not a departure from original principles but a creative integration with local values, institutions, and contexts. Key implications: For multi-ethnic nations, intergroup contact requires value consensus to avoid tokenism; institutional support is vital for scaling contact initiatives, especially in vast, diverse countries where policy guidance reduces costs/resistance; education is a strategic lever for shaping intergroup relations through national education systems. These features enrich IGCT's cross-cultural dimensions and offer a “Chinese experience” for global multicultural governance.

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# Dilemmas and Solutions in the Criminal Law Regulation of School Bullying

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**Abstract:** The phenomenon of campus bullying not only negatively impacts victims' physical and mental health and academic life but also poses a threat to campus harmony and stability, making it an important issue of significant social concern that urgently needs to be addressed. In recent years, governments at all levels and schools have adopted a series of measures attempting to curb the occurrence of this phenomenon. However, campus bullying incidents still occur from time to time. This current situation highlights the difficulties and inadequacies faced by existing legal regulations, especially criminal law regulations, when dealing with campus bullying. Current laws have ambiguities in behavior definition, clarification of responsible parties, and determination of sentencing standards, making it difficult to form effective deterrence and punishment against perpetrators. Based on this, this paper will propose practical and feasible solutions based on an in-depth analysis of the necessity and difficulties of criminal law regulation of campus bullying, providing solid legal support and guarantee for creating a safe and harmonious campus environment.

**Keywords:** Campus bullying; Criminal law regulation; Challenges; Solutions

**Online publication:** September 17, 2025

## 1. Introduction

With the rapid development of society and the continuous changes in educational environments, campus bullying has increasingly become a focal point of attention across all sectors of society. The campus should be a temple of knowledge and a cradle for the healthy growth of young people. However, the existence of campus bullying phenomena is like a dark cloud hanging over the hearts of many students. It not only brings physical and psychological trauma to victims, affecting their normal study and life, but also destroys the harmonious atmosphere of the campus and hinders the healthy development of educational endeavors. Faced with this severe situation, the criminal law regulation of campus bullying has urgency and importance. Law, as an important means of maintaining social order and ensuring fairness and justice, should play a more active role in addressing campus bullying issues. However, the reality is not so simple. Due to the complexity and diversity of campus bullying behaviors, as well as the special nature of the ages of the subjects involved, criminal law faces numerous

difficulties and challenges in regulating campus bullying. How to accurately define bullying behavior, how to clarify responsible parties, and how to establish reasonable sentencing standards — these are all issues that require deep thinking and exploration.

## **2. The necessity of criminal law regulation of campus bullying**

First, campus bullying behavior not only seriously violates the legitimate rights and interests of minors but also has profound negative impacts on victims' physical and mental health. This negative impact is not only reflected in victims' psychological trauma and physical harm, but may also spread further, triggering more serious social problems. Physical harm may lead to long-term health problems, affecting their normal life and study. Ineffective regulation of campus bullying behavior not only harms the bullied victims but, from a long-term perspective, will also have adverse effects on perpetrators, bystanders, schools, families, and even society as a whole <sup>[1]</sup>. Criminal law regulation, as the last line of defense for protecting minors' rights and interests, has an obvious necessity. Through criminal law regulation, the nature of campus bullying behavior and its corresponding legal consequences can be clearly defined, providing effective legal remedies for victims and ensuring their rights and interests receive due protection. At the same time, criminal law regulation can also impose appropriate legal sanctions on perpetrators, thereby maintaining the fairness and authority of the law, ensuring social order stability, and preventing similar incidents from recurring. Through the deterrent effect of the law, campus bullying behavior can be effectively curbed, protecting the legitimate rights and interests of minors.

Second, the frequent occurrence of campus bullying behavior actually reflects significant deficiencies in current social education and moral education. These deficiencies are not only manifested in inadequate school education but also involve neglect of family education and distortion of social values. While schools focus on academic performance, they often neglect students' mental health and moral education, leading to students lacking proper ways to handle conflicts. The absence of family education is manifested in parents' overindulgence or neglect of their children, failing to guide them in establishing correct values and behavioral norms in a timely manner. The distortion of social values has caused some unhealthy trends to spread on campus, encouraging the occurrence of bullying behavior. Criminal law regulation is not merely punishment for specific bullying acts, but also adherence to and defense of society's moral bottom line. Through the guiding and regulatory role of law, schools, families, and all sectors of society can be prompted to give higher attention and profound reflection to campus bullying issues, promoting the formation of a good atmosphere where the entire society pays common attention and actively participates in campus bullying prevention and control. Through strengthening the dual guarantee of education and law, campus bullying behavior can be effectively prevented and reduced, creating a harmonious and safe campus environment.

Finally, criminal law regulation of campus bullying is an inevitable requirement for building a rule-of-law society. As a microcosm of society, the effective resolution of campus bullying problems is directly related to the process of rule-of-law construction for the entire society. Campus bullying not only affects students' physical and mental health but may also trigger social dissatisfaction and unrest, affecting social stability. Through criminal law regulation, the thorough resolution of campus bullying problems can be promoted, providing a solid legal guarantee for building rule-of-law campuses. This not only helps create a safe and healthy campus environment where students can learn and grow in a carefree environment, but also lays a solid foundation for society's long-term stability and the in-depth advancement of rule-of-law construction, promoting overall social progress and civilized development. Through legal regulation and guidance, the rule-of-law awareness of the entire society

can be enhanced, promoting the construction of a rule-of-law society, and ensuring social harmony, stability, and sustainable development.

### **3. Dilemmas in the criminal regulation of school bullying**

Currently, although China's criminal law has established a series of systematic and detailed regulatory measures targeting juvenile crimes, it still faces numerous insurmountable dilemmas when dealing with the complex and diverse social issue of school bullying.

First, school bullying manifests in rich, varied, and ever-changing forms, involving multiple types of behaviors. These include soft violence such as verbal insults, mockery, and defamation. Though not directly causing physical harm, such behaviors can inflict severe psychological and mental trauma on victims. Over time, they may lead to psychological problems like inferiority and depression, and in severe cases, disrupt victims' normal study and life. There are also virtual bullying methods such as malicious attacks, rumor-mongering, and spreading rumors in cyberspace. Leveraging the anonymity and rapid spread of the Internet, these behaviors exert extensive and far-reaching impacts on victims and may even trigger cyber violence, leaving victims isolated and helpless under enormous psychological pressure. Additionally, there are acts of hard violence such as physical conflicts, beatings, and malicious damage to others' property, which directly threaten victims' physical and property safety. In severe cases, they may result in injury, disability, or even death of victims, bringing irreparable pain to their families. However, in the specific application of current criminal law provisions, it is often difficult to fully cover and effectively regulate these diverse bullying behaviors. As a result, many bullying acts fall into the ambiguous zone of the law, escaping due legal sanctions. This makes it hard for victims to obtain fair legal protection and psychological comfort; in extreme cases, it may even cause victims to lose trust in the law, develop resentment and resistance toward society, and affect social harmony and stability.

Second, perpetrators in school bullying incidents are often minors, posing numerous complex challenges in the determination of criminal liability and sentencing. Minors are immature in mental development, and their criminal motives, behavioral patterns, and consequences differ significantly and specifically from those of adults. When minors commit bullying acts, they are more prone to being influenced by emotional impulses, lacking sufficient awareness and foresight of the consequences of their actions. They often act extremely impulsively, struggling to exercise self-control and rational judgment. Therefore, effectively regulating and punishing their bullying behaviors while fully protecting minors' legitimate rights and interests and promoting their healthy growth has become a pressing issue. The age of perpetrators in school bullying cases tends to be younger, yet criminal law cannot regulate those under the age of 14 who commit school bullying. As a powerful tool to combat crimes and protect social stability, as well as people's personal and property safety, if criminal law fails to describe or regulate school bullying behaviors, it may lead to perpetrators escaping criminal liability, which is not conducive to curbing school bullying<sup>[2]</sup>. This not only requires further improving and refining legal provisions to better align with the characteristics of juvenile crimes, ensuring that legal provisions accurately cover various bullying behaviors, avoiding legal gaps, and safeguarding the rigor and applicability of the law, but also demands more precise, scientific, and humanized operations in judicial practice to ensure the fairness and rationality of legal application. It is necessary to impose necessary penalties on perpetrators to play a warning and educational role, while avoiding excessive negative impacts on their future development, ensuring that they can smoothly reintegrate into society and return to normal life and study after reforming their ways.



Finally, there is a lack of efficient communication mechanisms and collaborative platforms. The governance of school bullying requires close collaboration and linkage among schools, families, and society. As the main activity venue for minors, schools should establish and improve mechanisms for preventing and responding to school bullying, enhance teachers' and students' ability to identify and intervene in bullying behaviors, regularly carry out anti-bullying education and psychological counseling, create a harmonious campus environment, and ensure that students study and grow in a safe atmosphere. As the initial environment for minors' growth, families should attach importance to family education, cultivate children's empathy and awareness of the rule of law, promptly detect and correct children's abnormal behaviors, provide them with sufficient care and support, and help them establish correct values and behavioral norms. Society should provide necessary support and resources, create a positive social atmosphere that cares for the growth of minors, and enhance public attention to school bullying through media publicity, community activities, and other channels, forming a good situation where the whole society pays attention and supports. For example, schools should establish bullying prevention and control systems and carry out education on preventing juvenile cyberbullying, while families should educate minors on the rational use of the Internet and guide them not to engage in cyberbullying <sup>[3]</sup>. However, in practice, there is often a lack of efficient communication mechanisms and collaborative platforms among various subjects, making it difficult for prevention and governance efforts to form a synergy, resulting in poor effectiveness. In some cases, there even exist situations where each subject acts independently and shifts responsibilities to each other, making it difficult to effectively solve school bullying. The lack of multi-subject participation and the imperfection of collaborative mechanisms have further exacerbated the dilemmas in the criminal regulation of school bullying, making the problem harder to solve and eradicate.

#### **4. Paths for the criminal regulation of school bullying**

The complexity and diversity of school bullying behaviors pose challenges to criminal regulation. On one hand, school bullying often involves multiple forms such as verbal insults, physical conflicts, and cyberbullying, with varying natures, degrees, and consequences that are difficult to uniformly define and quantify, leading to difficulties and controversies in the application of law. On the other hand, participants in school bullying are mostly minors, with limited criminal capacity and psychological maturity. Finding a balance between protecting minors and maintaining social order is a problem that criminal regulation needs to address. Therefore, exploring paths for the criminal regulation of school bullying requires efforts from multiple aspects, such as clarifying behavioral definitions, improving the liability system, and unifying sentencing standards, to build a more scientific, reasonable, and effective legal regulatory system.

First, clearly define the legal definition and boundaries of school bullying behaviors. As the last line of defense for regulating social order, criminal law should neither disregard the strict conditions required for assuming criminal liability in order to achieve the purpose of punishment nor blindly decriminalize school bullying behaviors for the sake of protecting minors <sup>[4]</sup>. The law needs to clearly, specifically, and detailedly define school bullying behaviors, clarifying which acts constitute school bullying and which belong to minor conflicts or jokes. Such meticulous division can ensure that law enforcement officers have a clear guiding basis when handling relevant cases, enabling them to accurately identify and confirm bullying behaviors and avoid misjudgments caused by ambiguity and controversy. This can not only effectively protect the legitimate rights and interests of victims, allowing them to obtain timely legal remedies when bullied, but also form a strong deterrent and

punishment for perpetrators, thereby maintaining campus harmony and stability, and creating a safe and healthy campus environment. Only by clarifying the legal definition and boundaries can a solid foundation be laid for subsequent law enforcement and judicial work, ensuring the fairness and effective implementation of the law, and avoiding legal application difficulties caused by unclear definitions.

Second, improve the definition of responsible subjects and the accountability mechanism. In school bullying incidents, responsible subjects may include perpetrators, schools, parents, and other parties. The law needs to clearly define these responsible subjects and specify the specific responsibilities each party should bear. At the same time, establish an effective accountability mechanism to ensure that when school bullying occurs, the legal responsibilities of relevant responsible persons can be pursued promptly and accurately. This can not only enhance the deterrence of the law, making potential perpetrators hesitate to act, but also promote schools, parents, and other parties to actively fulfill their duties and obligations, forming a joint effort from multiple parties to jointly prevent and manage school bullying, thereby effectively reducing the occurrence of bullying incidents. By clarifying responsibilities and establishing an accountability mechanism, the government can ensure that every link is governed by law and accountable, forming an all-around protective network and avoiding the phenomenon of shifting responsibilities due to unclear accountability.

Third, unify sentencing standards and strengthen legal publicity and education. In handling school bullying cases, different regions and courts may have inconsistent sentencing standards, which not only undermines the fairness of the law but also weakens its authority. Therefore, the government needs to formulate a set of unified sentencing standards to ensure that courts at all levels can follow consistent standards when handling similar cases, avoiding unfair law enforcement. This can not only maintain the fairness and authority of the law but also enhance public trust in the law, making the law a powerful weapon to curb school bullying. Unified sentencing standards help eliminate regional differences, ensure that each case is handled fairly, enhance the credibility of the law, and avoid social dissatisfaction caused by unfair sentencing. The government needs to improve public attention to school bullying and enhance public legal awareness and awareness of the rule of law through various channels such as media publicity, community activities, and school lectures. Criminal law alone cannot completely eradicate school violence; strengthening the regulation of school violence through criminal law can have a certain deterrent effect on such behaviors, and at the same time, legal education for minors should be strengthened <sup>[5]</sup>. Meanwhile, schools should strengthen anti-bullying education, cultivate students' awareness of the rule of law through curriculum design and theme activities, and help them establish correct values. Families should focus on family education, promptly detect and correct children's abnormal behaviors, provide them with sufficient care and support, and create a warm and harmonious family environment. Only with the joint efforts of the whole society can a good atmosphere for preventing and managing school bullying be formed. Through all-round legal publicity and education, the legal literacy of the whole society can be improved, fundamentally preventing school bullying and creating a harmonious society with a strong sense of the rule of law.

Fourth, build a multi-party linkage and efficient collaborative system for prevention and governance. The prevention and governance of school bullying require the joint participation and collaboration of multiple forces, including schools, families, and society. The government needs to establish an effective communication mechanism and collaborative platform to promote close cooperation and linkage among all parties, forming a good situation of information sharing and resource complementarity. Only through the joint efforts of multiple parties to form a synergy can school bullying be fundamentally curbed, creating a safe and harmonious growth environment for minors and ensuring they thrive in a healthy and friendly atmosphere. Only by building a multi-party linkage

and efficient collaborative system can an all-round and multi-level protection mechanism be formed, ensuring that every child can grow up healthily in a safe and harmonious environment, and avoiding governance failure caused by the weakness of a single force.

## 5. Conclusion

Faced with the severe and complex social issue of school bullying, the government must profoundly recognize that although criminal regulation occupies an important position in the governance system, its effective implementation does not rely solely on the power of law alone. Instead, it requires the collaboration and joint efforts of multiple factors, including education, families, and society.

Specifically, by comprehensively strengthening legal education in schools and systematically enhancing students' legal awareness and self-protection capabilities, the government can effectively reduce the occurrence of bullying at the source and fundamentally curb the spread of this harmful phenomenon. As the cradle and first classroom for children's growth, families play a crucial role, with parents shouldering vital responsibilities. They ought to establish scientific and correct educational concepts, focus on cultivating children's empathy and sense of responsibility in daily education, actively guide children to learn to respect and understand others, and face everyone in life with love and tolerance, thereby sowing the seeds of kindness and friendship in their hearts.

All sectors of society should also actively participate in this governance process. Through various forms of media publicity, diverse public welfare activities, and other channels, the government can jointly create a positive social atmosphere that cares for the growth of minors and respects the development of every individual.

To sum up, the criminal regulation of school bullying is not an isolated existence but a complex, systematic project involving multiple factors such as law, education, families, and society. Only when these factors cooperate with each other, form a synergy, and the whole society pays attention and participates actively can people effectively prevent and address school bullying, creating a truly safe, harmonious, and healthy growth environment for minors.

## Disclosure statement

The authors declare no conflict of interest.

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# Research on Cost-Effective Optimization Strategies for Controlling Safety-Critical Parts

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**Abstract:** This research aims to demonstrate that, while adhering to the baseline of safety regulations, effective cost-optimized control of safety-critical parts can be achieved through strategies such as precise classification, process method optimization, supply chain collaboration, and data-driven approaches.

**Keywords:** Safety-critical parts control; Critical characteristics; Cost optimization

**Online publication:** September 17, 2025

## 1. Introduction

Under the constraints of economic efficiency and cost considerations within enterprises, optimizing the control of safety-critical parts is a highly practical and crucial issue. Within strict quality management system frameworks like IATF 16949, arbitrarily lowering the control level for genuine safety-critical parts is generally not permitted, especially when failure consequences involve personal safety, major regulatory violations, or catastrophic environmental impacts<sup>[1-4]</sup>.

The reason lies in the non-negotiability of “unacceptable risk”: The core definition of safety-critical parts stems from the severity of their failure consequences. Even if a failure could be 100% detected or easily repaired, the occurrence of the failure event itself (e.g., brake failure causing an accident, even if repairable afterwards) results in irreversible losses (casualties, massive fines, brand destruction). The core objective of safety-critical parts control is to prevent failures from occurring, not to rely on post-failure detection and repair.

Regulatory mandates concerning safety and environmental protection, customer requirements for safety-critical parts, and the core spirit of IATF 16949—prevention and continual improvement, not tolerating risk and dealing with it afterwards—all impose high demands on controlling safety-critical parts. However, this does not preclude seeking more cost-effective control methods.

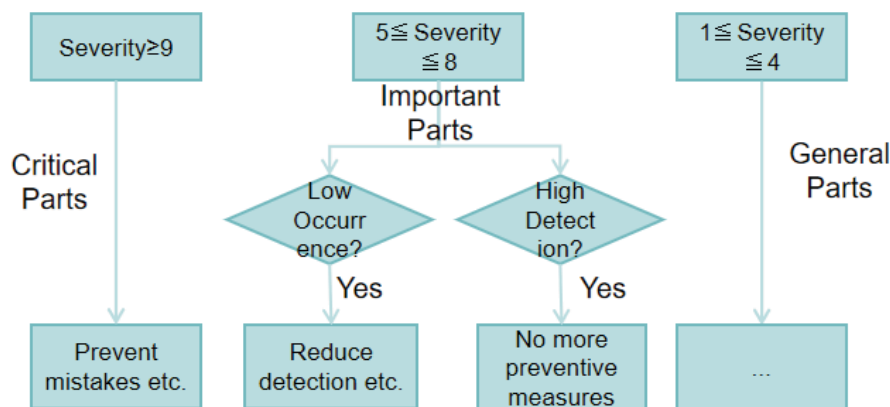
## 2. Precise identification and classification

The purpose of precise identification and classification is to ensure resources are allocated where they matter most. This can be approached from two aspects: Strict application of risk analysis tools like FMEA to distinguish critical from important characteristics and adopt different control strategies.

### 2.1. Strict application of risk analysis

Focus on severity: Only items with extremely high severity should be classified as “safety-critical parts/characteristics.” Avoid over-escalating the level of “important but not critical” items.

Utilize occurrence and detection for control strategy adjustment, while the classification of a safety-critical part cannot be lowered, Occurrence (O) and Detection (D) ratings can influence the intensity and cost of specific control measures<sup>[5]</sup>. For failure modes with low occurrence, monitoring frequency might be reduced (while still ensuring basic prevention and detection capability) or lower-cost preventive measures employed. For failure modes with high detection, if existing detection methods (e.g., automatic testing, 100% inline inspection) are highly reliable and cost-controlled, additional expensive preventive measures may be unnecessary (**Figure 1**). However, reliance solely on detection is insufficient; prevention is still a core method.



**Figure 1.** Critical characteristic SOD (Severity-Occurrence-Detection) decision tree

### 2.2. Distinguishing critical from important

For critical Parts/Characteristics for which failure consequences are highly severe (S9–10), involving safety, regulations, or loss of core functionality, strict control is mandatory, but methods can be optimized (see Section 3)<sup>[6]</sup>.

For important Parts/Characteristics for which failure consequences are moderately severe (S5–8), primarily affecting function, performance, customer satisfaction, or incurring high repair costs, relatively economical control strategies can be implemented (e.g., sampling inspection, process monitoring). And “detectable/easily repairable failure” can be a reasonable factor for lowering the control level (from Important to General).

## 3. Optimizing control methods themselves

Optimizing control methods does not mean reducing control rigor or relying solely on post-failure detection and repair. Instead, it involves shifting controls upstream, emphasizing mistake-proofing (poka-yoke) over detection, aiming for higher efficiency and lower cost, including the following aspects.



### 3.1. Mistake-proofing (poka-yoke) over detection

Mistake-proofing may require a higher upfront investment but yields the lowest long-term cost. One successful poka-yoke implementation can eliminate significant subsequent detection costs, rework/scrap costs, and field failure costs. Design simple, reliable mistake-proofing devices, prioritize mechanical, low-cost, easy-to-maintain solutions over complex automated inspection. Utilize existing resources, integrate poka-yoke functions into existing equipment or processes. For example, using sensors on a PLC to detect liquid flow position and trigger alarms via logic if values exceed setpoints.

### 3.2. Enhancing SPC effectiveness and efficiency

Optimize control chart selection, for continuous data, Xbar-R charts are often more sensitive and efficient than attribute charts like P charts (**Figure 2**: Xbar-R charts provide richer, more sensitive continuous data information). Rationalize sample frequency and size, based on process capability and risk analysis (Occurrence), and scientifically calculate the minimum required sample size and frequency to avoid oversampling. Adopt automated data collection and charting, use MES systems or simple sensors for automatic data capture, real-time SPC charting, and automatic alarms to reduce labor costs [7–8].

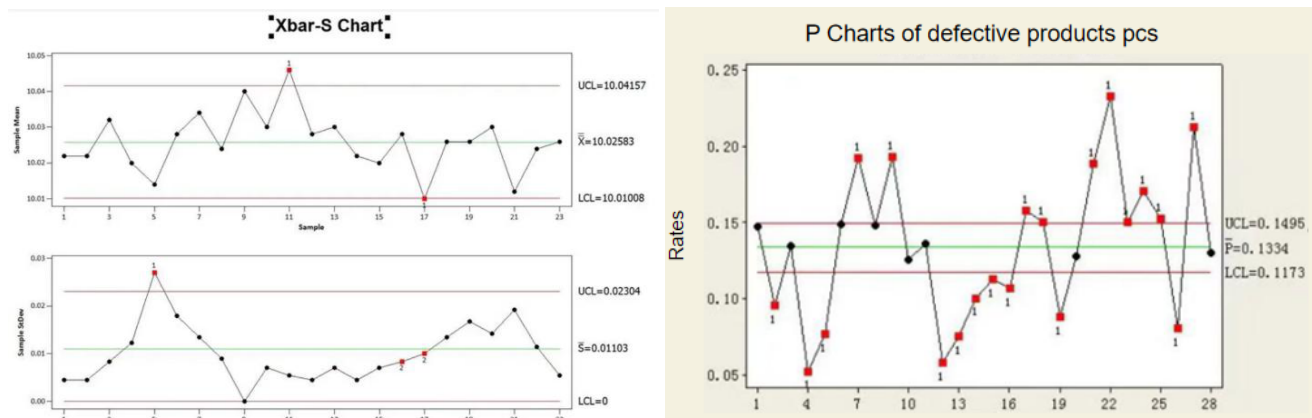
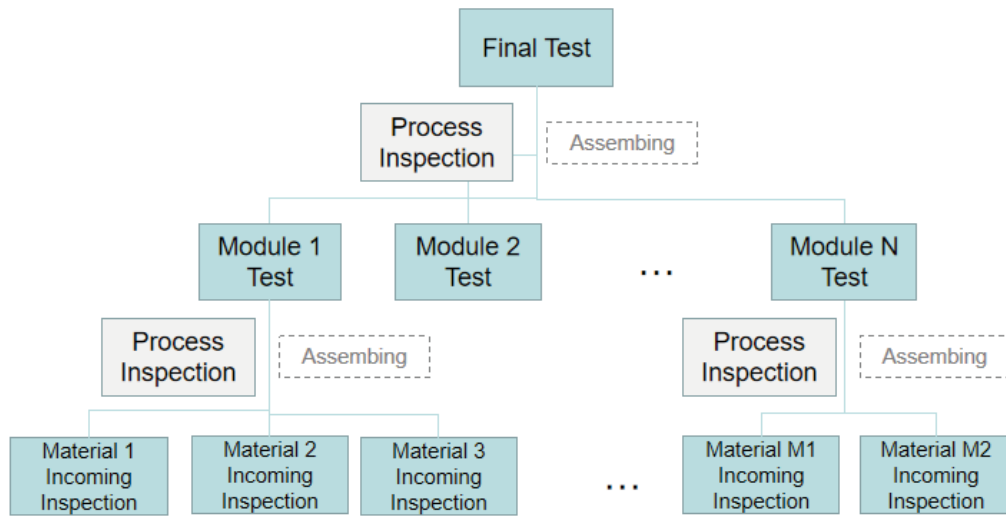


Figure 2. Comparison between Xbar-R charts and P charts

### 3.3. Modular testing and layered strategy

Modular testing: Testing critical characteristics at the sub-assembly or module level is more economical and facilitates easier problem localization than testing only at the final product stage. Use a layered sampling/testing strategy, combine supplier incoming inspection, in-process inspection, and final inspection, implementing sampling or testing schemes of varying strictness at different stages (**Figure 3**: Modular testing and layered strategy), to avoid relying solely on expensive 100% testing at the final stage.



**Figure 3.** Modular testing and layered strategy

### 3.4. Measurement system optimization

Select reliable, low-maintenance-cost gauges and instruments that meet precision requirements (MSA). Employ multi-parameter gauges or automated measurement equipment to improve measurement efficiency. While initial investment is higher, long-term gains from depreciation, labor savings, and reduced misjudgments improve overall efficiency. Conduct regular maintenance and calibration to ensure measurement system stability and reliability, to prevent misjudgments and extra costs due to measurement errors.

### 3.5. Standardization and training

Develop clear work instructions to reduce operational and inspection errors, lowering failures and rework caused by human error. Implement effective training to ensure operators and inspectors truly understand the importance of safety-critical parts and the correct operation/inspection methods, to improve first-pass yield.

## 4. Design optimization and supply chain collaboration

Design optimization and supplier collaboration are critical links, serving as the source for identifying and controlling critical characteristics and parts.

### 4.1. Design optimization

Simplify design: Such as reducing part count and complexity, to lower the associated number of critical characteristics. Enhance design robustness: Design products to be insensitive to minor manufacturing variations (high Cp/Cpk), to reduce the demand for stringent process control. Design for testability (DfT): Incorporate features in the design that facilitate economical and effective testing (e.g., reserved test points).

### 4.2. Early supplier involvement

Engage key suppliers during the design phase to co-design parts and participate in manufacturing processes. This helps to reduce the difficulty and cost of achieving critical characteristics from the source.

### 4.3. Supplier capability building

Invest in helping suppliers to improve their process capability and quality management level, especially regarding safety-critical parts control. Associating FMEAs, providing training, process audit coaching, and sharing best practices are all useful methods. These could ensure stable incoming quality, reduce internal inspection costs, and reduce failure risks.

## 5. Leveraging data and continuous improvement

Collect effective real data and utilize it for analysis to drive improvement <sup>[9–10]</sup>.

### 5.1. Cost-benefit analysis

Conduct quantitative analysis of the costs (investment) versus benefits (reduced failure costs, rework, warranty, recall risk) for proposed control measures (**Table 1**). Prioritize measures with a high return on investment (ROI).

**Table 1.** Example of ROI template

Styles	January	February	March	April	May	June
Cost						
Equipment cost						
Expenses of labour						
Training cost						
...						
Benefit						
Reduced failure costs						
Reduced rework costs						
Reduced maintenance costs						
...						
Profit						

### 5.2. Monitoring and feedback loop

Monitor the effectiveness of implemented safety-critical part controls (e.g., process capability indices, defect rates, poka-yoke effectiveness, failure costs) and actual costs (e.g., per-unit control cost, failure cost reduction rate) closely. Use data to drive decisions and continuously optimize control strategies (e.g., adjusting SPC parameters, improving poka-yoke devices, optimizing inspection points).

### 5.3. Lessons learned database

Establish and utilize a repository of historical failure data and improvement experiences to guide risk identification and control strategy formulation in new projects, to avoid redundant investments.

## 6. Conclusion

For genuine safety-critical parts and characteristics, without lowering core requirements (safety, regulations),

significant optimization is achievable. By implementing core strategies—precise classification, prioritizing mistake-proofing, efficient SPC/measurement, design optimization, supply chain collaboration, and data-driven decision making—the focus on “total cost” is elevated. This approach reduces the total cost of quality (prevention + appraisal + failure) while simultaneously enhancing system efficiency, freeing resources for higher-value activities, strengthening supply chain resilience, and boosting enterprise competitiveness.

## Disclosure statement

The author declares no conflict of interest.

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# Artificial Intelligence and Social Interaction: Evidence from Gift Money Expenditure

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**Abstract:** As artificial intelligence proliferates rapidly, understanding its impact on social interaction patterns becomes critical. Using national survey data and gift money expenditure as a proxy for social interaction, the study employs instrumental variable methods to identify the causal effect of AI use on individual social behavior. The study documents three key findings. First, AI use significantly reduces traditional social interaction through substitution effects, with instrumental variable estimates showing that OLS substantially underestimates the true magnitude, confirming the technology substitution hypothesis. Second, diminished social willingness serves as a key mediating mechanism—AI use reduces social behavior by weakening non-family social preferences, demonstrating how technology shapes behavior through preference channels. Third, the substitution effect exhibits significant demographic heterogeneity, with younger, more educated, and higher-income individuals displaying greater sensitivity to technology adoption, consistent with digital divide patterns. These findings provide micro-empirical evidence of social relationship transformation in the digital era. The results suggest policymakers should emphasize social inclusiveness in AI adoption while promoting balanced development between digital innovation and traditional social engagement.

**Keywords:** Artificial intelligence; Social interaction; Substitution effect; Gift money expenditure

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## 1. Introduction

In recent years, artificial intelligence has achieved national strategic importance in China through policies like the “Development Plan for New Generation Artificial Intelligence” and “Digital China” initiative, fundamentally altering traditional social interaction patterns.

Academic literature presents three AI conceptualizations: specialized discipline, intelligent automation process, and intelligent behavioral capability<sup>[1–3]</sup>. Despite definitional variations, scholars converge on AI’s core ability to simulate human behavior and cognition<sup>[4]</sup>. International research demonstrates AI’s potential to optimize industrial structure and enhance productivity, though employment effects show complexity with heterogeneous impacts across skill levels<sup>[5–9]</sup>. Chinese scholars argue AI promotes coordinated socioeconomic development by improving factor contributions and input-output efficiency, enhancing firm productivity, manufacturing innovation,



and supply chain resilience at micro levels, while addressing demographic aging challenges at macro levels <sup>[10–15]</sup>.

Social interaction encompasses interdependent communication activities through information exchange, influencing personal decisions <sup>[16]</sup>. Following Manski's framework, it comprises endogenous interaction, contextual interaction, and correlated effects <sup>[17]</sup>. Research shows social interaction significantly affects household financial decisions, asset allocation, and consumption choices, with online interaction effects consistently exceeding offline effects and narrowing urban-rural gaps <sup>[18–25]</sup>.

However, research examining AI's impact on social interaction remains limited. While emotional AI enables humanized interaction, it may generate “pseudo-intimate relationships”, disrupting traditional patterns. International scholars primarily examine social media's impact on face-to-face communication, while quantitative AI research remains scarce, particularly in China <sup>[26–27]</sup>.

The study examines gift money exchanges as a social interaction proxy, investigating AI use's impact on traditional social interaction. The study pursues two objectives: identifying and quantifying AI's causal impact on individual social behavior, and understanding underlying mechanisms and demographic heterogeneity through mediation analysis. The contributions include pioneering AI examination from social interaction perspectives, employing instrumental variables to address endogeneity, and providing empirical evidence for digital transition policy implications. The paper proceeds as follows: Section 2 develops a theoretical framework and hypotheses; Section 3 introduces data and variables; Section 4 constructs econometric models; Section 5 reports empirical results and robustness tests; Section 6 concludes with policy implications.

## **2. Theoretical analysis and research hypotheses**

### **2.1. Technology substitution effect**

According to the technology substitution theory, artificial intelligence technology may reduce individuals' dependence on traditional social interaction by providing functionally similar but more efficient services <sup>[28–29]</sup>. Artificial intelligence systems' information retrieval, question-answering, and basic companionship functions may partially substitute for information exchange and emotional support functions in traditional face-to-face communication, thereby affecting individuals' social interaction <sup>[30–31]</sup>. Based on the technology substitution effect theory, this study proposes:

Hypothesis 1: Artificial intelligence use has a negative impact on individual social interaction behavior. Specifically, increases in daily artificial intelligence usage time significantly reduce individuals' gift money expenditure and gift frequency.

### **2.2. Social willingness changes**

Based on social cognitive theory, long-term artificial intelligence usage experience may reshape individuals' social cognition and behavioral preferences <sup>[32]</sup>. The convenience and controllability of artificial intelligence interaction may reduce individuals' willingness to participate in traditional social activities, particularly more notably in non-kinship social networks <sup>[33–34]</sup>. Based on social willingness change mechanisms, this study proposes:

Hypothesis 2: Social willingness changes play a mediating role in the relationship between artificial intelligence use and social interaction. Artificial intelligence use reduces individuals' social interaction behavior by decreasing their social willingness.

### **2.3. Group heterogeneity effects**

According to digital divide theory and technology acceptance models, different groups have significant differences in

new technology acceptance and usage patterns<sup>[35]</sup>. Young groups, highly educated groups, and high-income groups typically have stronger technology adaptation capabilities and higher technology dependence, so artificial intelligence use's impact on their social interaction behavior may be more significant. Based on group heterogeneity theory, this study proposes:

Hypothesis 3: Artificial intelligence use's impact on social interaction exhibits heterogeneity across demographic groups. Young, highly educated, and high-income groups demonstrate more pronounced artificial intelligence effects.

### **3. Research design**

#### **3.1. Data sources and sample selection**

This study employs primary data from a national questionnaire survey conducted May 18–31, 2025, targeting residents aged 18 and above. The structured instrument contains 68 questions measuring artificial intelligence usage, social interaction expenditure, social willingness, and demographic characteristics. Pre-survey validation confirmed instrument reliability and validity.

#### **3.2. Variables**

##### **3.2.1. Dependent variables**

Individual social interaction behavior serves as our core dependent variable. Following Sun and Lin's approach, we use gift money expenditure as a proxy for social interaction, with gift frequency for robustness testing<sup>[20]</sup>. In China's traditional cultural context, gift money expenditure represents an important manifestation of individuals participating in social networks and maintaining interpersonal relationships<sup>[20, 36]</sup>. Gift money expenditure and gift frequency derive from questionnaire questions 185 and 186, measuring respondents' frequency of giving gifts in the past year and reflecting social activity participation intensity.

##### **3.2.2. Core explanatory variables**

Artificial intelligence usage behavior serves as our core explanatory variable. Following established practices in digital technology adoption research, individual technology usage intensity through daily AI usage time is measured, capturing respondents' cumulative engagement with mainstream AI services, including intelligent voice assistants, navigation systems, recommendation algorithms, and chatbots<sup>[37–38]</sup>. Usage time is selected as our proxy for three reasons. First, time indicators intuitively reflect individuals' AI dependence and engagement depth, effectively measuring technology adoption intensity<sup>[39]</sup>. Second, continuous time variables facilitate precise econometric analysis compared to discrete frequency indicators. Third, this approach is widely applied in digital social science research with established comparability and reliability<sup>[40–41]</sup>. This specification enables accurate identification of AI technology's impact mechanisms on individual social behavior.

##### **3.2.3. Control variables**

Following existing research, the study controls for personal and household characteristics affecting individual social interaction<sup>[21, 36, 42]</sup>. Personal variables include actual age and its squared term (capturing nonlinear effects), gender, education years, marital status, and mobile payment dependence. Household variables include logarithmic total annual income, household size, number of AI-knowledgeable members, duration since first AI contact, and household head's employment status, derived from questionnaire items 1–10 and 104–120. This specification eliminates potential confounding influences, ensuring accurate identification of AI use's net effect on social behavior.

### 3.2.4. Mediating variables

To test internal mechanisms through which artificial intelligence use affects social interaction, the study specifies “changes in respondents’ social willingness with family members and non-family members after using artificial intelligence” as mediating variables. Social willingness changes are measured using a continuous sliding scale from -100 to 100, where -100 indicates significantly weakened willingness, 0 indicates no change, and 100 indicates significantly enhanced willingness.

### 3.2.5. Instrumental variables

Considering potential endogeneity in artificial intelligence use, the study employs overall AI satisfaction as our instrumental variable. This choice satisfies standard instrument requirements: AI satisfaction directly influences usage intensity, primarily reflects objective technology evaluations rather than individual social preferences, and affects social behavior solely through usage patterns after controlling for other characteristics. This instrumental variable approach enables causal identification of AI use effects on social interaction. The variable measures respondents’ overall AI technology evaluation on a 1–100 point scale. Main variable definitions, measurements, and descriptive statistics are shown in **Table 1**.

**Table 1.** Main variable definitions, measurements, and descriptive statistics

Variable type	Variable name	Variable definition and measurement	Mean	Std. dev.	Min	Max
Dependent Variables	Gift Expenditure (gift_expense)	Total gift expenditure in the past year (in 100 yuan)	105.40	173.43	0.00	1500.00
	Gift Count (gift_count)	Number of gifts given in the past year	6.02	9.14	0.00	83.00
Core Explanatory Variable	Daily AI Usage (ai_use)	Daily artificial intelligence usage time (minutes)	12.28	19.37	0.00	94.36
Mediating Variable	Social Willingness Change (social_change)	Change in social willingness with non-family members after using artificial intelligence	6.21	33.36	-100.00	100.00
Instrumental Variable	Overall Artificial Intelligence Satisfaction (ai_availability)	Overall evaluation of artificial intelligence technology	60.51	27.10	0.00	100.00
	Log Household Income (log_income)	Natural logarithm of total household annual income	3.25	0.71	1.39	5.30
	Household Size (family_size)	Number of household members	3.62	1.09	1.00	7.00
Household Control Variables	Household AI Penetration (family_ai_access)	Number of household members knowledgeable about artificial intelligence	2.61	1.25	0.00	9.00
	Artificial Intelligence Familiarity Duration (ai_access)	Time from first contact with artificial intelligence to survey (months)	19.04	11.08	0.00	30.00
	Household Head Employment (employ)	Current work status of household head (1=employed, 0=unemployed)	0.89	0.31	0.00	1.00
	Age (age)	Actual age at survey time (years)	31.29	12.06	16.00	63.00
	Age Squared (age_sq)	Squared term of age	1123.45	917.86	256.00	3969.00
Personal Control Variables	Gender (gender)	Respondent gender (1=male, 0=female)	0.51	0.50	0.00	1.00
	Education Level (education)	Respondent education stage	6.395	1.825	3.00	9.00
	Marital Status (marital_status)	Respondent marital status (1=unmarried, 2=married, 3=other)	1.384	0.563	1.00	4.00
	Mobile Payment Dependence (mobile_payment)	Dependence on mobile payment	3.734	1.524	1.00	5.00
Observations			177	177	177	177

### 3.3. Descriptive statistics

**Table 1** presents descriptive statistics for key variables. Annual gift expenditure averages 10,540 yuan with a standard deviation of 17,343 yuan, while participants engage in approximately six gift exchanges per year. Daily artificial intelligence usage averages 12.28 minutes, with substantial individual variation reflected in the standard deviation of 19.37 minutes. The sample comprises predominantly young adults with a mean age of 31.29 years and a balanced gender distribution at 50.8 percent male. Educational attainment is high, averaging undergraduate level, with typical household sizes of three to four members. The social willingness change indicator averages 6.21, suggesting respondents perceive artificial intelligence use affects family social interaction. Overall, artificial intelligence satisfaction averages 60.51, indicating generally positive attitudes toward the technology.

## 4. Model specification

### 4.1. Benchmark regression model

To identify direct impact effects of artificial intelligence use on individual social interaction behavior, the study constructs the following benchmark regression model:

$$social\_interaction_i = \alpha_0 + \beta_1 ai\_use_i + \gamma controls_i + \varepsilon_i \quad (1)$$

### 4.2. Mediation effect model

To test Hypothesis 2 regarding the mediating mechanism of social willingness changes, the study adopts Jiang's two-step method for mechanism analysis<sup>[43]</sup>. Drawing on social cognitive theory and social network theory, the study first establishes the theoretical foundation: when individuals' social willingness decreases, their motivation to participate in traditional social activities weakens, thereby reducing gift expenditure. This theoretical logic is well-established in existing literature<sup>[44-47]</sup>. Social willingness's mediating role is tested through the following model:

$$social\_change_i = \alpha_1 + \delta ai\_use_i + \gamma_1 controls_i + \mu_i \quad (2)$$

Where  $social\_change_i$  represents changes in individuals' social interaction willingness with non-family members after using artificial intelligence services, measured by questionnaire question 211. If  $\delta$  is significantly negative, combined with the theoretical analysis, this validates social willingness changes' mediating role in artificial intelligence use's impact on social interaction.

### 4.3. Instrumental variable model

Artificial intelligence use may be endogenous due to three factors: omitted variable bias from unobservable characteristics such as technology preferences and social tendencies; reverse causality, where individuals with lower social needs may prefer artificial intelligence technology; and measurement error in self-reported usage time. To address these concerns, the study employs individuals' overall satisfaction with artificial intelligence technology as an instrumental variable.

First stage regression:

$$ai\_use_i = \delta_0 + \delta_1 ai\_availability + \gamma_3 controls_i + \eta_i \quad (3)$$

Second stage regression:

$$social\_interaction_i = \alpha_3 + \beta_2 \widehat{ai\_use}_i + \rho social\_change_i + \gamma_4 controls_i + \zeta_i \quad (4)$$

Where  $ai\_availability$  represents individuals' overall satisfaction with artificial intelligence technology, and  $\widehat{ai\_use}_i$  represents the first-stage predicted value.

Overall, artificial intelligence satisfaction serves as the instrumental variable because it directly influences usage intensity while remaining independent of social behavior decisions and affects social expenditure solely through usage patterns, measured on a 1–100 point scale.

## 5. Empirical results and analysis

### 5.1. Regression results and analysis

**Table 2** reports benchmark regression results examining daily artificial intelligence usage time's impact on social interaction. Models 1 and 3 include household and household head controls, while Models 2 and 4 add individual-level variables for robustness testing.

Daily artificial intelligence usage time exhibits significantly negative coefficients across all specifications, confirming the substitution effect on traditional social interaction. For gift expenditure, each one-minute increase in artificial intelligence usage reduces spending by 1.48 yuan in Model 1 and 1.46 yuan in Model 2, both significant at the 1% level. For gift frequency, the corresponding reductions are 0.062 and 0.054 gifts annually, significant at 1% and 5% levels, respectively. These consistent negative effects across both outcome measures strongly support Hypothesis 1 that artificial intelligence technology substitutes for traditional face-to-face social interaction.

Control variables yield expected results. Log household income positively affects both gift expenditure and frequency across all models, consistent with social activities as normal goods. Education level demonstrates positive significant effects in extended specifications, supporting higher social investment among educated groups<sup>[10]</sup>. Artificial intelligence familiarity duration shows positive effects in basic models but becomes insignificant when individual controls are added, suggesting this relationship operates through individual characteristics.

Model fit improves substantially with individual controls, with adjusted  $R^2$  increasing from 0.173 to 0.205 for gift expenditure and from 0.156 to 0.172 for gift frequency, while core coefficient significance remains stable, confirming robustness of the substitution effect.

**Table 2.** Analysis of artificial intelligence use's impact on social interaction

	(1)	(2)	(3)	(4)	(5)	(6)
	Gift expenditure	Gift expenditure	Gift count	Gift count	Social willingness	Social willingness
Daily AI Usage	-1.480*** (0.411)	-1.455*** (0.424)	-0.062*** (0.022)	-0.054** (0.024)	-0.294*** (0.103)	-0.318*** (0.107)
Log Household Income	68.306*** (21.038)	62.671*** (22.263)	1.855** (0.863)	1.661* (0.868)	1.311 (3.912)	0.821 (4.089)
Household Size	11.134 (17.960)	4.887 (16.882)	0.499 (0.508)	0.280 (0.472)	-1.789 (2.400)	-2.216 (2.605)
Household AI Penetration	-0.317 (11.259)	6.679 (10.825)	-0.994 (0.632)	-0.769 (0.473)	0.801 (2.389)	1.044
Artificial Intelligence Familiarity Duration	4.835*** (1.003)	-0.415 (1.582)	0.151*** (0.057)	-0.018 (0.135)	0.716*** (0.223)	0.064 (0.377)



**Table 1 (Continued)**

	(1)	(2)	(3)	(4)	(5)	(6)
	Gift expenditure	Gift expenditure	Gift count	Gift count	Social willingness	Social willingness
Household Head Employment	-55.512 (74.270)	-48.527 (74.865)	-0.371 (1.733)	-0.202 (1.785)	-4.140 (8.819)	-6.881 (8.680)
Age		-2.896 (18.502)		-0.014 (0.379)		2.309 (2.013)
Age (Squared)		0.005 (0.212)		-0.000 (0.005)		-0.034 (0.027)
Gender		16.824 (19.318)		0.027 (1.218)		-6.818 (4.965)
Education Level		37.002*** (12.230)		1.183** (0.586)		1.369 (2.566)
Marital Status		73.358 (60.574)		3.266 (2.689)		3.421 (6.844)
Mobile Payment Dependence		1.799 (8.286)		0.215 (0.774)		3.368 (2.595)
Constant	-176.987** (84.231)	-329.213 (203.543)	-0.987 (2.990)	-9.290 (7.652)	0.014 (17.206)	-38.547 (32.928)
Sample Size	177	177	177	177	177	177
Adjusted R <sup>2</sup>	0.173	0.205	0.156	0.172	0.260	0.174

Note: Robust standard errors in parentheses. \*\*\*, \*\*, \* indicate significance at 1%, 5%, 10% levels respectively

## 5.2. Heterogeneity analysis

This study examines the differential effects of AI use on social interaction across demographic dimensions.

Age and Gender effects: Following the WHO classifications and approaches by Liu et al. and Lin et al., samples are divided into young ( $\leq 44$  years) and middle-aged/elderly ( $\geq 45$  years) groups <sup>[48–49]</sup>. Young individuals exhibit significant coefficients of -1.404, while middle-aged/elderly groups show insignificant effects (-0.752), reflecting higher digital acceptance and stronger substitution patterns among younger users who treat AI as behavioral replacements rather than supplements <sup>[35]</sup>. Gender analysis reveals universal substitution effects, with males (-1.498) and females (-1.282) both significant at the 10% level, though males demonstrate slightly stronger impacts.

Education and income heterogeneity. Following Sun et al., high education groups (bachelor's degree or above) show substantially larger coefficients (-2.279) compared to low education groups (-0.325), aligning with technology-skill complementarity theory where educated individuals more effectively utilize AI for social substitution <sup>[50–51]</sup>. Income analysis reveals threshold effects: high income groups demonstrate significant impacts (-1.123) while low income groups remain insignificant (-0.247), reflecting differential access to premium AI services and superior technological substitution capabilities <sup>[52]</sup>.

Model performance: Adjusted R<sup>2</sup> varies substantially across groups, with middle-aged/elderly achieving the

highest fit (0.535) due to stable behavioral patterns, while low income groups show the lowest explanatory power (0.150), indicating complex socioeconomic constraints beyond AI usage.

**Table 3.** Heterogeneity analysis of artificial intelligence use’s impact on social interaction

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Young	Middle-aged/ elderly	Male	Female	Low education	High education	Low income	High income
Daily AI Usage	-1.404*** (0.489)	-0.752 (1.022)	-1.282* (0.647)	-1.498* (0.816)	-0.325** (0.149)	-2.279*** (0.758)	-0.247 (0.480)	-1.123** (0.487)
Constant	64.313 (482.100)	-472.384 (810.297)	-689.801*** (237.519)	69.142 (321.797)	-86.431 (53.172)	-1014.377* (514.045)	-558.929* (303.484)	-408.709 (266.706)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	143	34	90	87	63	114	67	110
Adjusted R <sup>2</sup>	0.234	0.535	0.244	0.221	0.266	0.190	0.150	0.250

Note: Robust standard errors in parentheses. \*\*\*, \*\*, \* indicate significance at 1%, 5%, 10% levels respectively. “Yes” indicates inclusion of household and individual-level control variables

## 6. Conclusions and implications

### 6.1. Main research findings

Based on national survey data from 177 samples, this study employs instrumental variable methods to examine AI use impacts on traditional social interaction, validating three core hypotheses. First, AI use significantly reduces social interaction behavior, with each additional daily usage minute decreasing gift expenditure by 145.5 yuan in benchmark regression and 1,057.9 yuan under instrumental variable estimation, confirming technology substitution effects and Hypothesis 1. Second, social willingness serves as a crucial mediating mechanism, with AI use significantly reducing non-family social willingness through preference-shaping pathways, supporting Hypothesis 2. Third, substitution effects exhibit significant heterogeneity, with young, highly educated, and high-income groups demonstrating stronger technology sensitivity, validating digital divide theory manifestations and confirming Hypothesis 3.

### 6.2. Theoretical contributions and policy implications

This study enriches digital technology’s social effects literature by identifying social willingness changes as a mediating mechanism, revealing preference-shaping processes in human-machine interaction. Findings provide new theoretical perspectives for understanding social relationship transformation and contribute to technology-society interaction research.

Policy implications emphasize social inclusiveness during AI adoption, particularly addressing substitution risks among young and high-skill groups. Educational guidance and institutional arrangements should promote balanced development between digital technology and traditional interaction. Social policy frameworks require updating to reflect technology-driven behavioral changes, while digital skill training for middle-aged, elderly, and low-income populations should be strengthened to narrow the digital divide.

### 6.3. Research limitations and future directions

Limitations include a small sample size (177 observations) constraining heterogeneity analysis, cross-sectional data preventing dynamic relationship examination, and gift expenditure as a limited social interaction proxy. Future research should employ large-scale longitudinal data to examine evolutionary trajectories, investigate differential effects across AI application types, and expand the scope to encompass broader social interaction forms for a complete understanding of digital-era social transformation.

This study provides micro-empirical evidence for AI-era social transformation, offering insights for addressing digital technology's challenges while promoting coordinated development between technological progress and social harmony.

### Disclosure statement

The author declares no conflict of interest.

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# Mao Zedong and the Strategic Choice of the CPC Central Committee: The Long March Landed—The Historical Logic and Practical Enlightenment of Northern Shaanxi

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**Abstract:** This study systematically examines the strategic decision-making process between Comrade Mao Zedong and the Central Committee of the Communist Party of China during the Long March, analyzing the multiple motivations behind choosing northern Shaanxi as the final destination and its profound historical impact. As an extraordinary strategic relocation in the history of the Chinese Communist Party, the Long March not only demonstrated the tenacious resilience of revolutionary forces but also became a pivotal turning point, influencing modern China's historical trajectory. The decision by Comrade Mao Zedong and the Central Committee to establish northern Shaanxi as the Long March endpoint was a critical choice rooted in profound strategic considerations, laying solid political, military, and popular foundations for subsequent revolutionary victories and the establishment of the New China. Through historical retrospection, this paper aims to reveal the intrinsic logic and practical implications of this strategic decision.

**Keywords:** Mao Zedong; Long March; Northern Shaanxi; Central Committee of the Communist Party of China (CPC); Strategic choice

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## 1. Comrade Mao Zedong's historical status and great contributions

Comrade Mao Zedong was the great leader of the Chinese people, an outstanding Marxist, and a remarkable proletarian revolutionary, strategist, and theorist. As the principal founder and visionary leader of the Communist Party of China, the People's Liberation Army, and the People's Republic of China, he pioneered the historical process of Sinicizing Marxism, laid the theoretical foundation for Mao Zedong Thought, and became the core of the Party's first generation of central leadership <sup>[1]</sup>. During the stormy revolutionary era, Comrade Mao Zedong, with extraordinary wisdom and unwavering resolve, led the Chinese people through arduous struggles

to overthrow the three mountains of imperialism, feudalism, and bureaucrat-capitalism, achieving a fundamental turning point in the nation's destiny. He was the great leader who spearheaded the people's liberation cause and established the new China. His revolutionary practices spanned all stages of the Chinese revolution—from early peasant movements to armed struggles and base area construction—demonstrating strategic foresight throughout <sup>[2]</sup>.

Through decades of revolutionary practice, Comrade Mao Zedong systematically developed a revolutionary ideological system of profound historical significance. By creatively applying Marxist principles, he conducted in-depth analyses of China's unique semi-colonial and semi-feudal social conditions. His scientific examination of the internal logic and objective prerequisites for the existence and development of China's revolutionary regime revealed the revolutionary law that “a spark can start a prairie fire”, while profoundly elucidating its strategic value in the overall revolutionary context. Mao made groundbreaking theoretical contributions to fundamental issues such as formulating land revolution programs, establishing principles for people's army construction, and developing theories for building proletarian political parties. These efforts gave rise to major strategic concepts like “armed agrarian revolution” and “surrounding the cities from the countryside.” Not only did these ideas provide theoretical guidance for China's revolutionary practice, but they also decisively influenced the seizure of national power, steering the Chinese revolution toward ultimate victory. The essence of Mao Zedong Thought lies in its integration of China's realities, emphasizing the unity of practice and theory, thereby providing action guidelines for the Party across different historical periods <sup>[3]</sup>.

Specifically, from the winter of 1925 to the spring of 1927, Comrade Mao Zedong applied Marxist class analysis methodology in works such as “Analysis of the Classes in Chinese Society” and “Report on the Hunan Peasant Movement.” He scientifically analyzed the economic status and political attitudes of various social classes in China, explicitly identifying peasants' issues as the core of the Chinese revolution. Mao highly praised the historical significance of peasant movements as “excellent”, emphasized the historical inevitability of proletarian leadership in peasant struggles, and laid the ideological foundation for the land revolution <sup>[4]</sup>. These early works established the basis for the revolutionary mass line. When the KMT-CCP cooperation collapsed in 1927, at a critical juncture of the revolution, he delivered the groundbreaking statement “Political power grows out of the barrel of a gun” at the Central Committee's emergency meeting (August 7th Conference), establishing the principle of armed seizure of political power and charting a new revolutionary course. Subsequently, Chinese Communists, represented by Comrade Mao Zedong, grounded in national realities, abandoned dogmatic adherence to foreign experiences. They creatively proposed strategic guidelines for establishing rural revolutionary bases and advancing the land revolution in areas where Kuomintang rule was weak, successfully pioneering a Chinese-characterized revolutionary path of encircling cities from the countryside and seizing political power through armed struggle. This approach enabled revolutionary forces to survive and grow stronger amidst white terror. For instance, the establishment of the Jinggangshan base area became a model practice of this strategy, validating the feasibility of encircling cities from the countryside <sup>[5]</sup>.

However, after 1931, Wang Ming's “leftist” dogmatic line dominated the Central Committee. By mechanically following Comintern directives and rejecting Comrade Mao Zedong's correct propositions aligned with China's realities, the Party leadership was marginalized, leading to his removal from both the Party and Red Army leadership. This critical error directly caused the Central Red Army's defeat in the Fifth Encirclement Campaign, resulting in severe losses for the Soviet forces. In October 1934, the Central Red Army was forced to initiate a strategic relocation—the Long March, a monumental historical journey involving tens of thousands of soldiers who traversed treacherous terrain while facing enemy blockades <sup>[6]</sup>. At a pivotal moment in January

1935, the Political Bureau of the CPC Central Committee convened the historic Zunyi Conference, which ended the dominance of leftist dogmatism within the Party and established Comrade Mao Zedong's leadership over both the Party and the Red Army. This decisive move saved the Party, the Red Army, and the Chinese revolution, marking a critical turning point in Party history. By October of the same year, after enduring immense hardships, the Central Committee and the main force of the Red Army successfully reached northern Shaanxi, concluding the Long March. The establishment of the revolutionary base in Northwest China paved the way for the subsequent formation of the Anti-Japanese National United Front <sup>[7]</sup>.

Examining Comrade Mao Zedong's monumental revolutionary endeavors and profound theoretical contributions—particularly the historic path he led the Chinese people to forge and the enduring ideological legacy he left behind—provides vital historical insights and practical guidance for the new era. These insights help us deeply comprehend the spirit of the 20th National Congress of the Communist Party of China, strengthen historical confidence, enhance proactive engagement with history, and advance the comprehensive modernization of China to build a modern socialist nation. His revolutionary ethos and methodology—such as the principle of seeking truth from facts, the mass line approach, and independence—continue to serve as powerful motivation driving our progress, offering enduring wisdom for contemporary governance <sup>[8]</sup>.

## **2. The strategic choice of the Long March to settle down in northern Shaanxi**

The Long March was a monumental strategic relocation undertaken by the Chinese Communist Party during revolutionary setbacks, aimed at preserving revolutionary momentum, seeking strategic opportunities, and forging new revolutionary frontiers. Over the course of a year-long arduous journey spanning 25,000 li (approximately 14,500 kilometers) across 11 provinces, Comrade Mao Zedong masterfully commanded the Central Red Army (First Front Army). Through four historic crossings—the Chishui River, Jinsha River, Dadu River, and the daring capture of Luding Bridge—comrades overcame Nationalist forces' relentless encirclement. They scaled snow-capped mountains, traversed treacherous grasslands, and endured unimaginable hardships, including harsh natural conditions and severe shortages. With unshakable revolutionary conviction and indomitable perseverance, they ultimately achieved their strategic relocation objectives. Despite heavy losses during the march, the Red Army preserved its core strength through tactical flexibility and unwavering resolve, laying crucial foundations for subsequent revolutionary endeavors <sup>[9]</sup>.

The choice of northern Shaanxi as the strategic foothold was a key decision made by the CPC Central Committee and Comrade Mao Zedong after careful consideration based on three profound considerations:

Firstly, the region boasts remarkable geographical advantages. Situated on the Loess Plateau, northern Shaanxi features a complex terrain with crisscrossing gullies and rugged ridges, creating natural barriers that make it easy to defend but difficult to attack. This terrain provides ideal conditions for establishing a solid base area, enabling the Red Army to conduct strategic defense and prolonged warfare. The densely packed ravines in this region offer natural concealment and ambush advantages, effectively reducing threats from enemy mechanized forces <sup>[10]</sup>.

Secondly, the revolutionary foundation was deeply rooted and solid. Communist leaders like Liu Zhidan and Xie Zichang persistently fought here for years, establishing and expanding the Northern Shaanxi Red Army and the Shaan-Gan Border Revolutionary Base. They founded Soviet governments, built broad popular support, and developed substantial armed forces – all providing crucial footholds and strong backing for the Central Red Army.

Local farmers who benefited from the land revolution actively supported the Red Army, forming a stable network of grassroots support <sup>[11]</sup>.

Thirdly, the strategic value of this region is exceptionally prominent. Situated in the heartland of Northwest China, it lies far from Nanjing—the Nationalist Party’s capital—where reactionary forces were relatively weak. Its proximity to the North China Anti-Japanese Front not only provided the Red Army with a vital base for recuperation and consolidation but also facilitated future expansion into the frontlines. This strategic position established a pivotal hub connecting Northwest, North China, and the entire nation. The geographical advantage enabled seamless coordination with revolutionary forces nationwide, paving the way for the formation of the Anti-Japanese National United Front <sup>[12]</sup>.

Landing in northern Shaanxi has great and far-reaching strategic significance:

It provided a valuable rear area for the Red Army to recuperate, reorganize, and grow stronger after suffering hardships, ended the mobile state of the ten-thousand-mile war, and gave the Chinese revolution a stable strategic foothold. The Red Army recovered its strength here, reorganized its troops, replenished its troops, and prepared for the subsequent Anti-Japanese War.

Building on the Central Soviet Area’s extensive revolutionary experience, the region achieved rapid consolidation and expansion of its base areas by intensifying land reform efforts and establishing robust Soviet governments at all levels. This garnered heartfelt support from impoverished farmers across northern Shaanxi and surrounding regions, reestablishing a solid mass foundation for the Chinese Revolution. Land reform policies such as rent reduction and interest relief not only improved rural livelihoods but also strengthened revolutionary cohesion <sup>[13]</sup>.

The military-civilian integration model of “military-civilian unity as one” developed through the Shaanbei practice became the core driving force for revolutionary forces to survive, grow, and strengthen. This model successfully explored a path to establish and consolidate revolutionary bases in underdeveloped regions, laying a solid political, military, and popular foundation for the Communist Party of China’s transition from regional separatism to nationwide governance. Emphasizing shared hardships between the army and people, this model forged a bond of trust that strengthened their unity <sup>[14]</sup>.

History has powerfully demonstrated that during critical revolutionary transitions, maintaining close unity and high cohesion among the Party, military, and people serves as the fundamental guarantee for overcoming all adversities and achieving victory. Through initiatives like the Zunyi Conference, Comrade Mao Zedong and the Central Committee of the Communist Party of China strengthened intra-Party solidarity and ideological alignment. By strictly enforcing the “Three Main Rules of Discipline and Eight Points for Attention” and addressing the hardships of the masses, they fostered a close bond between the army and civilians, forging an ironclad resolve across the entire Party and military. This ultimately enabled them to overcome severe challenges during the Long March and their initial arrival in northern Shaanxi. For instance, in the later stages of the Long March, rectification campaigns corrected erroneous ideologies and ensured troop unity <sup>[15]</sup>.

In the face of extreme difficulties in the northern Shaanxi region, such as poor soil, poor people, and a backward economy, the CPC Central Committee and Comrade Mao Zedong did not retreat, but creatively inherited and developed the economic construction experience of the Soviet areas:

“We will implement the economic policy of ‘combining military and civilian affairs and combining peacetime and wartime’, encourage the military to participate in production, develop the public economy and cooperative economy, and ensure wartime supplies. The military will cultivate wasteland and grow grain to achieve self-



sufficiency.”

The leaders launched a vigorous campaign of mass production, “do it by ourselves, have enough food and clothing”, and cultivated land, and set up factories to achieve self-sufficiency in food and daily necessities. The development of Nanniwan became a model and alleviated the shortage of materials <sup>[16]</sup>.

Establish a sustainable material security system, including taxation, trade, and finance, to break the enemy’s economic blockade. Obtain necessities through fair trade policies and trade with merchants in the white zone.

This initiative not only effectively alleviated the immense survival pressures faced by military and civilian personnel in the base areas, significantly reducing the burden on local communities, but also deepened the solidarity between the military and civilians through joint labor and struggle. It laid a solid material foundation for sustaining revolutionary endeavors over the long term. Furthermore, it provided valuable organizational experience for leading large-scale economic development after assuming national governance, while cultivating a substantial pool of economic management cadres—particularly financial professionals—who became talent reserves for New China’s construction <sup>[17]</sup>.

### 3. Conclusion

This article systematically elucidates the profound historical logic and practical significance of the CPC Central Committee’s decision to establish the Shaanbei base area through analyzing Comrade Mao Zedong’s historical status, theoretical contributions, and the pivotal historical event of the Long March’s final destination in northern Shaanxi. This strategic choice demonstrated Mao Zedong’s tactical wisdom and deep understanding of China’s national conditions, becoming a critical turning point for the revolution’s survival <sup>[18]</sup>. As people fully implement the spirit of the 20th National Congress of the CPC and embark on a new journey toward building a modernized China to advance national rejuvenation, revisiting Mao Zedong’s brilliant ideological legacy and revolutionary practices offers vital insights: Whether it be victories in revolutionary times or achievements during the construction period, people must steadfastly uphold correct political direction, focus on the grand goal of national rejuvenation, unwaveringly adhere to the Party’s correct line, and vigorously carry forward the fine traditions of self-reliance and hard struggle <sup>[19]</sup>. Mao Zedong’s practice teaches that facing challenges requires adhering to seeking truth from facts and following the mass line. Only by doing so can people effectively address various risks and obstacles on the path forward, overcome difficulties in historical endeavors, continuously write glorious new chapters for socialism with Chinese characteristics in the new era, and contribute Chinese wisdom and solutions to the world.

### Disclosure statement

The author declares no conflict of interest.

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# Practical Understanding of High School Students' Application of AI in Biological Cell Research

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**Abstract:** With the penetration of Artificial Intelligence (AI) technology into the field of biomedicine, “AI + Biology” has gradually become a new growth point in secondary science education. This article explores the club’s teaching cases, analyzing how high school students use AI tools to observe cell morphology, collect statistical data, and explore mechanisms. The study examines the transformation of AI technology in knowledge construction, scientific thinking, and innovative thinking, and discusses the value of this technology in practical biology teaching at the secondary level, providing empirical reference for cultivating the core literacy of biology among secondary students.

**Keywords:** High school students; AI; Biological cells; Practice

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## 1. Introduction

Humans are in the technological wave of the 21st century, where the integration of Artificial Intelligence (AI) and biology is pushing the boundaries of scientific research at an unprecedented speed. As high school students, the emerging force of the future scientific community, using AI technology in learning biological cell research and combining education with scientific research innovation, allows people to gain a deeper understanding of knowledge points. This article focuses on “biological cells” and analyzes how high school students apply AI technology to complex problems in cell biology. This reality not only witnesses the popularization of technology and the innovation of education, but also reveals the potential of young students to solve practical health problems, such as identifying key targets for cancer treatment and developing interactive learning resources. These practices enrich adolescents’ scientific exploration experiences and bring new developmental enlightenment to traditional education.

## 2. Practical understanding of high school students’ application of AI in biological cell research: A case study based on the biology club of XX High School

### 2.1. Tool selection

Based on the requirements of biology, the students formed a biology club. During the process of conducting biological cell research, the members selected suitable AI tools through literature research and teacher guidance.

The selected tools include: 1) Cell image recognition tools such as “CellProfiler” and “DeepCell”, which can automatically analyze the morphology of cells under the microscope, such as area, roundness, and fluorescence intensity, replacing traditional manual measurement operations; 2) Molecular simulation platforms such as “MolView” and “PyMOL Junior”, which can visually present the dynamic interactions of intracellular molecules, helping us understand the cell’s metabolic processes; 3) Data statistics and forecasting models, which can be accessed through platforms like “Excel + Python scripts” or “R Language Easy Tutorial.” These platforms can process multiple sets of experimental data, generate trend charts based on the data, and predict variable relationships.

## 2.2. Practical tasks

In this high school club learning task, with the theme of “The Effect of Drugs (such as Paclitaxel) on the Proliferation of Cervical Cancer Cells (HeLa Cells)”, practical learning will be conducted in stages:

### 2.2.1. Stage 1: AI-assisted cell morphology recording

In traditional teaching methods, students need to manually observe and draw cell morphology under a microscope, which is a time-consuming process and susceptible to subjective errors. In practice, the club members use an inverted microscope to capture images of HeLa cells, which are then uploaded to “DeepCell.” The platform automatically identifies cell boundaries through a trained Convolutional Neural Network (CNN) model, and generates a “cell area—time change curve.” The AI tool can produce results within 1 minute. Based on the results, annotations are made: abnormally shrinking cells may be a signal of apoptosis.

### 2.2.2. Stage 2: AI simulation of molecular interactions

To explore “how paclitaxel inhibits cell division”, in the course of research, the students used the “MolView” platform to build a 3D molecular model of paclitaxel (Taxol) and tubulin. On the model, the students adjusted the molecular conformation to observe binding sites, and combined the theory of “paclitaxel stabilizes microtubules” in the literature, using “PyMOL Junior” to simulate the dynamic changes presented during microtubule polymerization. The students found that through AI simulation, the process of microtubule over-stabilization leading to cell non-separation is far more intuitive and specific than the illustrations in textbooks (**Table 1**).

**Table 1.** Simulated data for high school biology research practice

Research step	AI tools/platforms used	Specific operations and findings
Molecular Structure Visualization	MolView	Constructed 3D models of paclitaxel and $\beta$ -tubulin, observed paclitaxel binding at the “Taxol binding site” (hydrophobic groove of $\beta$ -subunit)
Conformational Analysis	MolView dynamic adjustment	Rotating models revealed that the C-13 side chain of paclitaxel forms hydrogen bonds with M-loop residues of tubulin (e.g., His229), restricting microtubule depolymerization
Dynamic Process Simulation	PyMOL Junior	Simulation showed: in the presence of paclitaxel, microtubule fibers (13 protofilaments) remained intact during mitosis without normal depolymerization curves
Cellular Effect Validation	Microscope imaging + AI analysis	Comparison with the control group (untreated HeLa cells) showed: after 24-hour treatment with 10nM paclitaxel, the proportion of cells in mitosis increased by 300%
Dose-Effect Analysis	Excel data modeling	IC50 calculation showed: paclitaxel inhibited 50% of HeLa cell proliferation at $7.8 \pm 0.5 \text{ nM}$ concentration (detected by CCK-8 assay)

### 2.2.3. Stage 3: AI-driven scientific thinking training

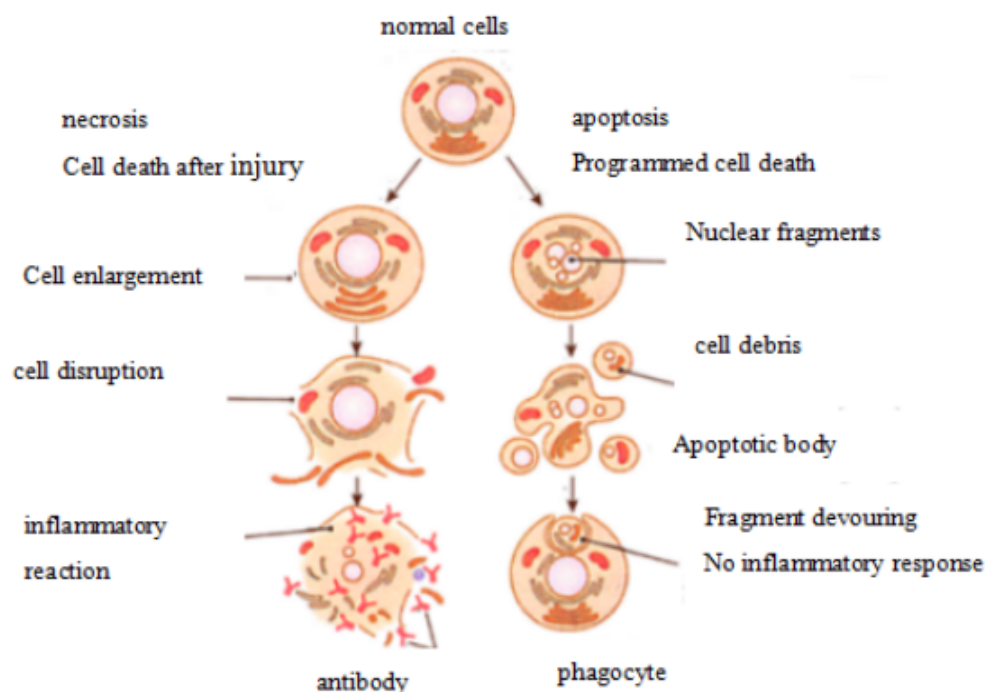
Through practical simulations, the students obtained corresponding experimental data, such as control group

experiments, low-concentration drug groups, and high-concentration drug groups. Then, we input these data into a Python script and use linear regression analysis to investigate the correlation between drug concentration and cell proliferation rate. Based on the conclusion the students obtained from practice: “Morphological changes in cells in the low-concentration group precede proliferation inhibition”, the students engage in a series of discussions and debates on whether the effect is due to direct drug toxicity or indirect signal interference. Through debate and AI-assisted literature review, the students arrive at the hypothesis that “it may trigger cell autophagy”<sup>[1]</sup>. This process involves recording experimental data, interpreting data, and verifying conclusions, which cultivates scientific thinking and has a positive effect on scientific thinking training.

### 3. Practical application of AI in biological cell research by high school students

#### 3.1. Systematic development of knowledge construction

In traditional classrooms, teaching knowledge about cell structures such as mitochondria, endoplasmic reticulum, and their functions often exists in isolation as “knowledge points.” The application of AI tools in the new era enables people to build a “structure-function-dynamics” cognitive connection in their minds, achieving systematic development of knowledge structures. For example, when analyzing “mitochondrial morphological changes and apoptosis”, through AI image recognition, the students discover that “apoptotic cell mitochondria fragment into pieces.” By combining this with observations from a molecular modeling platform, the students see that “cytochrome C is released from mitochondria and activates apoptotic proteins.” Finally, a complete logical chain of “mitochondria → functional abnormalities → apoptotic signal transmission” is formed in the mind (**Figure 1**). This helps the students engage in deeper learning, as AI connects static knowledge from textbooks into a dynamic knowledge system<sup>[2]</sup>.



**Figure 1.** Comparison between apoptosis and necrosis



### 3.2. Cultivating scientific thinking and achieving active inquiry

AI tools possess the characteristic of “explainability”, such as confidence scores in image recognition and parameter adjustments in simulation processes. This allows theoretical knowledge to be visualized, providing people with the practice of “validating hypotheses and refining models”. When completing a project, the students initially hypothesized that “higher drug concentrations lead to faster cell death”. However, AI statistical conclusions showed that “cells in the high-concentration group died faster”. Upon re-examining the experimental steps, the students discovered that high-concentration drugs might cause immediate cell shrinkage due to excessive toxicity, which was not correctly identified under the microscope. This made the students aware that “experiment design” needs to consider the precision of tool assistance. Based on this idea, the students improved the experimental method after consulting with the teacher. This process of “trial and error + correction” was enabled with the assistance of AI technology, allowing the students to truly understand that “scientific conclusions are based on evidence-based reasoning.”

### 3.3. Cultivating innovative thinking

In practical learning in biology, besides utilizing the ready-made functions of AI tools, students can also leverage them for “secondary development”. For instance, to address the issue of “DeepCell” being unable to recognize cells with uneven staining, students can write a simple script in Python and add a “color normalization” step for image preprocessing, which enhances the model’s accuracy<sup>[3]</sup>. Another group of peers designed an EXCEL prediction table based on the knowledge of “cell cycle regulation.” The table content focuses on the “drug exposure time—cell cycle arrest point”, providing theoretical knowledge for experiment conduction. Such “micro-innovations” in the teaching process are not complex but demonstrate the transition from being mere “technology users” to “technology improvers.”

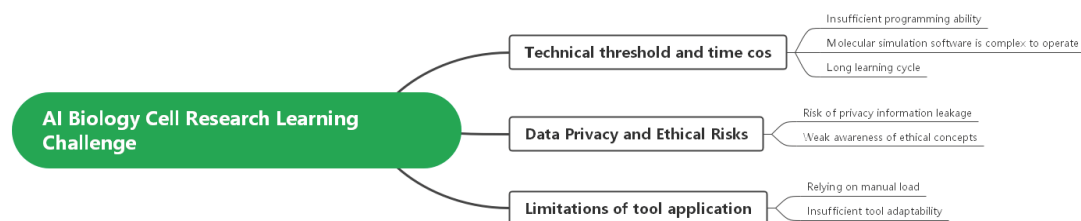
### 3.4. Foster a sense of collaboration and achieve interdisciplinary cooperation

The application of AI tools in biology breaks the traditional solo operation mode of biological practices, providing a feasible path for collaborative experiments. Image recognition in AI tools requires a combination of biological knowledge and transformation capabilities, while molecular simulation necessitates a collaboration between chemical knowledge and spatial imagination. During the practical learning process, community members are divided into different groups, such as the biological observation group, data programming group, and literature search group. Group members hold weekly meetings to discuss learning content. Conducting biological scientific research in this way enables students to deepen their understanding of knowledge points, enhance disciplinary thinking, and cultivate comprehensive literacy. AI modeling and models can help us grasp and understand the essence of life, promoting the development of scientific thinking in modern society<sup>[4]</sup>.

## 4. Challenges for high school students in applying AI to biological cell research

Currently, the challenges faced by high school students in using AI technology for biological cell research include technical thresholds and time costs, data privacy and ethical risks, and limitations in tool applications (**Figure 2**). Among the students, some are not proficient in Python programming and the operation of molecular simulation software, requiring additional time investment to meet the demands of technical applications. When using real cell images, patients’ tumor cells are often involved, and students lack awareness of “data ethics” during this process. Besides, AI technology is not omnipotent. Some AI models have relatively low accuracy when used in complex

samples, such as mixed cell lines, and often require teachers' guidance for verification.

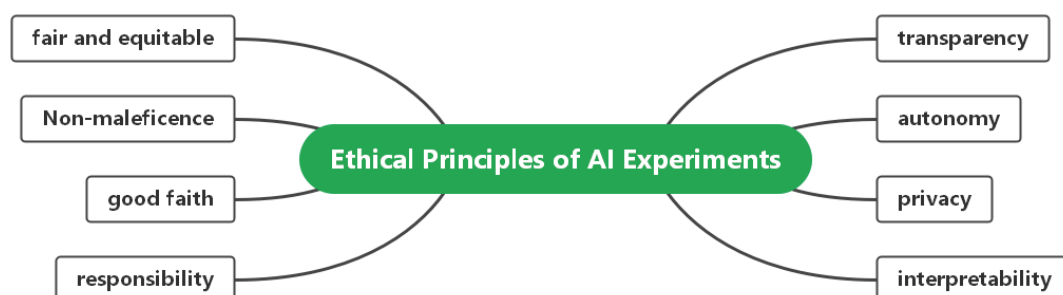


**Figure 2. Challenges in AI-assisted biological cell research and learning**

## 5. Practical optimization of high school students' use of AI in biological cell research

Firstly, tiered training and learning are conducted. For students in the basic tier, the focus is on “basic operation of AI tools and corresponding understanding of biological issues.” For example, through “micro-videos and step-by-step demonstrations”, students are helped to understand the installation of cell recognition tools, learn basic steps such as uploading images and setting parameters. For students with a certain theoretical foundation, the focus is on the application of “data statistics and simulation platforms.” They are taught basic Python syntax in teaching, guided to write simple scripts to generate trends, and interpret meanings. For students who are deeply interested and have outstanding subject abilities, the focus of training is on “secondary development of AI tools and interdisciplinary integration.” Students are encouraged to improve the limitations of existing tools, innovate, and write preprocessing scripts to enhance their innovation abilities <sup>[5]</sup>. Tiered training can improve the participation rate of club members, and during club activities, students can find corresponding learning goals based on their own levels, reducing technical anxiety.

Secondly, considering that data privacy and research ethics may be involved in learning, students integrate science and technology ethics education into discussions to cultivate a disciplinary attitude of “having bottom lines and being able to reflect” (**Figure 3**) <sup>[6]</sup>. For example, group debates and role-playing are introduced in teaching to guide peers to think about: “Which data can be used? How to avoid AI ‘bias’?” Adding ethical self-examination steps to each link of the experiment allows students to form the habit of “reflecting while operating”. Later, under the guidance of teachers, students write an “AI Experimental Ethics Log”, using a diary to explain the ethical issues involved in the operation, and try to make suggestions for improvement. This process of continuous learning through reflection plays an important supporting role in students' future learning and growth <sup>[7]</sup>.



**Figure 3. Ethical principles of AI experiments**

Finally, build a collaborative teaching network of “AI + teachers + students”<sup>[8]</sup>. Because AI-enabled cell research involves different disciplines such as biology, programming, and chemistry, it is necessary to establish a collaborative system in this context. Teachers can help us screen reliable AI tools. As the learning subjects, students can take the lead in various aspects such as experimental design, tool operation, and conclusion analysis to achieve interdisciplinary collaboration<sup>[9]</sup>. External experts mainly compensate for the limitations of school resources. In the new era, a normalized “online + offline” communication mode can be established to actively provide feedback on problems and share achievements, promoting continuous optimization through the “display—feedback—iteration” process, thus achieving the desired teaching effect<sup>[10]</sup>. For example, organize an “AI + Cell Research” achievement exhibition to showcase reports written during the experimental process, AI improvement tools, reflection logs, etc., and then invite school experts to review and improve them. Through this approach, AI tools can be fully utilized as auxiliary teaching tools, thereby facilitating the transformation of achievements into practice.

## 6. Conclusion

In summary, as high school students engaged in practical teaching activities of biological cell research utilizing AI, the implementation of such activities not only represents the application of modern technology but also embodies the “cognitive revolution.” Through the empowerment of AI tools, students can achieve a leap towards “dynamic connectivity” in knowledge construction and drive breakthroughs and transformations in tool creation in terms of innovation. In the new era, educators must consider the risks and challenges faced in the application of AI tools, such as ethical issues, to ensure their proper use. As AI technology continues to evolve in the future, the deep integration between AI technology and high school biology education will facilitate normalized experimental practices in the new era. Information technology will promote the development of thinking, which will be greatly beneficial for future progress.

## Disclosure statement

The author declares no conflict of interest.

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# Urban Innovation Ecosystems and Sustainable Development in a Latecomer City: A Case Study in Zhangzhou, China

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**Abstract:** Building a good innovation ecosystem for latecomer cities in regional integration can help achieve long-term sustainable development. This paper constructs a conceptual framework for urban innovation ecosystems from a life cycle perspective. This paper chose Zhangzhou City as a case to analyze the evolution of urban innovation ecosystems from 2004 to 2022. The study shows that Zhangzhou's innovation ecosystem is growing, and the system is improving steadily. However, the impact of mobility of innovation factors on the innovation ecosystem needs attention. This paper proposes that latecomer cities further improve the governance system related to the innovation ecosystem, construct an open and shared industry-university-research collaboration mechanism, and guide society in the construction of urban innovation ecology. The finding is important for understanding the construction of innovation ecosystems in developing cities.

**Keywords:** Innovation ecosystem; Sustainable development; Latecomer city; Case study

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## 1. Introduction

Innovation capability is an important cornerstone for promoting the sustainable development of the urban economy. For cities, the enhancement of comprehensive innovation capability depends on the construction of a good innovation ecosystem. The innovation ecosystem is the interaction between innovation subjects (enterprises, scientific research institutions, government, etc.), elements, and the environment, forming a sustainable complex ecosystem<sup>[1]</sup>. Research shows that by promoting knowledge creation, technology transfer, and enterprise innovation, an innovation ecosystem helps enhance regional innovation capability, industrial chain resilience, and the promotion of low-carbon economic development<sup>[2-4]</sup>.

The concept of a regional innovation ecosystem originates from the expansion of innovation system theory, which emphasizes innovation activities' social and technical network characteristics<sup>[5-6]</sup>. At present, relevant research on innovation ecosystems has discussed the interaction and synergistic development among



innovation subjects, innovation elements, and the innovation environment within the system and stressed that the government plays a key role in the regional innovation ecosystem by providing policy support, capital input, and an institutional environment to promote the development of the innovation ecology system <sup>[7]</sup>. The policy design of a regional innovation ecosystem needs to consider the region's specific conditions and the ecosystem's intrinsic needs to achieve policy effectiveness and adaptability <sup>[8]</sup>.

For the dynamic analysis of the urban innovation ecosystem, the spatiotemporal location of a city needs to be considered. First, each city is in a different "life cycle" in time. Owing to different historical development statuses, geographic locations, and policy influences, the speed of urban development varies. Some cities are in the prime of gradual development. Meantime, other cities face the problem of "contraction" during recessions <sup>[9]</sup>. On the other hand, a city's economy is spatially affected by the economic development status of the region in which it is located. Against the background of existing policies, local development within a province is rising in a spiral, accompanied by national policy in the two-way transformation of "coordinative regional development" and "key development of central cities" to achieve sustainable development as much as possible "with limited resources" and compete for various factor flows (likes capital flow, talent flow) between and within regions <sup>[10]</sup>. This means that once the "spillover effect" of the core cities in the region is lower than the "siphon effect", the gap between the "core-border" cities in the region will widen. Border cities are prone to weakening with the rise of core cities, while core cities will gradually weaken. Cities create development bottlenecks due to space limitations and public service provision <sup>[11–12]</sup>. Therefore, this case study will be helpful for further understanding the spatiotemporal evolution of the innovation ecosystem.

In this paper, Zhangzhou City was selected as the research object. On the one hand, Zhangzhou was a latecomer in the regional integration of Xiamen, Zhangzhou, and Quanzhou. In the past 20 years, it has transformed from an agriculture-based economy to an industry-oriented economy, and its economic growth has lagged behind Xiamen, a special economic zone, and Quanzhou, with a developed private economy. On the other hand, Zhangzhou has enjoyed good development momentum in recent years, and the government has been actively promoting various urban innovation policies. The case of Zhangzhou will help us understand the choices of innovative development strategies of latecomer cities against the background of regional policies; this is of particular importance in theory and policy.

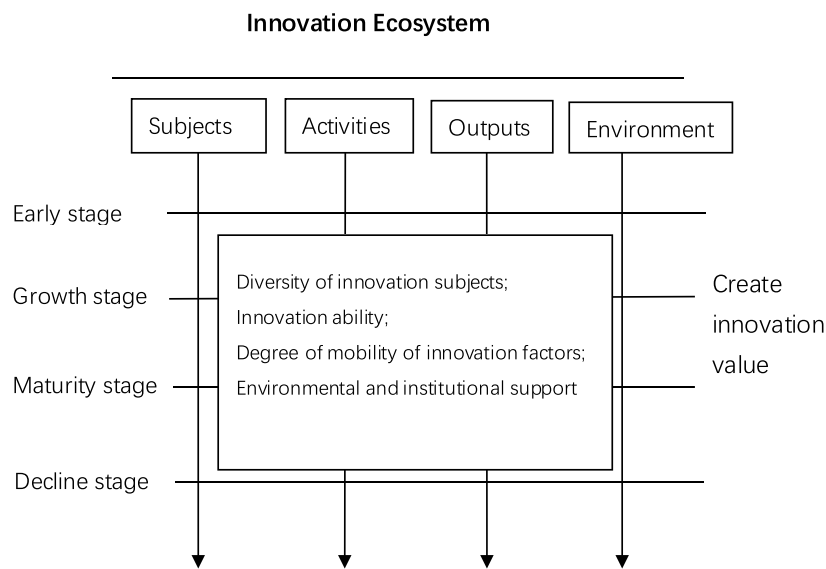
The paper is organized as follows: Section 2 discusses the conceptual framework. Section 3 presents the research design and describes the methods. Section 4 presents the case analysis, and Section 5 presents the conclusions and future directions for further research.

## 2. Framework of urban innovation ecosystems from the life cycle

The urban innovation ecosystem includes four components: innovation subjects, innovation activities, innovation outputs, and the institutional environment <sup>[13]</sup>. Innovation subjects refer to different types of players, including enterprises, research institutions, universities, governments, and individuals. Innovation activity is a series of innovation-related behaviors involving R&D, production, and trade. Innovation outputs include products, services, technologies, and knowledge resources. The institutional environment includes city laws and policies, and informal institutions such as culture and norms.

As shown in **Figure 1**, from the life cycle perspective, evolution analysis reveals that an urban innovation ecosystem will undergo the following stages: the early stage (germination stage), growth stage, maturity stage, or

decline stage, and innovation subjects, activities, outputs, and institutional environments differ <sup>[14–15]</sup>.



**Figure 1.** The evolution path of the urban innovation ecosystem

In the early stage, the number of innovation entities in the innovation ecosystem was relatively small, and the lack of interaction mechanisms further limited the number of innovation activities and outputs <sup>[16]</sup>. Compared with formal institutions, informal institutions play a more significant role in the early stage, and regions with an adventurous spirit and risk preference engage in relatively more innovative activities. According to the analysis of resilience characteristics, the innovation ecosystem is relatively fragile because there are few participants, the flow of resources and information is limited, and there is a lack of sufficient resources and capabilities to absorb and mitigate external shocks. Effective learning and adaptation mechanisms have not yet been formed.

During the growth stage, with the accumulation of resources and the expansion of the network, new entrants begin to increase, the mobility of the innovation ecosystem increases significantly, and capital, talent, information, and technology begin to flow more frequently. Formal institutional arrangements conducive to leading innovation activities are critical at this stage. A sound institutional environment leads to a rapid increase in innovation output, which manifests as a continuous increase in buffering and evolution, thereby significantly improving the resilience of the innovation ecosystem <sup>[17]</sup>. Conversely, due to internal imbalance or external black swan events, the innovation ecosystem can enter a negative cycle and be unable to further develop into the maturity stage or even decline.

An innovation ecosystem that has entered the mature stage has complex and diverse innovation subjects, efficient and systematic innovation activities, a relatively complete policy support system, industry norms, cultural identity, and the strength of innovation output radiating outward. The resilience of the innovation ecosystem reaches a maximum, which can effectively absorb shocks and maintain system stability. However, an innovation ecosystem at the mature stage may still decline under external or internal shocks. During recessions, the resilience of the innovation ecosystem is relatively fragile, and the system cannot effectively resist and recover from exogenous shocks.

The dimensional characteristics of innovation ecosystem resilience differ across different periods, and the

differences in the innovation ecosystems of different cities lead to different development paths of cities in the face of a shock. From the life cycle perspective, a resilient innovation ecosystem has diverse innovation subjects, efficient mobility of innovation factors, and sufficient environmental and institutional support, thus exhibiting high innovation capability. Such a system can promote the generation and application of knowledge, maintain competitiveness through interactions between subjects, quickly adapt to environmental changes, and effectively respond to the evolution of the market and technology. It can also recover quickly after a shock, breaking the original path dependence and improving the overall performance of the innovation ecosystem.

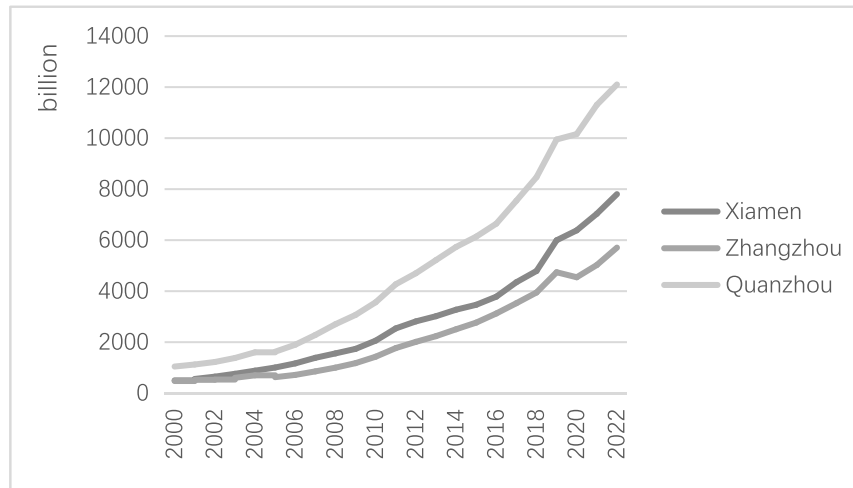
In the following section, the evaluation system is constructed from the four aspects of the diversity of innovation subjects, the degree of mobility of innovation factors, the environmental and institutional support, and the innovation ability. In detail, the study analyzed the Zhangzhou innovation ecosystem from 2004 to 2022 and its characteristics and imbalance level.

### 3. Cases and research methods

#### 3.1. Case introduction

Zhangzhou city is located in southeastern Fujian Province and governs four districts, seven counties, and five development zones. In higher-level planning, various policies have strongly promoted Xiamen–Zhangzhou–Quanzhou regional integration. The “Golden Triangle of Southern Fujian” is formed by Xiamen and Quanzhou cities. Urban agglomeration is a common feature of southern Fujian culture and geographic proximity. Regarding infrastructure, the integration of communication between cities and the connection of intercity high-speed railways and bus card swipes have been realized. In addition, the joint protection of water basins and cooperation in controlling environmental pollution have been carried out <sup>[18]</sup>. As mentioned earlier, Zhangzhou’s economic development is relatively weak within the urban agglomeration (**Figure 2**), and it was a latecomer in the urban agglomeration. The unbalanced development among regions may cause more resources to flow out of Zhangzhou in urbanization <sup>[19]</sup>. In addition, the development of the districts and counties within Zhangzhou is relatively uneven, and the economic policies are biased toward promoting the development of the central urban area (Longwen, Xiangcheng, Longhai, Changtai) and the four major development zones. The central city core area is an urbanization area promoted mainly by Zhangzhou city and the frontier of urbanization with Xiamen, with a relatively high level of economic development.

In contrast, other counties and districts are biased toward traditional agriculture and the cultural and tourism industry. To catch up with the development of its surrounding cities, Zhangzhou’s planning in recent years has focused on the differentiated development of characteristic regional industries, emerging manufacturing industries, and biomedicine and health industries. More significant policy support has also been given regarding talent introduction policies, subsidies for high-tech enterprises, and the construction of entrepreneurial incubation platforms. In terms of higher education resources, Zhangzhou currently has an undergraduate university and a branch campus of a key university, and these two schools are the leading players in promoting the establishment of a regional industry-university-research alliance. Therefore, with accelerating economic growth and policy support, is the quality of Zhangzhou’s innovation ecosystem steadily improving? This is what the authors want to explore further.



**Figure 2.** Xiamen, Zhangzhou, and Quanzhou's GDP from 2000 to 2022

### 3.2. Calculation steps: Measurement methods

This paper uses the distance method between superior and inferior solutions modified by the entropy weight method (entropy weight TOPSIS method) for measurement. In the measurement process, each reference indicator was first standardized to avoid differences caused by different units of each indicator. On this basis, the entropy weight method was used to assign the weight of each indicator objectively, and the TOPSIS method was finally used for ranking to ensure the authenticity and validity of the research data as much as possible. The specific operation steps of the above methods are as follows:

#### 3.2.1. Data standardization

The indicators are divided into positive indicators and negative indicators. The positive indicators are the indicators whose larger values are better. The opposite is true for the negative indicators. The original data needs to be standardized to eliminate the differences in the dimension and order of magnitude of different indicators.

$$\text{Positive indicators: } x'_{ij} = \frac{x_{ij} - \min(x_{1j}, x_{2j}, \dots, x_{nj})}{\max(x_{1j}, x_{2j}, \dots, x_{nj}) - \min(x_{1j}, x_{2j}, \dots, x_{nj})} \quad (\text{Formula 1})$$

$$\text{Converse indicator: } x'_{ij} = \frac{\max(x_{1j}, x_{2j}, \dots, x_{nj}) - x_{ij}}{\max(x_{1j}, x_{2j}, \dots, x_{nj}) - \min(x_{1j}, x_{2j}, \dots, x_{nj})} \quad (\text{Formula 2})$$

where  $i$  represents the year and  $j$  represents the  $j$ -th indicator in the indicator system.  $x'_{ij}$  refers to the normalized value.

#### 3.2.2. Proportion of standardized values

The proportion of the normalized value of the city's score under each indicator was calculated as  $P_{ij}$ , indicating the contribution level of different samples under different indicators.

$$P_{ij} = \frac{x'_{ij}}{\sum_{i=1}^m x'_{ij}} \quad (0 < P_{ij} < 1) \quad (\text{Formula 3})$$

where  $m$  represents the year.

(3) Calculate the information entropy and information utility values of the indicators

The information entropy formula for the  $j$ -th indicator is:

$$e_j = -\frac{\sum_{i=1}^m p_{ij} \ln p_{ij}}{\ln n} \quad (\text{Formula 4})$$

where  $n$  is a constant and where  $n$  is the number of indicators.

The information utility value  $d_j$  depends on the index information entropy  $e_j$ .

$$d_j = 1 - e_j \quad (\text{Formula 5})$$

The larger the information entropy is, the smaller the information utility value, and the smaller the weight.

#### (4) Calculate the indicator weights

The weight of an indicator is determined by the degree of contribution to the entire evaluation system; therefore, the formula for the weight is as follows:

$$w_j = \frac{d_j}{\sum_{i=1}^m d_j} \quad (\text{Formula 6})$$

#### (5) Calculate the optimal distance

Construct a weighting matrix of the measure indicators and calculate the optimal level  $Q_i^+$  and worst level  $Q_i^-$ :

$$Q = (q_{ij})_{m \times n} \quad (\text{Formula 7})$$

of which  $q_{ij} = W_j * Y_{ij}$ .

Then, calculate the Euclidean distance between each evaluation object and the optimal level and the worst level. The specific calculation formula is as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^m (q_{ij} - Q_j^+)^2} \quad (\text{Formula 8})$$

### 3.2.3. Construction of innovation ecosystem indicators

In this study, considering the principles of data scientificity, representativeness, and availability, the authors select 19 secondary indicators that could reflect Zhangzhou city's characteristics from the four dimensions of the diversity of innovation subjects, degree of mobility of innovation factors, environmental and institutional support, and innovation ability. These indicators represent the status of the innovation ecosystem.

The diversity of innovation subjects is divided into enterprise diversity, university diversity, and industrial diversity. The quantity and quality of innovation subjects from enterprises and universities should be considered. The degree of mobility of innovation factors includes three aspects: capital flow, goods flow, and labor mobility. Knowledge and technology flows are not included because they are difficult to measure. Considering that Zhangzhou is a coastal port city, the water-borne freight volume is selected as one of the measurement indicators. In terms of environmental and institutional support, from the resource dimension, in addition to the accumulation of economic resources required for innovation activities, natural and social resources are added, of which industrial sulfur dioxide emissions are a negative indicator. Innovation ability starts from innovation activities and selects representative indicators to measure innovation input and output. **Table 1** lists the specific indicators and weights.



**Table 1.** Index system of the Zhangzhou innovation ecosystem

Dimension	Weight	Primary indicators	Secondary indicators	Weight
Diversity of innovation subjects	0.1956	Enterprise diversity	Quantity of R&D by enterprises above the designated size	0.0791
		College Diversity	Number of students in colleges and universities	0.0236
			Number of full-time teachers in institutions of higher learning	0.0304
		Industrial diversity	Diversity of industrial structure	0.0625
Innovation ability	0.2297	Innovation input	R&D internal expenditures	0.0488
			Science expenditures in the government budget	0.0418
		Innovation outputs	Number of domestic patents granted	0.0830
			R&D personnel of enterprises above the designated size	0.0560
Degree of mobility of innovation factors	0.2319	Fund flow	Import and export trade amount	0.0415
			Per capita actual use of foreign capital in the current year	0.0423
		Goods flow	Road freight volume	0.0566
			Waterborne freight volume	0.0707
Environmental and institutional support	0.3429	Labor Mobility	Number of employees	0.0207
		Policy support	Financial investment in education	0.0527
			Industrial sulfur dioxide emission	0.0280
		Natural environmental	Number of books in public libraries	0.0875
			Number of beds in medical and health institutions	0.0594
		Social and environmental resources	GDP per capita	0.0533
Economic resources	Per capita balance of deposits in financial institutions at the end of the year	0.0619		

## 4. Evaluation and analysis of the Zhangzhou innovation ecosystem

### 4.1. Measurement results

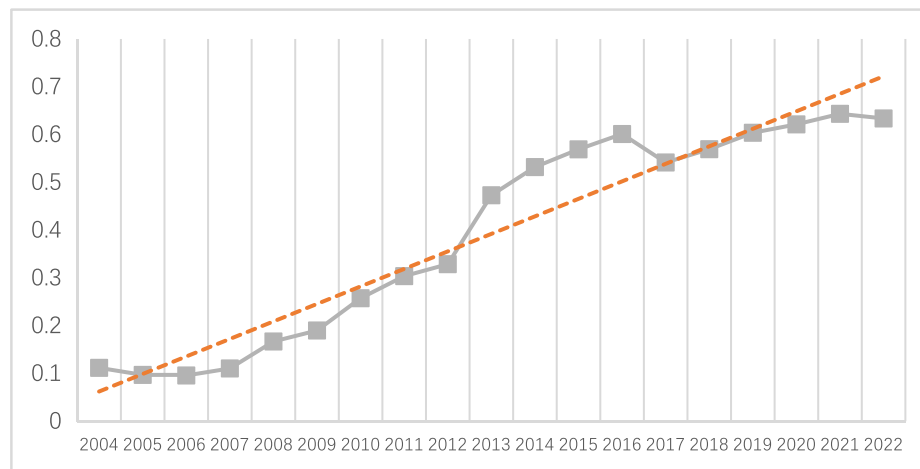
The relevant data used in this paper are the “Zhangzhou Statistical Yearbook”, “China City Statistical Yearbook”, “Zhangzhou Statistical Bulletin on National Economic and Social Development”, and the Fujian Provincial Bureau of Statistics from 2004 to 2023.

This paper uses the entropy weight TOPSIS method for measurement analysis. **Table 2** lists the overall score results of Zhangzhou’s innovation ecosystem from 2004 to 2022. The value will reach a maximum in 2021, reaching 0.64, nearly six times greater than the 0.11 reported in 2004. Zhangzhou’s innovation ecosystem has shown good growth over the past ten years.

**Figure 3** visually reflects the variation range of Zhangzhou’s innovation system from 2004 to 2022. From 2004 to 2007, the value was relatively low and did not increase significantly. From 2008 to 2016, the value exhibited two precise growth intervals. Since 2017, the value has shown a slight increase in the range and stable fluctuations. Even after the outbreak of the epidemic in 2020, there was no significant decline. Preliminary judgment shows that Zhangzhou’s innovation ecosystem entered the growth stage in 2008, which has continued.

**Table 2.** Zhangzhou innovation ecosystem evaluation scores

Year	Numerical value	Ranking
2004	0.11	16
2005	0.10	18
2006	0.10	19
2007	0.11	17
2008	0.17	15
2009	0.19	14
2010	0.26	13
2011	0.30	12
2012	0.33	11
2013	0.47	10
2014	0.53	9
2015	0.57	7
2016	0.60	5
2017	0.54	8
2018	0.57	6
2019	0.60	4
2020	0.62	3
2021	0.64	1
2022	0.63	2

**Figure 3.** Changes in Zhangzhou's innovation ecosystem from 2004 to 2022

## 4.2. Dimension analysis

This paper conducts an in-depth analysis of four dimensions to further analyze the innovation ecosystem's status: the diversity of innovation subjects, the degree of mobility of innovation factors, environmental and institutional support, and innovation capability.

#### 4.2.1. Diversity of innovation subjects

As shown in **Table 3**, the diversity of Zhangzhou's innovation ecosystem increased steadily from 2004 to 2022, reached a maximum in 2020, and then declined slightly. After the richness of species and the evenness of individual distributions were considered, the Shannon-Weiner index, commonly used in ecology, was used to measure the diversity characteristics of the subjects. The specific formula is as follows:

$$H = -\sum(p_i * \ln(p_i)) \quad (\text{Formula 9})$$

$P_i$  represents the proportion of a particular species in the total amount, and  $H$  is the index value.

**Table 3.** Diversity of Zhangzhou's innovation ecosystem

Year	Diversity	Ranking
2004	0.06	17
2005	0.04	19
2006	0.06	18
2007	0.09	16
2008	0.13	15
2009	0.16	14
2010	0.18	13
2011	0.19	12
2012	0.21	11
2013	0.30	10
2014	0.36	9
2015	0.39	8
2016	0.47	7
2017	0.53	6
2018	0.64	5
2019	0.88	2
2020	0.93	1
2021	0.82	4
2022	0.84	3

As shown in **Table 4**, the Shannon index of Zhangzhou's innovation ecosystem remained between 0.17 and 0.21 from 2004 to 2022, which is a relatively stable state. There was no significant increase or decrease in diversity. That is, the number of species in Zhangzhou in enterprises, universities, and industries was a steady increase of the same magnitude; therefore, there was no significant change in the numerical values.

**Table 4.** Results of the Shannon-Wiener index

Year	Shannon Weiner
2004	0.21
2005	0.20
2006	0.18
2007	0.17
2008	0.17
2009	0.17
2010	0.17
2011	0.17
2012	0.17
2013	0.17
2014	0.18
2015	0.18
2016	0.19
2017	0.19
2018	0.20
2019	0.20
2020	0.19
2021	0.19
2022	0.19

#### 4.2.2. Innovation capability

Innovation capability refers to the ability of the innovation ecosystem to accumulate experience and knowledge, obtain innovation outputs, and enhance the system's creativity through the innovation activities of innovation subjects. As shown in **Table 5**, from 2004 to 2022, the contribution of Zhangzhou's innovation ecosystem and the continuous increase in innovation capability indicates that the innovation input-output ratio of Zhangzhou's regional innovation ecosystem is increasing each year and that the allocation of innovation resources and the innovation environment has achieved a certain extent.

**Table 5.** Innovation capability of Zhangzhou's innovation ecosystem

Year	Innovation ability	Ranking
2004	0.00	19
2005	0.02	18
2006	0.04	17
2007	0.05	16
2008	0.07	15
2009	0.12	14
2010	0.15	13
2011	0.22	12

**Table5 (Continued)**

Year	Innovation ability	Ranking
2012	0.28	11
2013	0.34	10
2014	0.35	9
2015	0.40	8
2016	0.47	7
2017	0.54	6
2018	0.69	4
2019	0.77	3
2020	0.80	2
2021	0.82	1
2022	0.69	5

#### 4.2.3. Degree of mobility of innovation factors

As shown in **Table 6**, from 2004 to 2022, the degree of factor mobility in Zhangzhou's innovation ecosystem fluctuated significantly. It peaked in 2015, continued to decline, and then returned to the 2010 level after 2019. The main reason may be the decrease in foreign direct investment and foreign trade cargo throughput.

**Table 6.** Degree of mobility in Zhangzhou's innovation ecosystem

Year	Mobility	Ranking
2004	0.04	19
2005	0.04	18
2006	0.09	17
2007	0.13	16
2008	0.30	15
2009	0.32	14
2010	0.47	8
2011	0.56	6
2012	0.54	7
2013	0.62	5
2014	0.78	2
2015	0.81	1
2016	0.71	3
2017	0.64	4
2018	0.43	9
2019	0.36	13
2020	0.37	12
2021	0.42	10
2022	0.42	11

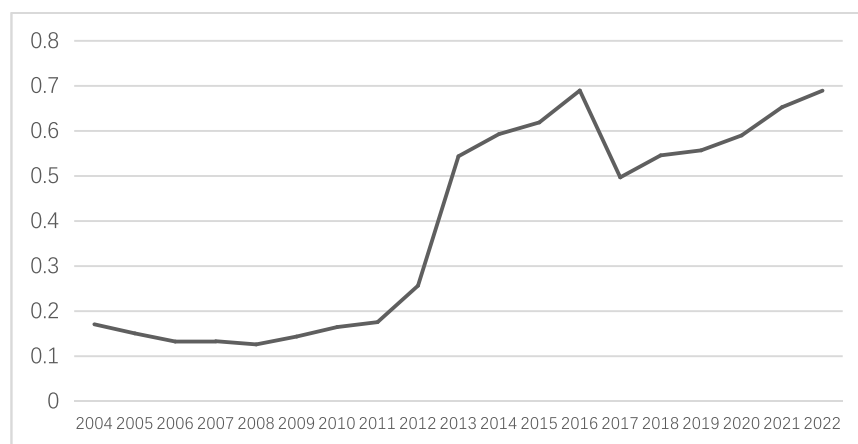


#### 4.2.4. Environmental and institutional support

Environmental and institutional support are important dimensions for innovation ecosystems to resist external shocks, and a higher score indicates better system buffering. As shown in **Table 7**, between 2004 and 2022, the environmental and institutional support level for Zhangzhou's innovation ecosystem generally shows an increasing trend. **Figure 4** clearly shows that there was a clear upward trend from 2011 to 2016. At this stage, policy support and resource accumulation achieved relatively high growth. Although there was a slight decline in 2017, it restarted an upward trend after 2018.

**Table 7.** Environmental and institutional support for Zhangzhou's innovation ecosystem

Year	Environmental and institutional support
2004	0.17
2005	0.15
2006	0.13
2007	0.13
2008	0.13
2009	0.14
2010	0.16
2011	0.18
2012	0.26
2013	0.54
2014	0.59
2015	0.62
2016	0.69
2017	0.50
2018	0.55
2019	0.56
2020	0.59
2021	0.65
2022	0.69



**Figure 4.** Changes in environmental and institutional support

### 4.3. Summary

The analysis of the above four dimensions reveals that, given the large fluctuations in the flow of innovation factors, the constantly increasing innovation capability and environmental and policy support are the reasons for the increase in the overall quality value of Zhangzhou's innovation ecosystem. Zhangzhou's innovation ecosystem is accumulating resources to cope with external shocks and, at the same time, is evolving through continuous learning and adaptation. Although the diversity of innovation subjects measured by the Shannon index has not changed significantly, the complexity and dynamics of the system are increasing. In addition, the large fluctuations in innovation factors may be caused by rapid changes and adjustments in the system and external shocks. In general, Zhangzhou's innovation ecosystem is in the growth stage and has not yet entered the mature stage.

## 5. Conclusions

This paper suggests that the resilience of the urban innovation ecosystem is affected by various factors, among which the interactions among innovation subjects, the mobility of innovation factors, and the institution construction within the system are critical. Therefore, this study uses life cycle theory to theoretically analyze the characteristic evolution of the urban innovation ecosystem, measures the spatiotemporal evolution of Zhangzhou's urban innovation ecosystem from 2004 to 2022, and uses various indicators to analyze the four levels of resilience. In this paper, through an analysis of the evolution process of the quality and characteristics of Zhangzhou's innovation ecosystem, the authors find the following conclusions:

First, latecomer cities in the process of regional integration need to pay attention to the siphoning effect of core cities to avoid the shock caused by the outflow of innovation factors.

Second, in the growth stage, the urban innovation ecosystem improves system quality mainly through the accumulation of resources and an increase in the innovation input-output ratio.

In summary, an innovation ecosystem is the key for urban economies to survive, develop, and prosper in a dynamically changing environment. For cities such as Zhangzhou, the problem is promoting the urban innovation ecosystem from the growth stage to the mature stage by constructing the institutional environment. The authors think that the enhancement of the vitality of the innovation ecosystem and the promotion of the sustainable development of cities should be based on the following suggestions:

First, the governance system related to the innovation ecosystem should be improved. Constructing an inclusive institutional environment should attract more innovative subjects and elements. Innovation subjects should be guided to increase responsible innovation behavior. Cooperation among innovation subjects should be promoted, and the relationships between innovation subjects should be regulated. The competitive relationships among companies provide good external conditions for innovation activities.

Second, the diversity and interaction level of the innovation subjects in the ecosystem should be enhanced. Make full use of the existing mechanisms to build a further open and shared industry-university research collaboration mechanism and cooperation and exchange platform to guide more SMEs to actively participate in it, promote the cross-border and cross-industry flow of knowledge and technology within the innovation ecosystem, and further promote innovation—the transformation and application of achievements in the industrial chain.

Third, society should be further guided in participating in the urban innovation ecosystem, establishing relevant digital asset trading platforms, building a market-oriented innovation financing system, and jointly investing in the construction of innovation infrastructure. The allocation and flow of innovation elements should

be optimized through the participation of diverse stakeholders.

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## Disclosure statement

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# From “Field Immersion” to “Portrayal”: A Study on the Ethnic Space Construction in Intangible Cultural Heritage Micro-Documentaries

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**Abstract:** In the context of digital technology reshaping the film and television communication ecosystem, micro-documentaries, with their short duration and lightweight characteristics, have become an important medium for the dissemination of Intangible Cultural Heritage (ICH). As a composite of material and spiritual culture, the ethnic characteristics of ICH need to be visually represented through the creative construction of cinematic space. This paper, based on a film and television arts perspective, uses “space construction” as the core analytical framework to explore how ICH micro-documentaries achieve ethnic visual expression through “residence-based” realistic space documentation, “portrayal-based” psychological space symbolization, and “synchronized” cultural space visual encoding. The study finds that these works, through audiovisual construction of geographical landscapes and life scenes, psychological space presentation of the emotions and cognition of inheritors, and symbolic reorganization of audiovisual elements like costumes, lighting, and composition, not only represent the socialized living heritage of ICH but also strengthen ethnic cultural identity through the unique narrative logic of documentary film.

**Keywords:** ICH micro-documentary; Ethnicization; Space construction; Cultural imagery

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## 1. Introduction

The living character and inheritance characteristics of Intangible Cultural Heritage (ICH) make it naturally compatible with the “representation” and “communication” aspects of film and television art. With the development of short video technology, ICH micro-documentaries, typically ranging from 5 to 12 minutes in length, have become a key medium connecting ICH with the general public, thanks to their advantages of being “short, fast, and refined” in dissemination. These works focus on traditional craftsmanship (such as embroidery and ceramics), ethnic performing arts (such as opera and dance), and folk activities (such as sacrificial rituals).



Through cinematographic recordings, they break the limitations of time and oral transmission, transforming ICH from “invisible inheritance” into “visible visual texts.”

As a cross-medium for both film art and ICH dissemination, the core value of ICH micro-documentaries lies not only in cultural preservation but also in the cinematic reconstruction of ethnic memory. The local customs, daily practices, and clothing designs presented in these films are all cultural codes formed over time, carrying the survival wisdom and spiritual core of specific ethnic groups. As Professor Song Junhua of Sun Yat-sen University stated, the concept of ICH protection, “seeing people, objects, and life”, emphasizes a “life-based” logic of inheritance. This concept aligns closely with the film art narrative principle of “focusing on people and moving people through emotions”<sup>[1]</sup>. In the interaction between these film art and ICH dissemination, ICH micro-documentaries use innovative cinematic language to weave scattered folk symbols into a systematic ethnic narrative, showcasing the uniqueness of ICH while strengthening ethnic cohesion and cultural confidence through the construction of cultural identity.

## **2. The sentiment of field immersion: The ethnic roots of realistic space documentary**

“Residence” emphasizes the deep involvement of the recorder in the site of ICH inheritance. Its theoretical foundation can be traced back to the “participatory observation” method in visual anthropology — that is, capturing the symbiotic relationship between ICH and the ethnic environment through the recorder’s immersive experience in the real space. This “rooted” documentary approach is not a simple replication of spatial appearances, but a “deep interpretation” of the visualized ethnic lifestyle.

### **2.1. Geographical and topographical symbolization: The visual anchor of ethnic living space**

The geographical features (such as natural landscapes and architectural styles) of the real space serve as the “material containers” of ethnic culture. As stated in the Book of the Han (Hanshu), “Customs differ within a hundred miles, practices vary across a thousand miles”, reveals the shaping effect of geographical differences on cultural diversity. Cinematic language, through the use of visual symbols, transforms these “differences” into perceptible visual representations.

From the perspective of film semiotics, the geographical space in ICH micro-documentaries has a dual meaning of “signifier and signified”: the geographical appearance (signifier) is directly presented by the camera through shots of mountains, rivers, and buildings, while the ethnic cultural connotation (signified) needs to be deeply expressed through cinematography. For example, in the Jiangsu TV non-material cultural heritage documentary series *The Rebirth of All Things — Bamboo-Root and Ceramic Art*, the geographical landscape of bamboo forests and the architecture of Western Sichuan serve as the spatial foundation. Wide-angle shots of the swaying bamboo shadows and close-ups of the hands of bamboo weaving artisans form a visual echo, making the “bamboo forest” not just the production scene for “bamboo weaving craft”, but also a visual representative of the wisdom of “local materials and natural principles” unique to the Shu region. Similarly, in the documentary *I Repair Cultural Relics at the Forbidden City* by China Central Television, the shots of the red walls and yellow tiles of the Forbidden City, coupled with the carved beams and painted rafters, represent the historical space in cinematic form. These visual representations link the geographical symbol of “The Forbidden City” with the solemnity of “Peking culture” and the rigor of palace craftsmanship. The camera’s movement and pacing (slow and steady) also

subtly align with the “craftsmanship spirit” of the real world.

The cinematic presentation of geographical landscapes essentially decodes the “ethnic way of life” through the use of camera angles, movements, and compositions, allowing viewers to perceive the origins of ICH and, consequently, understand the ethnic roots of its culture — as film theorist André Bazin said, “The ontological significance of images is to make space the witness of history.”

## **2.2. The cinematic restoration of living space: The visual fragment of ethnic daily practices**

Living space is a more micro and detailed real-world domain, focusing on the daily practices of ICH inheritors. Here, “reality” is not simply a replication of the scene, but rather a continuous capture of the “interaction between person, ICH, and daily life” through carefully designed shots — that is, how ICH is integrated into the daily activities of the inheritors, such as eating, living, and socializing, and becomes an organic part of the ethnic way of life.

An exemplary case is the second season of the Youku series *The Great Craftsman — The Romance of the Revival of Chinese Lacquerware*. The film follows the daily life of an ICH inheritor through long, following shots: shopping for lacquer materials with his wife in the morning (mid-shot, showing cooperation), discussing pattern designs in the evening under the light (close-up, capturing expressions), and a conversation with his wife as she wipes his tools (close-up, emphasizing details). These shots restore “lacquerware restoration” from a mere “craft display” to a “living practice”, making the “craftsman’s spirit” not an abstract concept but a specific persistence in everyday life. Similarly, in *Heritage* episode two, *Weaving Flames*, the shots of Li Wen picking fire grass in the mountains (tracking shots, showing labor), learning to weave cloth from her grandmother (fixed shot, emphasizing inheritance), and stripping plant stems with her mother (two-person shot, highlighting family collaboration), deeply connect the “fire grass weaving” ICH with the ethnic traits of “family ethics” and “intergenerational inheritance” among the Yi people.

By entering the living space from the “participant” perspective, the recorder avoids presenting ICH in a “specimen” manner. As ICH scholar Fang Lili emphasizes in her theory of the “post-ICH era”, ICH is not “static cultural heritage” but rather a “living cultural practice”<sup>[2]</sup>. The cinematic restoration of living space respects this “vitality” — by recording the repetitive labor of the inheritors (such as repetitive embroidery or polishing) in long takes, ICH is returned from being a “cultural exhibit” to “ethnic everyday life”, with the duration of the shots themselves becoming a visual metaphor for the “difficulty of inheritance.”

## **3. The significance of portrayal: The symbolization of psychological space and the resonance of ethnicity**

Psychological space is the projection of the inner activities of individuals, encompassing not only the emotions and cognition of ICH inheritors but also the emotional resonance generated by the audience through the imagery. In documentary creation, the externalization of this space is achieved through symbolic audiovisual means (such as shot composition, lighting, editing, and special effects). The core of this is to transform the abstract concept of “ethnicity” into a perceptible “emotional experience”, thus promoting the construction of cultural identity.

### **3.1. Cinematic tension between reality and ideal: The contemporary dilemma of ethnicity in film**

The psychological space of ICH inheritors often presents a tension between “ideal” and “reality”: their love for ethnic culture drives their perseverance, while commercialization and inheritance gaps expose them to survival

dilemmas. This conflict is visually reflected through contrast shots and montage techniques, and it becomes a typical cinematic depiction of ethnicity in contemporary contexts.

An exquisite example of this is presented in the episode “I Am Not ‘Eastern Barbie’, I Am a Beijing Silk Figure” from the ICH Evolution Theory documentary series produced by Tencent Video and the China Intangible Cultural Heritage Protection Association. The film employs cross-cutting editing to show two sets of shots: a focused close-up of Qi Congying (the third-generation inheritor of Beijing silk figures) adhering to the principle of “purely handmade” (ideal), and a medium shot of her apprentice He Mei feeling lost in an empty workshop (reality); a warm scene of Qi Congying touching a silk figure (tradition) juxtaposed with He Mei conducting market research at a cultural creative fair (innovation). This contrast not only portrays the “conflict between master and apprentice” but, through cinematic montage, elevates it into a deeper battle between “cultural purity” and “effective dissemination” — the visual presentation of psychological space provides a window into understanding the dynamic inheritance of ethnicity. As film psychology research suggests, “contrast shots can intensify the audience’s awareness of the contradiction, transforming them from bystanders into thinkers.”

This cinematic depiction of conflict does not negate inheritance but highlights the resilience of the ethnic spirit through “perseverance in adversity.” When Qi Congying says in an interview, “This craft is a remembrance of my ancestors; it must not be broken” (shot in first-person narration), her facial close-up (with a determined gaze) and the blurred background filled with silk figures form a visual focal point, turning her personal belief into a collective declaration of the ethnic “inseparable” attachment to its culture.

### **3.2. Audiovisual translation of psychological cognition: The emotional pathways of ethnic resonance**

Another dimension of psychological space is the emotional resonance between the audience and the inheritors, achieved through film techniques such as “first-person narration” and “jump-cut editing for psychological visualization.”

First-person narration allows the inheritor to express their emotions directly, transforming their feelings for ICH into an emotional experience that the audience can perceive. In the Here is Fuzhou ICH episode, the inheritor of Fuzhou rice noodles recalls, “When my grandmother taught me, she said, ‘The noodles should be as thin as a strand of hair, and your heart should be as calm as still water.’ I’ve repeated this thousands of times for decades, not for money, but because I’m afraid her words will end with me.” This narration, captured through a close-up shot of the inheritor’s wrinkled eyes and calloused hands, transforms the repetitive labor into not only a skill inheritance but also a “family memory” and “ethnic filial piety” visual carrier. The slow, heavy pacing of the language and the long shot duration reinforce the authenticity of the emotion.

“Jump-cut editing”, on the other hand, externalizes the psychological activity of the inheritor through time and space reorganization in the film. In *The Great Craftsman*, the restoration of lacquerware is depicted with fast switching between shots: the close-up of cracked lacquer (close-up), the focused gaze of the craftsman (close-up), the smooth texture of the restored pattern (mid-shot), and the appreciative smile of his wife (wide shot). This editing not only showcases the restoration process but, through variations in visual rhythm (from broken to complete), conveys a psychological sense of accomplishment — this accomplishment itself is a metaphor for the “regenerative power” of ethnic culture.

According to the mirror neuron theory in film psychology, the audience emotionally resonates with the protagonist’s psychological portrayal, achieving a transformation from cognition to identification. When the

audience feels moved by the inheritor's persistence, their emotional experience transcends the individual level, becoming a collective recognition of the ethnic culture — this is the core value of the cinematic construction of psychological space.

#### **4. The language of synchronization: Audiovisual symbol encoding of cultural space and the sublimation of ethnicity**

Cultural space is the fusion of real space and psychological space, referring to the “ethnic cultural domain” constructed through audiovisual elements such as costumes, lighting, and composition. The core of this is to transform ethnicity into a “visually and sensually perceivable” cinematic aesthetic, achieving a resonance between “traditional symbols” and “contemporary aesthetics.”

##### **4.1. The visual symbol system of costumes: Cinematic markers of ethnic identity**

As the most direct symbolic carrier of ethnic culture, costumes in ICH micro-documentaries serve a dual function: both as “identity markers” and as “narratives of customs.” From the perspective of film styling, the colors, patterns, and cuts of costumes are not only the external representations of ethnic identity but also key carriers of cultural encoding within the narrative.

In the micro-documentary *Heritage of the Heart* by China Central Television, the costumes of Tibetan people in Sichuan are presented in close-up shots, showing the bright red and royal blue color scheme (symbolizing piety and sanctity), the prayer flag patterns on sleeves and skirts (representing religious beliefs), and the wide design (adapted to the plateau climate). These elements are not isolated but are visually connected with the hand movements of the Tibetan people as they spin prayer wheels. Thus, “costumes” become a dynamic image of “ethnic spirit.” Similarly, in *This Embroidery*, the “embroidered ball patterns” and “indigo dyeing” technique of Zhuang costumes are presented in macro shots, showing embroidery details. The “costumes” not only display the “embroidery craftsmanship” but also serve as a visual symbol of the Zhuang people's cultural values — “embroidered balls symbolize love, indigo represents auspiciousness.”

As film styling scholar Jin Yike said, “Costumes in images are ‘talking symbols’, with every design carrying cultural information”<sup>[3]</sup>. Through the cinematic presentation of costumes, ICH micro-documentaries achieve the cognitive effect of “seeing the tribe through the clothes”, laying the visual foundation for ethnic visual expression.

##### **4.2. The emotional narrative of lighting: Cinematic metaphors for the warmth of ethnic culture**

In ICH micro-documentaries, lighting is not only a “tool for illumination” but also a “temperature symbol” for conveying cultural emotions. Many works prefer natural light and warm tones (yellowish, orange-red), as they can use the contrast of light and shadow to metaphorically represent “the weight of history” and “the warmth of inheritance.”

The “sunset teaching embroidery” scene in *This Embroidery* is highly representative. An elderly Zhuang grandmother sits in the doorway teaching her granddaughter embroidery, with the light from the setting sun casting diagonal rays through the door frame, creating light and dark spots on both the grandmother and the embroidery. The light areas emphasize the sheen of the embroidery thread, while the shadowed parts hide the cluttered background. This use of natural lighting not only realistically restores the rural living scene but also uses the “sunset” imagery (time passing) to hint at the “urgency of inheritance”, while the “warm tones” convey the intimacy of



“grandmother and granddaughter.” This creates a “culturally warm transmission” of ICH inheritance. Similarly, Transmission of the Songs of the Dong records the “Dong People’s Grand Songs” in the morning light of the mountains, with diffused light passing through tree leaves and falling on the singers. The soft lighting weakens the details of the people’s faces but emphasizes the overall harmony of “man and nature”, with the purity of the light itself becoming a metaphor for the “heaven and earth unity” spirit of the Dong people.

The “critique of everyday life” theory by Henri Lefebvre provides an explanation for this use of lighting. The combination of natural light and warm tones transforms the everyday living space into a cultural domain with aesthetic value, allowing the audience to experience the warmth of ethnic culture through light and shadow.

### **4.3. Cinematic formal aesthetic expression: The cinematic embodiment of ethnic aesthetic DNA**

The composition of ICH micro-documentaries often draws on traditional Chinese painting techniques (such as the use of blank space and freehand brushwork), using the division of the frame to convey the unique aesthetic DNA of ethnic culture. This “painterly composition” is not a simple formal imitation but a cinematic response to the “ethnic aesthetic psyche.”

In *The Great Craftsman*, when presenting the details of lacquerware, the composition adopts “close-up + large blank space”: on the left side of the frame is the twisted branch pattern of the lacquerware (occupying one-third of the frame), while the remaining blank space only has the small caption “Thousand Years of Lacquer Art, One Piece for a Lifetime” (occupying one-tenth of the frame). This composition comes from the traditional Chinese ink painting concept of “counting white as black”, highlighting the exquisite beauty of the lacquerware (the beauty of ethnic craftsmanship) through close-up, while the “blank space” allows the audience to imagine, subtly aligning with the “reserve and restraint” aesthetic of Chinese culture. Similarly, in *The Hundred Crafts of the Sea*, when recording coin production, the “golden ratio” composition is used: the artisan is positioned at one-third of the frame (the visual focus), while scattered tools and unfinished products fill the remaining two-thirds. This composition follows the “balance principle” of Western film aesthetics but also emphasizes the “human-centered” view of Chinese creation, with the symmetrical arrangement of tools itself aligning with the “order” and “fairness” cultural values carried by coins.

This “ethnic” handling of composition subtly guides the audience to subconsciously accept the ethnic aesthetics through visual experience, thereby enhancing their cultural identification. As film aesthetic scholar Rudolf Arnheim said, “The balance of composition can provoke the audience’s psychological identification with cultural order.”

## **5. Conclusion**

The ethnic space construction in ICH micro-documentaries is a progressive process, moving from “realistic documentation” to “psychological resonance” and then to “cultural identity.” The cinematic artistry of these works runs through the entire process: real space is documented through geographical and life scenes; psychological space is symbolized through emotional audiovisual expressions; and cultural space is creatively reconstructed through elements such as costumes, lighting, and composition. Together, these elements form a “visible, perceptible, and recognizable” narrative system, transforming ICH from a “niche heritage” into a “mainstream cultural symbol.” In the “post-ICH era”, the value of this spatial construction lies not only in cultural inheritance



but also in allowing ethnicity to gain new vitality in contemporary contexts through innovative cinematic expressions. As Fang Lili said, ICH protection should “avoid conservatism and focus on its true value in social development.” ICH micro-documentaries, through the ethnic audiovisual coding of space, create a dialogue between tradition and modernity, resonance between niche and mass, providing a unique cinematic path for the construction of cultural confidence.

## Disclosure statement

The authors declare no conflict of interest.

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# The Impact Mechanism of Digital Currency on Commercial Bank Deposit Business

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**Abstract:** With the rapid development of digital currency, its impact on commercial bank deposit business has become increasingly significant. This paper conducts an in-depth analysis of the fundamental effects of digital currency on commercial bank deposit business, including the role of digital currency characteristics in driving deposit business transformation and the restructuring of deposit business models. It explores the impact of digital currency on deposit scale, revealing the substitution effect of digital currency and changes in deposit volume, the money multiplier effect, and deposit expansion, as well as shifts in deposit structure and stability analysis. Furthermore, the study examines the influence of digital currency on deposit business operations, including the optimization of deposit processing workflows, the transformation of risk management, and the enhancement of customer service experiences. Finally, strategies for commercial banks to respond to the impact of digital currency on deposits are proposed. The research indicates that digital currency exerts profound effects on commercial bank deposit business, necessitating proactive adaptation through strengthened digital infrastructure, innovative deposit products and services, enhanced risk management, and interbank collaboration to meet the demands of the digital currency era.

**Keywords:** Digital currency; Commercial banks; Deposit business; Impact mechanism

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## 1. Introduction

Driven by the wave of digitalization, digital currency, as an emerging form of money, is gradually reshaping the operational landscape of the traditional financial system. As a core component of the financial system, commercial banks have witnessed profound impacts on their deposit business due to digital currency. Studying the impact mechanism of digital currency on commercial bank deposit business not only facilitates a deeper understanding of the intrinsic characteristics of digital currency and its repercussions on the financial system but also provides theoretical foundations and practical guidance for the transformation and innovation of commercial banks in the digital currency era. This paper aims to systematically analyze the impact mechanism of digital currency on

commercial bank deposit business, unveiling the underlying economic logic and financial principles, thereby offering valuable insights for commercial banks to address the challenges of digital currency and achieve sustainable development. The analysis will focus on four key dimensions: The fundamental impact of digital currency on deposit business, its influence on deposit scale, its effects on deposit business operations, and the corresponding strategies for commercial banks. Through this comprehensive examination, the paper seeks to elucidate the full spectrum of digital currency's impact on commercial bank deposit business <sup>[1]</sup>.

## **2. Basic impact of digital currency on commercial bank deposit business**

### **2.1. Characteristics of digital currency and transformation of deposit business**

Digital currency, with its unique attributes, has had a profound impact on commercial bank deposit services. The programmability of digital currency enables deposit services to flexibly adapt to diverse market demands. Through preset smart contracts, deposit products can automatically adjust interest rates, terms, and other elements based on market conditions, enhancing business flexibility and customer experience. For example, when market interest rates rise, smart contracts can automatically increase deposit rates, allowing customers to enjoy timely benefit increases <sup>[2]</sup>.

The immutability of digital currency ensures the security and transparency of deposit transactions through distributed ledger technology. Each deposit transaction is permanently recorded on the blockchain, and any attempt to tamper with the data will be quickly identified and rejected by the network, effectively preventing fraud and erroneous operations and enhancing the security of deposit services <sup>[3]</sup>.

The anonymity of digital currency plays a significant role in protecting depositors' privacy. Although transaction records of digital currency are public, the identity information of both parties involved in the transaction can be protected through encryption technology, ensuring that depositors' privacy is not disclosed. This characteristic enhances customers' trust in deposit services and promotes the healthy development of deposit services <sup>[4]</sup>.

### **2.2. Reconstruction of the deposit business model**

The emergence of digital currencies has driven the transformation of deposit business models from account centralization to decentralization. Traditional deposit businesses rely on the centralized account system of banks, while digital currencies have achieved peer-to-peer transfer and storage of deposits through decentralized distributed ledger technology. This transformation not only improves the efficiency of deposit businesses but also reduces operating costs <sup>[5]</sup>.

The trend towards online and physical-free deposit services is becoming increasingly evident. With the widespread adoption of digital currencies, customers can now conduct deposit operations anytime, anywhere, through terminal devices such as mobile phones and computers, eliminating the need to visit bank branches. This online and physical-free deposit model not only enhances the customer experience but also promotes inclusive financial services <sup>[6]</sup>.

Innovation in deposit interest and interest calculation methods is also a crucial aspect of the restructuring of deposit business models. The introduction of digital currency has made the calculation and payment of deposit interest more flexible and diverse. Banks can design differentiated deposit products based on factors such as customers' deposit amounts, terms, and risk preferences, and offer personalized interest calculation methods, thereby attracting more deposit funds <sup>[7]</sup>.

### **2.3. Reshaping of competition pattern in the deposit business**

Digital currency has broken the geographical constraints of traditional commercial banks in the deposit business. In the past, small and medium-sized banks were at a disadvantage in attracting deposits from other regions due to their limited branch network. However, with the help of the internet, digital currency enables customers to easily deposit funds into any bank that has opened relevant services, giving small and medium-sized banks the opportunity to compete with large banks for deposit resources on a broader scale <sup>[8]</sup>.

Meanwhile, digital currencies have given rise to new competitors. Leveraging their strong technological R&D capabilities and vast user base, technology companies have ventured into the field of digital currency deposits. The deposit products they offer are often innovative and highly attractive, posing a challenge to traditional commercial banks. Commercial banks need to continuously enhance their digital currency service capabilities and optimize their deposit products to occupy a favorable position in the new competitive landscape.

## **3. Impact of digital currency on commercial bank deposit scale**

### **3.1. Substitution effect of digital currency and changes in deposit volume**

The proliferation of digital currency has generated a notable substitution effect on commercial bank deposit volume. As digital currency gains traction, customers increasingly prefer converting cash and demand deposits into digital currency for storage and transactions. This shift not only reduces cash circulation within the banking system but also affects overall deposit volume.

The migration from cash deposits to digital currency deposits is a primary manifestation of this substitution effect. Driven by convenience and security considerations, customers are more inclined to store cash in digital wallets rather than traditional bank accounts, leading to a decline in cash deposits and a rise in digital currency deposits <sup>[9]</sup>.

Similarly, the conversion of demand deposits to digital currency deposits represents another significant aspect of this effect. Demand deposits, characterized by high liquidity and low interest rates, are increasingly being replaced by digital currency deposits, which offer greater flexibility and potential returns <sup>[10]</sup>.

### **3.2. Money multiplier effect and deposit expansion**

The introduction of digital currency has significantly influenced the money multiplier, thereby facilitating the expansion of bank deposit volume. The money multiplier refers to the ratio by which a unit of central bank-issued base money amplifies the total money supply. The adoption of digital currency has accelerated money circulation velocity and reduced holding costs, thereby strengthening the money multiplier effect <sup>[11]</sup>.

The programmability and anonymity of digital currency enhance the efficiency and security of money circulation. Customers can effortlessly conduct deposit, withdrawal, and transfer operations, minimizing idle cash outside the banking system. This streamlined circulation mechanism elevates the money multiplier, enabling central bank-issued base money to be more rapidly converted into bank deposits <sup>[12]</sup>.

Moreover, the issuance of digital currency reduces banks' reserve requirements. Traditionally, banks are required to maintain a certain reserve ratio to meet withdrawal demands. However, digital currency allows customers to conduct deposit and withdrawal operations anytime, diminishing the need for reserves and further amplifying the money multiplier effect.

### **3.3. Deposit structure changes and stability analysis**

The widespread adoption of digital currency has significantly altered the deposit structure of commercial banks,

thereby influencing deposit stability. As digital currency becomes more prevalent, customers increasingly favor storing funds in digital wallets over traditional bank accounts. This shift has led to a rise in the proportion of time deposits relative to demand deposits <sup>[13]</sup>.

From a stability perspective, the growing share of time deposits enhances the stability of bank deposits. Time deposits, characterized by longer tenures and stable interest rates, provide banks with a reliable funding source. In contrast, demand deposits, with their high liquidity and volatility, are more susceptible to market sentiment and customer behavior. The increasing proportion of time deposits thus mitigates liquidity risks and bolsters deposit stability <sup>[14]</sup>.

However, these structural changes also impose new demands on banks' risk management capabilities. Banks must strengthen the management and deployment of time deposits to ensure optimal fund allocation and returns. Simultaneously, they must monitor fluctuations in demand deposits and implement measures to address potential liquidity risks <sup>[15]</sup>.

## **4. The impact of digital currency on the operation of commercial bank deposit business**

### **4.1. Optimization of deposit business processing flow**

The introduction of digital currency has optimized the processing flow of commercial bank deposit services. Traditional deposit services require customers to visit bank branches for deposit and withdrawal procedures, which are cumbersome and inefficient. The popularization of digital currency has enabled customers to conduct deposit operations anytime and anywhere through terminal devices such as mobile phones and computers, greatly improving the efficiency of business processing <sup>[16]</sup>.

Specifically, the process of depositing and withdrawing digital currency is simpler and faster. Customers only need to initiate a deposit or withdrawal request in their digital wallet, and the system can automatically complete the transfer and recording of funds. This decentralized approach reduces intermediary steps and human intervention, thereby lowering operational risks and error rates <sup>[17]</sup>.

Interbank transfers of digital currency deposits have also become more convenient and cost-effective. Traditional interbank transfers require clearing and settlement through multiple intermediary banks, which is cumbersome and expensive. However, interbank transfers of digital currency utilize distributed ledger technology to facilitate peer-to-peer fund transfers, eliminating the need for clearing and settlement through intermediary banks, thereby reducing transfer costs and time <sup>[18]</sup>.

### **4.2. Transformation of deposit business risk management**

The widespread adoption of digital currencies has had a profound impact on the risk management of commercial bank deposit services. Traditional risk management for deposit services primarily relies on manual review and monitoring, which is inefficient and prone to errors. The introduction of digital currencies has enabled more intelligent and automated risk management <sup>[19]</sup>.

Specifically, the traceability of digital currency enables every deposit transaction to be recorded and traced. Banks can analyze these transaction data to promptly identify potential money laundering, fraud, and other risky behaviors, and take corresponding measures to prevent and handle them.

The smart contract technology of digital currency also provides new tools for risk management. Smart contracts can automatically execute preset risk management rules, such as limiting the transfer-in and transfer-out



of large deposits and monitoring abnormal transaction behaviors. This automated risk management approach not only improves efficiency but also reduces the risk of human intervention.

### **4.3. Improvement of customer service experience in the deposit business**

The widespread adoption of digital currencies has significantly enhanced the customer service experience in commercial banks' deposit services. Traditional deposit services require customers to visit bank branches, resulting in long waiting times and an unsatisfactory service experience. However, the introduction of digital currencies has enabled customers to conduct deposit operations anytime and anywhere, enjoying a more convenient and efficient service.

Specifically, personalized services for digital currency deposits have become possible. Banks can design differentiated deposit products and provide personalized services based on factors such as customers' deposit amounts, terms, and risk preferences. For example, exclusive deposit products and wealth management services can be provided for high-net-worth customers, while convenient mobile deposit services can be offered to younger customers.

The intelligent service for digital currency deposits has also enhanced customer experience. Through artificial intelligence and big data technology, banks can provide customers with more precise deposit suggestions and risk warnings. Customers can inquire about deposit-related issues at any time through the intelligent customer service system and receive timely and accurate answers <sup>[20]</sup>.

## **5. Strategies for commercial banks to cope with the impact of digital currency deposits**

### **5.1. Strengthen digitalization construction and enhance deposit business processing capabilities**

Facing the challenge posed by digital currencies, commercial banks should strengthen their digitalization efforts and enhance their deposit business processing capabilities. Specifically, banks should increase their investment in financial technology and introduce advanced technological means such as blockchain, artificial intelligence, and big data to improve the information processing capacity and business efficiency of their deposit operations.

Banks should optimize their deposit business information systems and infrastructure construction. By establishing efficient, stable, and secure business systems, they can ensure the smooth operation of deposit services and data security. Banks should also strengthen cooperation with other financial institutions and technology companies to jointly promote the development and innovation of digital currency deposit services.

### **5.2. Innovate deposit products and services to meet diversified needs**

Commercial banks should actively innovate deposit products and services to meet the diversified needs of customers. Specifically, banks should design differentiated deposit products and provide personalized services based on factors such as customers' deposit amounts, terms, and risk preferences. For example, they can launch high-yield fixed-term deposit products, flexible demand deposit products, and innovative deposit products that combine the characteristics of digital currencies.

Banks should also strengthen the marketing and promotion of their deposit services. Through multi-channel and multi-form marketing strategies, they can enhance customers' awareness and acceptance of deposit products. Additionally, banks should enhance communication and interaction with customers, promptly understand their needs and feedback, and continuously optimize deposit products and services.

### **5.3. Strengthen risk management to ensure the stable operation of the deposit business**

Commercial banks should strengthen risk management to ensure the stable operation of their deposit business. Specifically, banks should establish a comprehensive risk management system and internal control mechanism to ensure that risks associated with the deposit business are manageable. Banks should enhance their monitoring and early warning efforts for deposit business, promptly identifying and addressing potential risky behaviors.

Banks should also strengthen communication and collaboration with regulatory authorities. By promptly understanding changes in regulatory policies and requirements, they can adjust and improve their risk management systems and internal control mechanisms. Banks should also actively participate in the activities and work of industry self-regulatory organizations, jointly promoting the healthy development of digital currency deposit business.

### **5.4. Carry out interbank cooperation to jointly address the challenges posed by digital currencies**

Commercial banks should actively engage in interbank cooperation to jointly address the challenges posed by digital currencies. Specifically, banks should strengthen cooperation and exchanges with other financial institutions and technology companies, jointly researching and exploring development models and innovative paths for digital currency deposit services. By sharing resources and complementing each other's strengths, they can achieve mutual benefit, win-win results, and common development.

Banks should also actively engage in international cooperation and exchange activities. By staying informed about the latest developments and trends in international digital currency and drawing on international best practices, banks can promote the development and innovation of their own digital currency deposit services. Furthermore, banks should strengthen communication and collaboration with international financial organizations and regulatory bodies, jointly promoting the standardized development and healthy operation of global digital currency deposit services.

## **6. Conclusion**

This paper provides an in-depth analysis of the impact mechanism of digital currency on commercial bank deposit business, highlighting its role in driving deposit business transformation, influencing deposit scale, and optimizing deposit operations. The findings underscore the profound effects of digital currency on deposit business, presenting both challenges and opportunities. Commercial banks must proactively adapt by strengthening digital capabilities, innovating deposit products, enhancing risk management, and fostering collaboration to thrive in the digital currency era. This study enriches theoretical research on digital currency and deposit business while offering practical guidance for banks navigating digital transformation. It holds significant theoretical and practical value.

## **Disclosure statement**

The author declares no conflict of interest.

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# How Does Belief in a Just World Affect the Life Satisfaction of University Teachers?

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**Abstract:** To explore the relationship between university teachers' Belief in a just world (BJW) and Life Satisfaction (LS), and to identify underlying mediating mechanisms, this study employed a structural equation model with BJW as the independent variable, LS as the dependent variable, job burnout (JB) and gratitude as mediating variables, and subjective economic status as a control variable. A sample of 225 university teachers completed the Belief in a Just World Questionnaire, the Teacher Job Burnout Questionnaire, the Gratitude Questionnaire-6, and the Life Satisfaction Questionnaire. Results showed: (1) BJW directly and positively predicted LS ( $\beta = 0.28$ ,  $P < 0.001$ ); (2) JB and Gratitude exerted parallel mediating effects between the relationship of BJW and LS (indirect effects = 0.221 and 0.060, respectively).

**Keywords:** Belief in a Just World; Life satisfaction; Job burnout; Gratitude

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## 1. Introduction

Life satisfaction (LS) refers to an individual's subjective evaluation and judgment of their overall quality of life <sup>[1]</sup>. As a cognitive component of subjective well-being, it is also one of the important indicators for measuring mental health. It shows a significant positive correlation with subjective well-being <sup>[2]</sup>. Studies have shown that LS is significantly associated with factors such as physical health, socioeconomic status, personality, and external stress. For example, Palmore et al. found that physical health and subjective socioeconomic status can significantly predict an individual's life satisfaction <sup>[3]</sup>. Peng reached consistent conclusions regarding the relationship between socioeconomic status and life satisfaction <sup>[4]</sup>.

University teachers play a pivotal role in education and society. Their satisfaction with life not only directly affects their job performance and mental health, but also indirectly influences the development of students. Previous studies on LS of university teachers have mainly focused on the impact of external factors such as work-family conflict and various stressors, while few studies have explored the influence of teachers' internal individual

factors on LS <sup>[5]</sup>.

The belief in a just world (BJW), first proposed by Lerner, refers to the conviction that individuals get what they deserve in life <sup>[6]</sup>. Early research focused on victim blaming in judicial contexts, showing that people devalue victims to maintain their BJW <sup>[7]</sup>. With the rise of positive psychology, attention has shifted to BJW's adaptive functions, including providing psychological security and a sense of control. As a cognitive framework for interpreting life events, BJW influences coping strategies during adversity, thereby impacting mental health.

Furnham claimed that the BJW provides psychological buffers against the harsh realities of the world as well as personal control over one's destiny <sup>[8]</sup>. A study of 406 employed and unemployed individuals found that BJW can enhance job satisfaction and boost mental health, including LS and self-esteem <sup>[9]</sup>. However, few studies explored the relationship between LS and BJW among university teachers, as well as the influence of other mediating factors in this relationship.

Based on this, this study has three objectives. The first is to explore the relationship between BJW and LS among university teachers. The second aim is to identify potential mediating factors in this relationship and seek possible paths to improve university teachers' LS. The last one is to propose possible directions and prospects for future research.

## **1.1. BJW and LS**

Based on Tomaka and Blascovich's stress-coping model, BJW serves as a psychological resource that facilitates positive cognitive appraisal of stressors, thereby protecting subjective well-being (SWB), with LS as its cognitive component. Empirical support includes findings that BJW predicts a higher level of psychological well-being and lower levels of depression in graduate students <sup>[10]</sup>. It was claimed that perceived social justice had a positive effect on LS after controlling for demographic variables <sup>[11]</sup>. Furthermore, research has confirmed that BJW positively correlates with SWB among university teachers in Western contexts <sup>[12]</sup>. Thus, the authors hypothesize:

H1: BJW has a positive predictive value for LS among university teachers.

## **1.2. Mediating mechanisms of BJW on LS**

### **1.2.1. The mediating role of job burnout (JB)**

Siegrist's effort-reward imbalance model posits that chronic work stress arises when efforts exceed rewards, leading to job burnout (JB) <sup>[13]</sup>. The authors propose that low BJW, reflecting doubt in proportional rewards, promotes JB. Additionally, the Justice Motive Theory posits that people are motivated to believe the world is fundamentally just, where efforts and outcomes align. Individuals with higher levels of BJW are more likely to invest in their futures and then facilitate goal-directed behavior <sup>[9]</sup>. A strong BJW should foster investments in one's occupational career and alleviate concerns about the future. Consistent with this, Desrumaux et al. found that stronger BJW relates to lower emotional exhaustion in employees <sup>[14]</sup>.

A study of 109 nurses stated that the experience of burnout, including exhaustion and disengagement, has a direct impact on their LS <sup>[15]</sup>. Anand and Arora examined the relationship between JB and LS of executives of multinational companies, and the result showed a significant negative correlation between JB and LS <sup>[16]</sup>. This connection was also supported among university employees <sup>[17]</sup>.

### **1.2.2. The mediating role of gratitude**

Gratitude is conceptualized as a tendency to respond with appreciative emotion once an individual identifies



others' generosity in contributing to themselves<sup>[18]</sup>. According to the justice motive theory, concern for justice is based on a "personal contract" between individuals and their social environment. In developing their personal contract, individuals learn the importance of mutually honored commitments between individuals who deserve fair treatment. In line with this belief, individuals are more likely to attribute their good fortune to the kindness of others. Consistent with this belief, individuals tend to ascribe their good fortune to the benevolence of others because individuals with high BJW believe that those who have helped them deserve to be rewarded and that they should express their gratitude<sup>[19]</sup>.

As a validated well-being enhancer, gratitude mediates between BJW and prosocial behavior. It played a mediating role to link BJW to LS in college students<sup>[20]</sup>. Thus, the authors hypothesize:

H2: JB mediates the BJW-LS relationship.

H3: Gratitude mediates the BJW-LS relationship.

## **2. Methods**

### **2.1. Participants**

The study employed a snowball sampling strategy to recruit 225 valid participants via WeChat dissemination. The sample comprised 70 (31%) males and 155 (69%) females. Given the complex model with four variables, the sample size met the minimum requirement of 10 cases per parameter.

### **2.2. Instruments**

#### **2.2.1. Belief in a Just World questionnaire**

This scale was developed by Dalbert and subsequently adapted for use in Chinese contexts by Su et al.<sup>[21]</sup>. It comprises 13 items on a 5-point Likert scale, measuring two dimensions: General Belief in a Just World and Personal Belief in a Just World. Cronbach's  $\alpha$  of the scale in the study was 0.94.

#### **2.2.2. Teacher job burnout questionnaire**

Adapted from Maslach et al. by Shi, this 16-item scale assesses three dimensions of Job Burnout (JB): emotional exhaustion, depersonalization, and reduced personal accomplishment<sup>[22]</sup>. It is a 5-point Likert scale. Cronbach's  $\alpha$  in the study was 0.94.

#### **2.2.3. Gratitude Questionnaire-6**

The Chinese version of McCullough et al.'s Gratitude Questionnaire-6 (GQ-6) was used, with the last item omitted due to ambiguous wording. It is a 5-point Likert scale (ranging from 1 = strongly disagree to 5 = strongly agree), with high reliability and validity. Higher scores indicate a higher level of gratitude. In this study, Cronbach's  $\alpha$  of the scale was 0.81.

#### **2.2.4. Life satisfaction scale**

Life satisfaction was measured using Diener's (1994) 5-item scale. It is a 5-point Likert scale, with high reliability and validity. A higher score indicates greater satisfaction with life. Cronbach's  $\alpha$  of the scale in the study was 0.88.

## **2.3. Procedures and data analysis**

The study conducted an online questionnaire survey via SoJump. Participants received informed consent that

explained the study's purpose and provided assurances of confidentiality. Additionally, they did not need to provide any personal information. Those measures could minimize social desirability bias. SPSS 22.0 was used for reliability tests, and PROCESS 3.5 was used for regression analyses.

## 2.4. Control variables

Guided by the relative deprivation theory, researchers also controlled subjective economic status (SES) due to its impact on LS via perceived income inequality<sup>[23]</sup>. Empirical evidence shows teachers often report income-effort disparity, which undermines LS<sup>[24]</sup>. Therefore, the authors explored the relationship between SES and LS among college teachers. Besides, regression analysis was conducted while controlling for SES. In the study, participants evaluated their economic status by the question "How is your economic status compared with others." The score ranges from "1 = very high" to "5 = very low". A higher score represents a lower level of economic status.

## 3. Results

### 3.1. Common method variance

The authors employed the Herman single-factor test to evaluate the potential threat of Common Method Variance (CMV) in the study. The results of this test indicated that the first factor accounted for 38.31% of the variance, suggesting that there is no significant problem of CMV present in the study.

### 3.2. Preliminary analyses

**Table 1** shows the Pearson correlations. SES was significantly correlated with LS, JB, and BJW. Specifically, university teachers with a higher SES exhibited lower levels of JB, were more inclined to perceive the world as just, and were more satisfied with their lives.

**Table 1.** Descriptive statistics and correlation analysis of variables

Variables	Mean	SE	1	2	3	4
1. Belief in a Just World	3.41	0.65				
2. Burnout	2.69	0.74	-0.58**			
3. Gratitude	3.40	0.48	0.37**	-0.20**		
4. Life Satisfaction	3.06	0.85	0.57**	-0.57**	0.32**	
5. Subjective Economic Status	3.25	0.69	-0.26**	0.27**	-0.10	-0.43**

Note: N=225, \* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ . M, Mean; SD, Standard Deviation

### 3.3. Mediating effects analyses

To test whether JB and Gratitude functioned as parallel mediators in the relationship between BJW and LS, the authors conducted a mediation analysis using the PROCESS Macro (Model 4; Hayes, 2018) with 5,000 bootstrap samples<sup>[25]</sup>. This model examines the direct effect of BJW on LS and the indirect effects transmitted through JB and Gratitude independently.

**Table 2** summarizes the statistical values of direct effects analyses. The direct effect of BJW on LS was significant ( $\beta = 0.28$ ,  $P < .001$ ). Additionally, BJW negatively predicted JB ( $\beta = -0.54$ ,  $P < .001$ ) and positively predicted Gratitude ( $\beta = 0.37$ ,  $P < .001$ ). JB negatively predicted LS ( $\beta = -0.31$ ,  $P < .001$ ), and Gratitude positively

predicted LS ( $\beta = 0.13, P < .05$ ).

**Table 2.** Regression analysis of variable relationships in the parallel mediation model

IDV	DV	R <sup>2</sup>	F	B	$\beta$	t
BJW	JB	0.35	59.09	-0.62	-0.54	-9.66***
BJW	GRA	0.13	17.26	0.27	0.37	5.66***
BJW	LS	0.48	51.60	0.36	0.28	4.40***
JB	LS			-0.36	-0.31	-5.19***
GRA	LS			0.22	0.13	2.42*

Note: Controlling for SES. BJW, Belief in a Just World; JB, Job burnout; GRA, Gratitude; LS, Life Satisfaction; DV, Dependent Variable; IDV, Independent Variable

**Table 3** displays the standardized regression coefficients ( $\beta$ ), standard errors (SE), and 95% bias-corrected bootstrap confidence intervals (CIs) for mediating paths. The results indicated three key indirect effects. The indirect effect of BJW on LS through JB was significant ( $\beta = 0.22$ , 95% CI = [0.131,0.318]). The indirect effect through Gratitude was significant ( $\beta = 0.06$ , 95% CI = [0.002 to 0.14]). The total indirect effect (sum of the two individual indirect effects) was significant ( $\beta = 0.28$ , 95% CI = [0.17 to 0.40]). The 95% CIs didn't include 0, thus both parallel mediating effects were significant. **Figure 1** displays the validated structural model.

**Table 3.** Significance analysis of mediating effects

Path	Indirect effect	SE	95% Confidence Interval	
			Lower Limit	Upper Limit
BJW-JB-LS	0.17	0.48	0.13	0.32
BJW-GRA-LS	0.06	0.34	0.00	0.14
Total indirect effect	0.23	0.58	0.17	0.40

## 4. Discussion

Previous studies have shown that BJW positively predicts LS. Most focused on specific groups. However, empirical inquiry into university teachers remains scarce. This study addresses this gap by examining the relationship between BJW and LS among university faculty, as well as the mediating mechanisms underlying this association. Findings reveal that university teachers' BJW directly and negatively predicts LS, while JB and Gratitude exert partial parallel mediating effects.

The results support Hypothesis 1, confirming that BJW directly predicts LS among university teachers, consistent with prior research <sup>[12]</sup>. As a psychological resource, BJW mitigates the impact of external stressors, thereby maintaining mental health and enhancing LS. Specifically, university teachers with stronger BJW exhibit higher LS.

To dissect the underlying mechanisms, this study introduces JB (negative pathway) and Gratitude (positive pathway) as mediating variables. Mediation analyses confirm parallel mediating effects, supporting Hypotheses 2 and 3. On the negative pathway, job burnout explains how BJW influences LS: when individuals perceive

unfair treatment, effort-reward imbalance triggers burnout, which in turn diminishes LS. On the positive pathway, Gratitude mediated the effect of BJW on LS. It may be explained that individuals with a stronger BJW attribute positive outcomes to others' benevolence, thereby fostering Gratitude toward their environment. Grateful individuals perceive the social context more positively and employ adaptive coping strategies, thereby enhancing LS.

## **5. Limitations and future directions**

The study provides more comprehensive insights into the relationship between BJW and LS of university teachers. It confirmed that SES is a key factor influencing university teachers' BJW, JB, and LS. In addition, it provided evidence that BJW increases LS indirectly by reducing JB and enhancing gratitude. However, there are several limitations as follows.

First, the participants in this study were recruited through forwarding among acquaintances, which resulted in insufficient sample representativeness. Therefore, caution should be taken when interpreting the results and applying them in a general sense. Future studies could expand the sample size while improving sample representativeness, thereby enhancing the generalizability of the research findings.

Second, BJW comprises two dimensions: personal belief in a just world (PBJW) and general belief in a just world (GBJW). Previous research has indicated that these two dimensions have somewhat different impacts on subjective well-being. However, the present study used the total average score of BJW for mediation path analysis, neglecting the differences between the dimensions. Future research could attempt to build a model using the average scores of each dimension to provide more details.

## **6. Theoretical and practical implications**

Although with some limitations, the study makes several contributions. First, the findings contribute to the literature on BJW and LS by identifying dual parallel mechanisms (Gratitude and BJ) through which BJW affects LS in university teachers. Researchers know more details about the relationship between BJW and LS.

Second, interventions aimed at promoting LS of university teachers should target the identified mediators. For example, workshops focused on enhancing Gratitude or reducing JB could mitigate the negative effects of BJW.

Third, for policymakers, fostering university teachers' BJW through fair career development policies (e.g., salary equity, transparent promotion systems) could enhance their level of BJW and subsequently elevate LS, thereby contributing to social well-being.

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## **Disclosure statement**

The authors declare no conflict of interest.

## Author contribution

Yinqiu Tan conceived the idea of the study and wrote the paper. Kong Xia conducted the survey and the data analysis.

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# Adsorption Mechanism of Wet Strength Agents in Lignocellulosic Fibers and Their Regulatory Effect on Paper Wettability

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**Abstract:** This study focuses on the adsorption mechanism of wet strength agents in lignocellulosic fibers and their regulatory effect on paper wettability. Through experimental analysis and theoretical discussion, the adsorption process and mode of action of wet strength agents on the surface of lignocellulosic fibers are clarified, and the inherent mechanism by which they affect paper wettability is revealed. The research results have important theoretical and practical guiding significance for optimizing paper production processes and improving paper performance.

**Keywords:** Lignocellulosic fibers; Wet strength agents; Adsorption mechanism; Paper wettability; Regulatory effect

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## 1. Introduction

In the paper industry, lignocellulosic fibers are one of the most commonly used raw materials. The performance of paper is influenced by various factors, among which wettability is a key indicator that directly relates to the printability, writing performance, and packaging applications of paper<sup>[1]</sup>. Wet strength agents, as chemical additives that can significantly affect paper wettability, have attracted much attention regarding their adsorption mechanism in lignocellulosic fiber raw materials and their regulatory effect on paper wettability. Deep research in this field is conducive to developing more efficient and environmentally friendly paper production technologies to meet the growing market demand.

## 2. Types and adsorption mechanisms of wet strength agents for lignocellulosic materials

### 2.1. Types and characteristics of wet strength agents

#### 2.1.1. Common types of wet strength agents

Currently, the wet strength agents commonly used in lignocellulosic materials mainly include polyamide

polyamine epichlorohydrin resin (PAE), polyethyleneimine (PEI), and cationic polyacrylamide (PAM). PAE is a water-soluble cationic thermosetting resin that offers advantages such as good wet strengthening effects, low usage amounts, ease of use, easy recovery of damaged paper, and non-toxicity. It is currently the most widely used wet strength agent. PEI is a polymer with high cationic density that can form strong bonds with cellulose in pulp, thereby improving the wet strength of paper. It is often used for special-purpose papers such as filter paper and industrial paper. By introducing cationic groups, cationic PAM can interact with negatively charged lignocellulose, improving the wet strength of paper. It is commonly used for packaging paper and decorative paper, etc. <sup>[2]</sup>.

### **2.1.2. Characteristics of wet strength agents**

Wet strength agents are generally non-toxic, odorless, and can be used under various conditions, including neutral, slightly alkaline, and acidic environments. Additionally, these agents have the functions of aiding retention and filtration, which can improve the retention rate of pulp fibers, clarify white water, and reduce pulp flocculation and wet web breaks <sup>[3]</sup>. Different types of wet strength agents vary in terms of molecular structure, charge density, and reactivity, and these differences determine their adsorption behavior on lignocellulosic materials and their effects on regulating paper wettability.

## **2.2. Adsorption mechanism of wet strength agents in lignocellulosic materials**

### **2.2.1. Electrostatic adsorption**

The surface of lignocellulose is typically negatively charged, which is due to the ionization of groups such as carboxyl groups on the molecular chains of cellulose and hemicellulose in aqueous solutions. Most wet strength agents are cationic polymers with a large number of cationic groups, such as amino and quaternary ammonium groups, on their molecular chains. Therefore, there is a strong electrostatic attraction between the wet strength agent and lignocellulose, which is one of the main driving forces for the adsorption of wet strength agents on the surface of lignocellulose <sup>[4]</sup>. For example, the cationic groups in PAE molecules can attract the negative charges on the surface of lignocellulose, enabling PAE molecules to rapidly adsorb onto the lignocellulose surface. The presence of this electrostatic adsorption can be verified through Zeta potential analysis. When PAE is added to a lignocellulose suspension, the Zeta potential of the system changes significantly, shifting from a negative value to a positive value, indicating that PAE molecules have adsorbed onto the lignocellulose surface, changing its surface charge properties.

### **2.2.2. Hydrogen bonding**

Besides electrostatic adsorption, hydrogen bonding also exists between wet strength agents and lignocellulose. As mentioned earlier, lignocellulose molecular chains contain a large number of hydroxyl groups, while wet strength agent molecules may also contain groups capable of forming hydrogen bonds with hydroxyl groups, such as amino and hydroxyl groups. These groups interact through hydrogen bonding, further enhancing the adsorption stability of the wet strength agent on the lignocellulose surface. Taking PEI as an example, the amino groups on its molecular chain can form hydrogen bonds with the hydroxyl groups on the lignocellulose surface, allowing PEI molecules to be firmly adsorbed onto the lignocellulose surface. The formation of hydrogen bonds can be detected through infrared spectroscopy. Before and after adding the wet strength agent, infrared spectroscopy tests on lignocellulose reveal shifts or intensity changes in absorption peaks related to hydrogen bonding, indicating the formation of hydrogen bonds between the wet strength agent and lignocellulose.

### **2.2.3. Chemical reaction**

Some wet-strength agents can chemically react with lignocellulosic fibers to form chemical bonds, achieving a stronger bond. For example, under certain conditions, the epoxy groups in PAE molecules can undergo ring-opening reactions with hydroxyl groups in lignocellulosic fibers, forming ether bonds. The formation of these chemical bonds stabilizes the bond between PAE and lignocellulosic fibers, making it difficult to detach. The occurrence of chemical reactions can be confirmed through X-ray photoelectron spectroscopy (XPS) analysis. XPS can detect changes in the elemental composition and chemical state of the surface of lignocellulosic fibers. When PAE reacts with lignocellulosic fibers, characteristic peaks related to ether bonds appear in the XPS spectrum, proving the existence of chemical reactions. The adsorption of wet-strength agents in lignocellulosic raw materials is a complex process, and electrostatic adsorption, hydrogen bonding, and chemical reactions often coexist and synergize, jointly determining the adsorption effect of wet-strength agents.

## **2.3. Regulatory effect of wet-strength agents on paper wettability**

### **2.3.1. Impact on paper surface tension**

The adsorption of wet-strength agents alters the chemical composition and structure of the paper surface, thereby affecting its surface tension. When wet-strength agents adsorb onto the paper surface, the hydrophilic or hydrophobic groups on their molecular chains become exposed, changing the paper's wettability. If the wet-strength agent's molecular chain contains more hydrophilic groups, such as amino groups in PAE molecules, it enhances the paper surface's hydrophilicity, reducing surface tension. Conversely, if the molecular chain contains more hydrophobic groups, it increases the paper surface's hydrophobicity, raising surface tension. Contact angle measurements provide a direct indication of changes in paper surface tension. Adding PAE to the paper reduces the contact angle of water droplets on the paper surface, indicating enhanced hydrophilicity, decreased surface tension, and improved wettability.

### **2.3.2. Impact on the pore structure of paper**

The pore structure of paper also has a significant impact on its wettability. The adsorption and crosslinking of wet strength agents between lignocellulosic fibers can alter the pore structure of paper. On one hand, the adsorption of wet strength agents may fill some pores in the paper, reducing pore size; on the other hand, crosslinking between wet strength agent molecules may form a network structure, increasing the compactness of the paper. Smaller pore sizes and a more compact structure can increase the resistance of liquids penetrating the paper, thereby affecting its wettability. Equipment such as mercury porosimeters can be used to analyze the pore structure of paper. Studies have found that as the amount of PAE increases, the average pore size of paper gradually decreases, and the porosity decreases, indicating that the addition of PAE alters the pore structure of paper and affects its wettability.

### **2.3.3. Impact on the bonding force between paper fibers**

One of the main roles of wet strength agents is to enhance the bonding force between paper fibers, and changes in this bonding force can indirectly affect the wettability of paper. When wet strength agents undergo adsorption and crosslinking reactions with lignocellulosic fibers, more chemical bonds or hydrogen bonds are formed between the fibers, resulting in tighter bonding. This tight bonding can reduce fiber swelling and water absorption, protecting existing hydrogen bonds between fibers, thus reducing the water absorption of paper and improving its wettability. For example, the crosslinked network structure formed by PAE in paper can effectively restrict fiber movement, reduce water absorption and swelling of fibers, enabling the paper to maintain good strength and low water

absorption in a wet state. Changes in the bonding force between paper fibers can be detected through methods such as tensile testing. As the amount of wet strength agent increases, both the dry and wet tensile strengths of paper improve, indicating enhanced bonding force between fibers, reduced water absorption, and controlled wettability of the paper.

### 3. Experimental section

#### 3.1. Experimental materials

Bleached sulfate softwood pulp (produced by a certain paper mill, Kappa number 12.5, fiber length 1.8–2.2 mm) was selected as the lignocellulosic raw material. Its main chemical components are: cellulose 68.5%, hemicellulose 19.2%, lignin 2.3%, and ash content 0.5%. The wet strength agents used were commercially available polyamide polyamine epichlorohydrin resin (PAE, produced by a certain chemical company, solid content 12.5%, pH 3.0–6.0, viscosity 15–100 mPa·s), polyethyleneimine (PEI, molecular weight 10,000, solid content 30%, from a certain biotechnology company), and cationic polyacrylamide (CPAM, molecular weight 8 million, cationic degree 30%, from a certain material company) <sup>[6]</sup>. The experimental water was deionized water (conductivity  $\leq 10\mu\text{S/cm}$ ), and other reagents (NaOH, HCl, etc.) were analytically pure.

#### 3.2. Experimental instruments

All instruments used in this experiment are listed in **Table 1**.

**Table 1.** Experimental instruments

Instrument name	Model	Manufacturer	Primary application
Dynamic Zeta Potential Analyzer	Nano-ZS90	Malvern Instruments, UK	Measures the zeta potential of fiber suspensions
Fourier Transform Infrared Spectrometer (FTIR)	Nicolet iS50	Thermo Fisher Scientific, USA	Analyzes hydrogen bonding and functional group changes
X-ray Photoelectron Spectrometer (XPS)	ESCALAB 250Xi	Thermo Fisher Scientific, USA	Detects surface elements and chemical states
Contact Angle Meter	OCA20	DataPhysics, Germany	Measures paper surface contact angles
Mercury Porosimeter	AutoPore IV 9500	Micromeritics, USA	Analyzes paper pore structure (pore size, porosity)
Universal Testing Machine	CMT6104	MTS Systems, China	Tests dry/wet tensile strength of paper
Standard Sheet Former	ZQJ1-B	Hangzhou Qingtong Boke Automation, China	Produces paper sheets with basis weight of 80 g/m <sup>2</sup>
Constant Climate Chamber	BPS-100CL	Yiheng Instruments, China	Paper conditioning (23°C, 50% RH)

#### 3.3. Experimental methods

##### 3.3.1. Paper sample preparation

- (1) Pulp pretreatment: Soak the softwood pulp board in deionized water for 24 hours, then disintegrate it with a standard disintegrator (3000 r/min) for 10 minutes to prepare a 0.5% (mass concentration) fiber suspension. Adjust the pH to  $7.0 \pm 0.1$  with 0.1mol/L NaOH or HCl <sup>[7]</sup>.
- (2) Wet strength agent addition: Add different amounts (0.2%, 0.4%, 0.6%, 0.8%, 1.0% based on the mass of the absolutely dry pulp) of PAE, PEI, and CPAM to the fiber suspension, and stir for 15 minutes on a



magnetic stirrer (300 r/min) to ensure uniform dispersion of the agents.

- (3) Sheet formation and processing: Use a standard sheet former to create paper samples with a basis weight of 80g/m<sup>2</sup>. After vacuum dewatering (-0.08 MPa, 2min), the samples are dewatered in a press (0.3 MPa, 3min) and finally dried in a dryer (105 °C, 5min). Place the paper samples in a constant temperature and humidity chamber (23 °C, 50%RH) for 24 hours to equilibrate before use. Repeat each experiment 3 times and take the average value <sup>[8]</sup>.

### 3.3.2. Characterization of the adsorption mechanism

- (1) Electrostatic adsorption test: Take 0.1% fiber suspension, add different amounts of wet strength agent, stir for 10 minutes, and measure the Zeta potential of the suspension using a Zeta potential meter at a test temperature of 25 °C. Measure each sample 5 times and take the average value.
- (2) Hydrogen bonding analysis: Wash the fibers adsorbed with wet strength agent 3 times with deionized water (to remove unadsorbed agent), freeze-dry, mix with KBr, and press into tablets. Scan with FT-IR in the range of 4000–400cm<sup>-1</sup>, with a resolution of 4cm<sup>-1</sup> and 32 scans. Compare and analyze changes in characteristic peaks of hydroxyl (around 3400cm<sup>-1</sup>) and amino groups (around 3300cm<sup>-1</sup>) <sup>[9]</sup>.
- (3) Chemical reaction verification: Use XPS to analyze changes in fiber surface elements, with an Al target (1486.6eV), vacuum degree of 1×10<sup>-8</sup>Pa, and an analysis area diameter of 500 μm. Perform peak fitting on C1s and N1s spectra, and calculate the proportion of ether bond (C-O-C) characteristic peak (binding energy 286.5eV) <sup>[10]</sup>.

### 3.3.3. Wettability and related performance tests

- (1) Contact angle measurement: Use a contact angle meter to perform the sessile drop method test. Drop 5 μL of deionized water onto the surface of the paper sample, record the contact angle at 0s, and measure 5 different positions for each sample to obtain an average value.
- (2) Pore structure analysis: The pore distribution of the paper sample was measured using a mercury intrusion porosimeter with a test pressure range of 0.001–414 MPa (corresponding to pore diameters of 3.6 nm–1.1 mm). The average pore diameter and porosity were calculated.
- (3) Strength performance testing: According to the GB/T12914-2018 standard, the dry tensile strength of the paper sample was tested using an electronic universal material testing machine. For the wet tensile strength test, the paper sample was soaked in deionized water for 30 minutes, removed, and the surface water was absorbed with filter paper before immediate testing. The stretching speed was 10 mm/min.

## 4. Discussion

### 4.1. Adsorption characteristics of wet strength agents

With the increase in PAE addition, the Zeta potential of the lignocellulosic fiber suspension gradually shifted from negative to positive, indicating that PAE molecules were gradually adsorbed onto the surface of the lignocellulosic fibers through electrostatic adsorption. FT-IR analysis showed significant shifts and intensity changes in absorption peaks related to hydrogen bonding after adding PAE, demonstrating the formation of hydrogen bonds between PAE and lignocellulosic fibers. XPS analysis revealed the emergence of characteristic peaks associated with ether bonds after the reaction between PAE and lignocellulosic fibers, confirming the occurrence of chemical reactions. These results suggest that the adsorption of PAE in lignocellulosic fiber raw materials is a combined effect of

electrostatic adsorption, hydrogen bonding, and chemical reactions.

## 4.2. Effects on paper wettability

Contact angle measurement results indicated that as the amount of PAE increased, the contact angle of water droplets on the paper surface gradually decreased, indicating improved wettability of the paper. Mercury intrusion porosimeter test results showed that with increasing PAE usage, the average pore diameter of the paper gradually decreased, and the porosity decreased. This suggests that the addition of PAE altered the pore structure of the paper, thereby affecting its wettability. Tensile test results demonstrated that both the dry and wet tensile strengths of the paper significantly increased with increasing PAE usage, while the water absorption of the paper decreased. This indicates that PAE enhances the bonding force between paper fibers, thereby improving the wettability of the paper. Based on these combined results, it can be concluded that the wet strength agent PAE effectively regulates the wettability of paper by altering factors such as surface tension, pore structure, and inter-fiber bonding force.

## 5. Conclusion

This study deeply explored the adsorption mechanism of wet strength agents in lignocellulosic materials and their regulatory effects on paper wettability. The adsorption of wet strength agents on the surface of lignocellulose fibers is achieved through a combination of electrostatic adsorption, hydrogen bonding, and chemical reactions, which enable the wet strength agents to be strongly adsorbed onto the lignocellulose fibers. The regulation of paper wettability by wet strength agents is primarily achieved by influencing the surface tension of the paper, pore structure, and inter-fiber bonding force.

## Disclosure statement

The author declares no conflict of interest.

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