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The Moderating Role of Culture in the Relationship Between Financial Inclusion and Financial Performance of Small and Medium-Sized Enterprises in Manyu Division, Cameroon

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Abstract

This study investigates the moderating role of local culture in the relationship between financial inclusion and the financial performance of Small and Medium-Sized Enterprises (SMEs) in Manyu Division, Cameroon. A survey was conducted on a sample of 330 SMEs in Manyu Division, Cameroon. Questionnaires were used to collect data, which were then analyzed using the SEM-PLS technique. The research findings show that, although financial services do not have a statistically significant effect, other results indicate a beneficial effect on financial performance. Additionally, local culture was found to strengthen this relationship. With the moderation of local culture, the path coefficient value is 0.319, and the significance value is 0.010. culture strengthens the interaction between financial service quality and the financial performance of SMEs in Manyu Division, with a significant value of 0.048, which is less than 0.05. Therefore, the test result shows that the nature of culture moderation is quasi-moderation, as both the direct effect coefficient (0.048) and the moderation effect coefficient (0.010) are less than 0.05. The study supports the Resource-Based Theory as a theoretical contribution, making it relevant in reducing barriers to the growth of SMEs. The relevance of this article lies in providing new insights from the perspective of users, namely SMEs, whose numbers are still relatively small, particularly in terms of utilizing unique local genius values to enhance the interaction between financial inclusion and SMEs' financial performance. The study's insights contribute to the financial inclusion literature by highlighting the critical role of culture in shaping the financial performance outcomes of SMEs. The findings have implications for policy makers, financial institutions, and SMEs seeking to enhance financial performance through inclusive financial services tailored to cultural context.

Keywords: financial inclusion, culture, financial performance, SMEs, Manyu Division, Cameroon

1. Introduction

In a highly competitive business world, the operational sustainability of a company depends on financial performance; this applies to all lines of business, including Small and Medium-Sized Enterprises (SMEs), the smallest yet vital sector. For SMEs to remain viable today and in the future, their capacity to enhance their financial performance is crucial. The issue of financial performance in the SMEs segment is critical because it reflects the level of profitability achieved. A high level of profit allows SMEs to develop their businesses more effectively.

Conversely, A low-profit level hinders SMEs in fulfilling financial obligations, servicing debts, and increases the risk of bankruptcy. Suharman et al. (2022) said financial performance encompasses multiple metrics of corporate efficacy, including revenue and sales. This suggests that analyzing multiple financial variables can provide a comprehensive understanding of the financial health of SMEs. Ullah (2020) explains how financial difficulties affect employment growth and business sales. To improve the performance of SMEs, strategic initiatives are

necessary, including more efficient financial management, product and service diversification, market development, and the pursuit of innovative financial solutions.

The phenomenon that occurs is that SMEs in Manyu Division struggle to improve and typically face significant challenges (Moscalu et al., 2020). SMEs face various obstacles, but the primary one preventing them from doing better is financial access (Lakuma et al., 2019; Desmiyawati et al., 2023). Enhancing financial access across regions amplifies income-generating prospects and guarantees the availability of financial resources that support SMEs in executing economic activities and mitigating risks (Yangdol & Sarma, 2019; Yogantara et al., 2024). This initiative aims to enhance the business productivity of SMEs.

Referring to the Resource-Based Theory (RBT) proposed by Barney (1991), enterprises can leverage both valuable and potentially valuable resources, which can be material or intangible. Financial inclusion falls into the category of intangible resources, which aims to reduce barriers that hinder the growth of SMEs and ultimately improve their financial performance. The judicious deployment of organizational resources enhances both the efficacy and efficiency of operational processes.

Financial inclusion has emerged as a critical factor in promoting economic growth, reducing poverty, and enhancing financial stability, particularly for Small and Medium-Sized Enterprises (SMEs) (Demirgüç-Kunt & Klapper, 2012; World Bank, 2018). By providing access to financial services, SMEs can overcome capital constraints, invest in business opportunities, and improve their financial performance (Beck & Demirgüç-Kunt, 2006). However, the effectiveness of financial inclusion initiatives can be influenced by various contextual factors, including culture (Guiso et al., 2006; Stulz & Williamson, 2003). Cultural dimensions such as collectivism, uncertainty avoidance, and long-term orientation can shape financial behaviors, attitudes, and decisions, ultimately affecting the relationship between financial inclusion and financial performance (Hofstede, 2001).

Looking at the context of study, Manyu Division is situated in the South West region of Cameroon, where most communities are the most deprived as a result of years of the Anglophone crisis and below average agricultural harvests with little means to resist the continuous cycle of shocks and stresses (Chai et al., 2018; Guiso et al., 2004). Manyu Division is characterized by a significant ethnic diversity and financial practices (Valente et al., 1997). This diversity suggests that ethnic heterogeneity should be considered along key dimensions of ethnicity, which would help refine our analysis (Kim et al., 2020; De Walque et al., 2017).

In Manyu Division, it has been noticed that members of the same ethnic group form informal meetings based on trust and custom. These groups often raise huge sums for the community and individual development. This has greatly encouraged the formation of ethic associations due to its benefits. Most SMEs in Manyu Division are principally involved in trading with neighboring country like Nigeria (Cook et al., 2000). Manyu division is one of the divisions of the South West Region of Cameroon. The division covers an area of 9,565km2 and as of 2005 the population of 181,039. The capital of Manyu Division is Mamfe. Manyu Division is endowed with good climate and rich soils for economic activities and in addition with good roads following the tarring of Bamenda-Mamfe-Ekok and Kumba-Mamfe stretch of roads which are all linked to Nigeria that women in Manyu Division do trade with and are actively involved in entrepreneurial activities. However, Beck & Brown (2011) have indicated that SMEsin Manyu division face several challenges. Therefore, this research work aims to understand the unique challenges of SMEs in Manyu division as the first step needed to stimulate their financial performance. Before we proceed, it is necessary to present the map of Manyu Division.

Manyu division is one of the divisions that makes up the six divisions of the south west region in Cameroon. It has four sub divisions which include: Eyumojock sub division, Mamfe sub division, Akwaya Sub division and Upper Bayang sub division. It is bordered by the Federal Republic of Nigeria in the West, The North West region in the North, Ndian division in the south and in the west by Kupe Manenguba. This division is situated in the Equatorial rainforest from two to sixth degree North and characterized by heavy rainfall of about 2000mm. The average temperature is at about 25 degree Celsius. Thus, the climatic conditions are much favourable in the cultivation of both staple and cash crops.

Manyu division just like any other division in Cameroon is mostly characterized by a rural population with Mamfe town which is the biggest town and capital of Manyu division serving as the only semi-urban setting. The main economic activities are centered on agriculture and trading. They produce some food crops such as maize, plantains, cassava, Cocoyam, Yams, Bananas, vegetables, etc. The main cash crops produced by indigenes of this division include; Cocoa and Oil palm which serve as the greatest source of income to the locals.

The division has a road transportation network linking the Federal Republic of Nigeria, the Northwest region and the rest of south west regions following the tarring of Bamenda-Mamfe-Ekok stretch of road and Mamfe-Kumba road respectively as seen in figure below. According to Neba (2002) in his book *Geography of Cameroon*, this improvement in transportation network has brought about increase in trading activities especially for agricultural products with the greatest demand coming from neighboring country Nigeria which is the most populated Nation

in Africa. Research and development activities in recent times in Manyu division have faced numerous challenges due to the crisis situation in that part of the country. The main activity practiced in this region is agriculture dominated by the cultivation of both cash and food crops. The division is mostly characterized by rural settings. Over 80% of the population leaves in rural dwellings with the only major town being Mamfe town which host government and private institutions and is the capital of Manyu division.

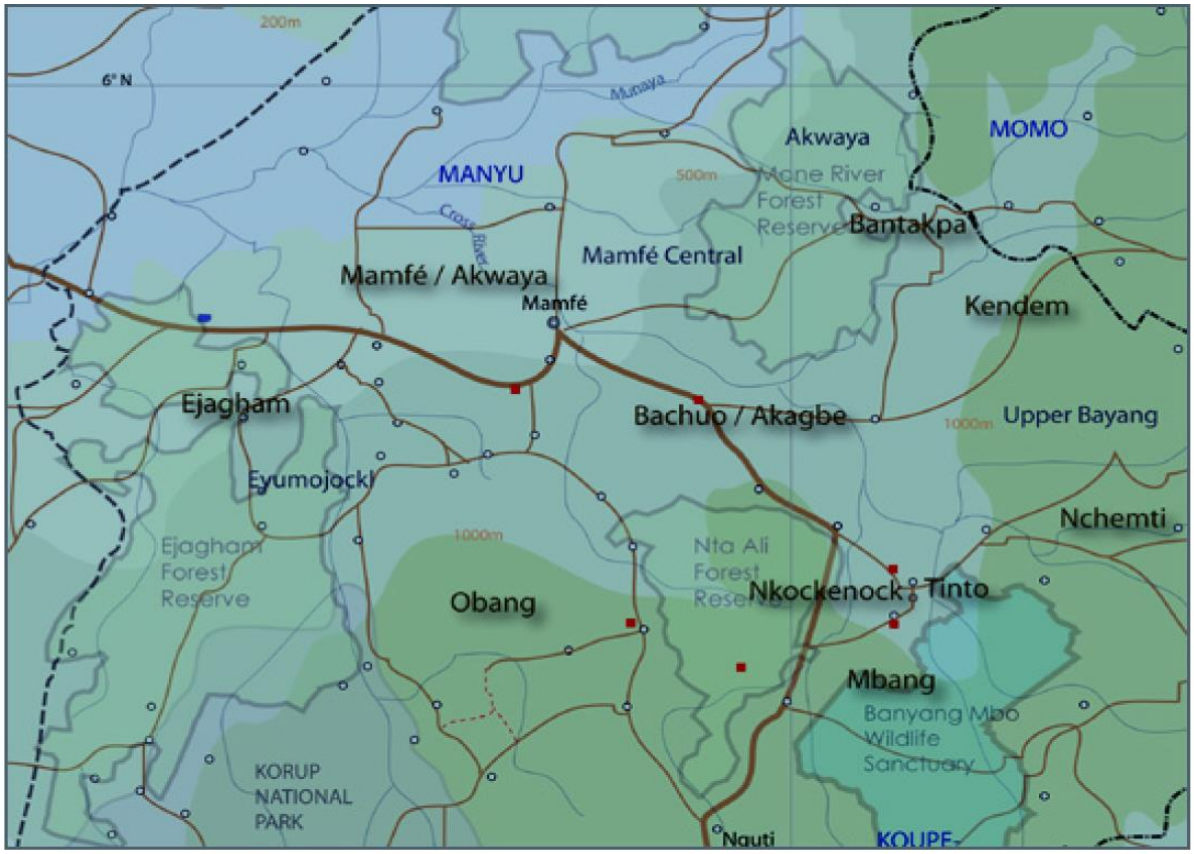

Figure 1. Map of Manyu Division

Source: Pemunta (2011).

The Manyu people's culture emphasizes community and cooperation, which can inform financial practices and promote a balance life. Community-based financial practices are encouraged. Rotating savings and credit associations (ROSCAs) or "njangis" are common, promoting financial inclusion and cooperation (Ardener, 1964; Besley et al., 1993). Group savings and lending practices foster a sense of community and shared responsibility (Bähre, 2007). Promoting Financial Literacy and Planning through traditional financial knowledge and practices are passed down through generations, emphasizing the importance of saving and budgeting (Lwiza & Nnko, 2017). Elders and community leaders provide guidance on financial management and planning (Takem, 2024). Manyu people value entrepreneurship and self-sufficiency, with many engaging in small-scale farming, trading, and craftsmanship (Fonjong, 2013). This emphasis on entrepreneurship promotes financial independence and resilience (Kiggundu, 2002).

Also, the Manyu people believe in finding a balance between material wealth and spiritual growth. Their culture emphasizes the importance of giving back to the community and honoring ancestors, promoting a sense of social responsibility (Takem, 2024). In addition, respect for Elders and Tradition. Elders are revered for their wisdom and experience, providing guidance on financial matters and life decisions (Takem, 2024). Traditional practices and customs are respected and passed down through generations, promoting cultural continuity and stability (Fonjong, 2013). These cultural practices can contribute to a more balanced and fulfilling life, emphasizing the importance of community, cooperation, and financial responsibility.

Although financial inclusion plays a vital role in the growth of SMEs, not all SMEs take advantage of it (Liu et al., 2021). This is demonstrated by the reality that a significant portion of the global population continues to be inadequately served by modern financial services (Ghosh & Vinod, 2017). Furthermore, the use of financial

inclusion to drive the growth of SMEs remains very modest. This can be caused by several issues, including access to finance, incompatibility between financial products and market needs, and difficulties in securing financing (Owusu et al., 2021; Pranatasari et al., 2021).

In recent decades, research on financial performance and financial inclusion has become a significant subject of academic study. In Cameroon, financial inclusion has become a top priority of the financial track. Numerous studies investigating the relationship between financial inclusion and financial performance in small and medium Sized enterprises (SMEs) have produced inconsistent findings.

Research indicates that financial performance is influenced by financial inclusion (Owusu et al., 2021; Eton et al., 2021; Kalaipriya Kalaieesan, 2021; Thathsarani & Jianguo, 2022). Conversely, various other findings confirm that financial inclusion is not effective for the financial success of SMEs (Pranatasari et al., 2021; Amin & Pamungkas, 2022; Bhattacharyya et al., 2023; Marini et al., 2024).

Although the significance of financial inclusion has been extensively acknowledged, and prior research has identified several aspects that influence financial inclusion, cultural factors may not have been sufficiently considered, despite their considerable potential to support financial inclusion and encourage optimal financial outcomes for SMEs in Manyu Division, Cameroon, the cultural role is significant and serves as a guiding philosophy and spirit in the conduct of business activities by business actors. Despite the growing recognition of financial inclusion's importance, there is limited understanding of how culture moderates its impact on financial performance, particularly in developing economies (Allen et al., 2016). This study aims to address this knowledge gap by investigating the moderating role of culture in the relationship between financial inclusion and financial performance of SMEs in Manyuul Division, Cameroon. By exploring the interplay between financial inclusion, culture, and financial performance, this research provides insights into the design and implementation of financial inclusion initiatives that are tailored to specific cultural contexts, ultimately contributing to the financial sustainability and growth of SMEs in Manyu Division, Cameroon.

Also, the majority of preceding articles are written from a macro perspective, with most studies focusing on country-level or overall economy and banking sector analysis (Adugna, 2024). However, research from the user's perspective, such as SMEs, is still relatively scarce. This study makes a substantial contribution and presents novel insights from the user standpoint, specifically SMEs, whose numbers remain relatively small, particularly in terms of leveraging unique local genius values to enhance the interaction between financial inclusion and SMEs' financial performance.

Focusing on local genius values, this study offers new insights into how local characteristics can enhance the interaction between financial outreach and corporate financial health, providing a more holistic approach. It can guide policymakers and practitioners in designing agendas that are more appropriate to the needs of SMEs and help formulate more effective strategies to support their growth in the financial sector.

This study continues in the next section by conducting a literature review. Then, it introduces the theoretical framework and proposed hypotheses, covers the data collection methods, and provides a comprehensive analysis of the survey results. The research paper concludes by discussing the theoretical and practical implications of the findings and offers suggestions for future research.

2. Theoretical Review

2.1 Resource-Based Theory (RBT) by Jah Barney (1991)

RBT, also known as Resource-Based Theory, popularized by Barney (1991), is one of the most significant theories in the history of management theory, particularly in the context of indicator theory, which focuses on resources and capabilities. The primary assumption of this theory is that a corporation can earn increasingly substantial competitive advantages and achieve good financial and non-financial performance by possessing, monitoring, and utilizing strategic assets, including both intangible and tangible assets (Barney, 1991).

Resources and capabilities are two essential elements that companies must possess at the business level. RBT emphasizes what can make resources better and why competitors cannot easily get, create, or imitate better resources. The characteristics and capabilities of resources referred to as "strategic assets" are the answer. RBT also highlights that to comprehend and implement strategies aimed at enhancing the company's efficiency and effectiveness, it is necessary to refer to company-controlled resources, such as assets, processes, competencies, business attributes, knowledge, and information (Barney, 1991).

Company resources can originate from within or outside the organization. Internal resources include product management, development and study capabilities, culture, product organization, logistics, and low-cost development. Meanwhile, external resources, such as the supplier network, client demand, and technological changes (Kozlenkova et al., 2014), also play a role. A business that utilizes its resources effectively can create a competitive advantage for the company compared to its peers. This advantage can manifest in the form of good

business financial performance.

3. Conceptual Review

3.1 Financial Performance of MSMEs

Based on a company's ability to generate earnings, financial performance is assessed and measured. Fatihudin et al. (2018) defined financial performance as a business's ability to manage and utilize its resources effectively. Financial performance can reveal a business's financial status, allowing it to be determined whether it is good or bad, and can then be investigated using financial analysis techniques. The financial performance of SMEs serves as a crucial determinant of a business's overall success and long-term viability. The assessment of financial performance plays a pivotal role in illustrating the financial conditions over a specific timeframe, encompassing various metrics of corporate efficacy (Widiatami et al., 2024).

SMEs must evaluate their strategies before making critical decisions to enhance their financial performance. The significance of financial performance lies in its role as an indicator of the profitability of micro, small, and medium-sized enterprises (SMEs). Zubair et al. (2020) found that the performance assessments of SMEs are often carried out haphazardly.

This indicates that the awareness of performance evaluation among SMEs remains relatively low. To keep contributing significantly to economic development, SMEs must connect their financial performance to the broader external business environment. With the correct approach and assistance from numerous stakeholders, including the government and financial institutions, the current difficulties can be resolved. SMEs can thrive, expand, and compete in the market when they have strong financial performance. Strategic initiatives are necessary to enhance the financial performance of SMEs. SMEs can significantly improve their financial performance by maximizing financial inclusion (Mamaro & Sibindi, 2022).

3.2 Financial Inclusion

Financial inclusion is an inclusive financing program that strives to deliver a wide variety of financial facilities to the underserved, low-income persons, and SMEs. These services include capital credit, savings, financial transfer services, and insurance. In practice, microfinance is a form of program based on the concept of financial inclusion. Financial inclusion is a diverse and active topic. The three dimensions of the lens for promoting financial inclusion are access, use, and quality (Al-Eitan et al., 2022; Presidential Regulation of the Republic of Indonesia No. 114 of 2020). Financial inclusion has been globally acknowledged as one of the key options for firm growth, particularly for SMEs (Mago & Chitokwindo, 2014).

Financial inclusion for SMEs entails ensuring that these businesses have access to financial facilities tailored to their specific needs. Financial inclusion may serve as a pivotal element in the expansion and sustainability of enterprises. Enhanced access to finance and the utilization of banks for working capital financing will improve the financial performance of SMEs (Bhattacharyya et al., 2023).

Utilizing banking for working capital financing offers advantages such as reduced interest rates, access to banking services, and increased funding availability. Policy makers, development organizations, and financial institutions can help SMEs unlock their potential to drive inclusive and sustainable economic growth by addressing their needs and challenges in accessing financial services (Thathsarani & Jianguo, 2022). Based on the literature review, this study posits the following hypothesis:

H1: Accessibility of financial facilities affect the financial performance of SMEs in Manyu Division.

H2: The use of financial facilities has an effect on the financial performance of SMEs in Manyu Division.

H3: The quality of financial facilities affects the financial performance of SMEs in Manyu Division.

In the life of a Manyu Man, especially the Bayangi's, some customs or teachings reflect various cultural concepts about life. The Manyu Division, located in the Southwest Region of Cameroon, is home to the Banyangi people, who have a rich cultural heritage. Some cultural concepts and teachings that reflect various aspects of life among the Banyangi people include respect for elders: In Banyangi culture, elders are highly respected for their wisdom, experience, and knowledge (Fonjong, 2013). Children are taught from a young age to show respect to their elders, who play a significant role in passing down cultural values and traditions (Takem, 2024).

The Banyangi people place a strong emphasis on community and cooperation (Ndonko, 2015). They believe in working together to achieve common goals and supporting one another in times of need (Fonjong, 2013). Also, the Banyangi people have a strong sense of traditional values, including respect for ancestors and the importance of honoring one's heritage (Takem, 2024). Traditional practices and customs are an integral part of Banyangi culture, and are often passed down from generation to generation (Ndonko, 2015). Hospitality is an important aspect of Banyangi culture which is also a perquisite for business success, with visitors often being welcomed with open arms and treated with great respect (Fonjong, 2013). The Banyangi people take pride in their ability to host

guests and provide for their needs (Takem, 2024).

In addition, initiation and rites of passage are important cultural practices among the Banyangi people (Ndonko, 2015). These ceremonies mark important transitions in life, such as birth, initiation into adulthood, marriage, and death (Fonjong, 2013). Storytelling is a valued tradition among the Banyangi people, with oral narratives passed down through generations (Takem, 2024). These stories often contain moral lessons and teachings that help to shape the values and beliefs of the community (Ndonko, 2015). These cultural concepts and teachings reflect the rich cultural heritage of the Banyangi people and play an important role in shaping their identity and way of life (Kadjeng, 2010).

Based on RBT, it is evident that a company's internal capabilities are crucial for managing its unique resources, enabling it to gain a competitive advantage. The Bayangi people believe that, culture is an intangible asset that supports financial inclusion and encourages optimal financial performance among SMEs in Manyu Division. In the Manyu area, culture plays a decisive role and serves as a guiding philosophy for corporate actors in their business activities.

The Manyu culture, if appropriately implemented, can strengthen the relationship between the accessibility of financial services (referring to the extent to which the financial system penetrates) and the financial performance of SMEs. Makdissi et al. (2020) explained that culture has been proven to be important in stimulating SMEs.

Positive values in local culture can help an organization improve its financial performance. Implementation of the Manyu culture will encourage members and company management to make better decisions to support the company's performance. Based on the literature review, the following hypotheses are formulated:

H4: The role of culture in strengthening the interaction between accessibility of financial facilities and financial performance of SMEs in Manyu Division.

H5: The role of culture in strengthening the interaction between the utilization of financial facilities and the financial performance of SMEs in Manyu Division.

H6: The role of culture in strengthening the interaction between the quality of financial facilities and the financial performance of SMEs in Manyu Division.

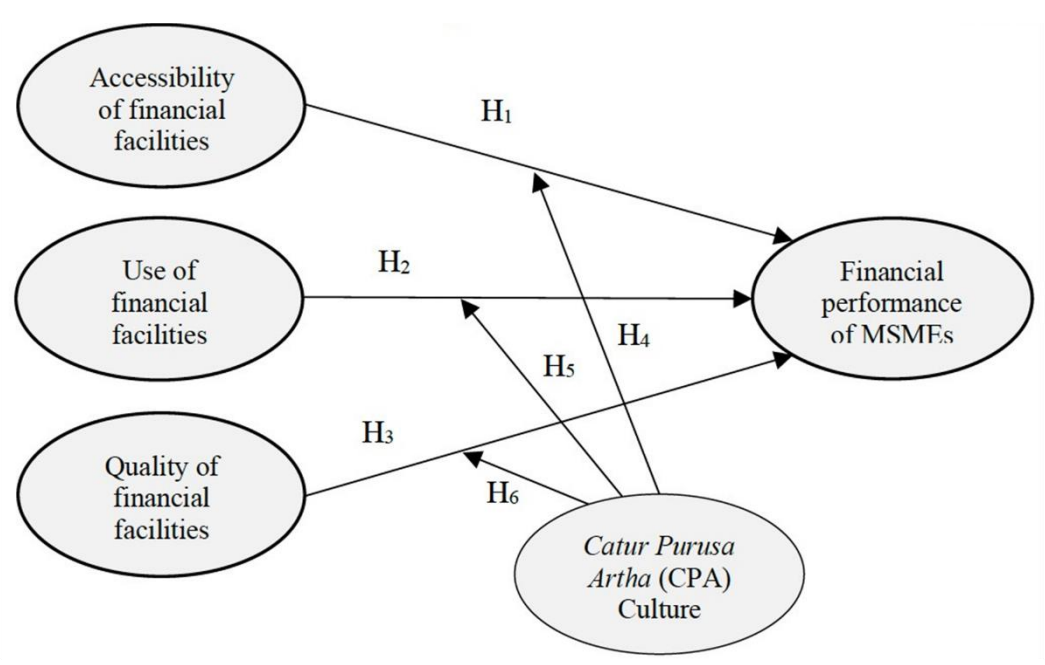

Figure 2. Conceptual framework

Source: Author (2025).

4. Methodology

4.1 Data and Sampling

The study adopted a cross-sectional research design and quantitative method. The primary survey conducted enabled the researcher to obtain facts and answers from the population at one specific point in time which increased

the validity and generalizability of findings. A cross-sectional research design was used because it allows collecting data from the population over a shorter period. It is even the cheapest and less time-consuming research design than others, easily collects data, and excludes the recurring mistakes which were common in longitudinal research design (Bongomin et al., 2016). The quantitative research approach was used because it relied on measurable evidence and therefore influenced a high degree of control over a phenomenon (Bhattacherjee, 2012). It was used to quantify the problem by way of generating numerical data or data that could be transformed into usable statistics. It was also used to quantify behaviors, attitude, opinions, and other defined variables and generalized results from a larger sample population. This investigation uses quantitative method to investigate the fundamental interaction between these variables.

The study population was 466 SMEs in Manyu Division, registered with the divisional taxation office and the Divisional Delegation of Small and Medium-Sized Enterprises Office in 2024. By focusing on SMEs, this study can provide valuable insights into how financial inclusion contributes to enhancing financial performance and strengthening their position in the global market. It can also offer practical recommendations to stakeholders to support the growth of SMEs.

The target population are SMEs in Manyu Division. The population for this study was drawn from the four sub divisions namely Upper Banyang, Akwaya, Mamfe Cenral and Eyomojock. The number of SMEs per each sub division used in the study were as follows:

Table 1. Location of SMEs in Manyu Division

Sub Division	**Frequency**	**Percent**	**Cumulative Percent**
Mamfe Central	89	27.0	27.0
Upper Banyang	79	23.9	50.9
Eyumojock	89	27.0	77.9
Akwaya	73	22.1	100.0
Total	**330**	**100.0**	**-**

Source: Author (2024).

Data was collected according to the specified sample size based on the following criteria: (1) Proprietor and administrator of small, and medium-sized enterprises. This approach facilitates a deeper comprehension of the internal dynamics and decisions that impact business success. (2) The owner and manager of the SMEs. This determination is based on the respondents' greater familiarity with the culture used in this study, specifically the Manyu culture. A total of 330 samples were generated using these predetermined criteria.

The researcher made use of a stratified sampling technique to sample the region by dividing Manyu division into subgroups called subdivision. This helps to improve accuracy and representativeness of the entire population and reducing sampling bias. The researcher also used the purposive sampling technique by using the SMEs who can provide valuable insight into the research questions because of their line of business activities which is related to the aim of the study and the problem in question. A purposive sampling technique have been chosen for this study. In this technique, only a specific group of people can provide the required information because they are the only one who have knowledge and expertise of that particular area. The characteristics of these SMEs were of great interest to the study.

The distribution of the questionnaires was based on a convenience sampling and a snowball sampling or chain-referral sampling. The researcher made use of a convenience sampling because data was collected SME who were easily accessible, available and willing to take part. The snowball sampling method is mostly referral-based, and a researcher can obtain a sample through referrals (Etikan et al., 2016; Naderifar et al., 2017). The primary data source nominates other possible data sources who are eligible to participate in the study using this procedure. Snowball sampling is a common business research technique. It is widely used in situations when the population is unknown and challenging to collect primary data through a direct conversation with the participant, such as in the case of insecurity as a result of the NOSO (North West and South West) crisis which was ongoing during the data collection process, where there was certain luck down days and as a result of insecurity the fear of meeting somebody you have never met before made the snowball sampling technique a convenient sampling technique for this study. The researcher used a non-discriminative exponential snowball sampling method based on relationship and trust, in which the first person is engaged and then receives multiple referrals.

The reason for selecting this sampling method is that snowball sampling methods can be used when no official list

of names of the participant is available. It is not easy to obtain data about the population like in the current study. Snowball Sampling has many advantages. It may save time and money since it is easier to find samples, and it is also more cost-effective because it is more convenient and less expensive than other ways. On the other hand, snowball sampling may generate bias and margin of error, and people may be uncooperative and refuse to engage in the study and that is why it was also complement with other sampling methods. Also, efforts will be made to ensure that such bias are eliminated by the researcher to ensure that accurate data was collected for the analysis.

4.2 Sample Size Calculation

The target population for this study is SMEs in Manyu Division. For this study, Yamane (1967) sample size formulae will be used to calculate the required sample size. Data from the divisional delegation of small and medium size enterprises indicated that there are about 466 SMEs in Manyu Division.

Applying the Yamane (1967) sample size formular: $n = \frac{N}{1 + Ne^2}$. Where: n= sample size of population, N=

Total sample population (from the Ministry of SMEs in Mamfe, N= 466 SMEs) and e= Standard error (mathematically assumed to be 5% (0.05)).

Hence, the minimum sample size according Yamane technique is equivalent to 316 respondents. However, for robustness, we targeted a total of 330 SME in Manyu division. Thus, 330 questionnaires were administered to SMEs in Manyu Division which is greater than the approve sample size of 316 SME as per our scientific calculation.

4.3 Instruments of Research and Measurement

The investigation of the accessibility, utilization, quality of financial services, and financial performance of MSMEs employs measurement techniques that have been established, tested, and verified by prior researchers. The instrument used to measure the accessibility of financial facilities was adapted from the research of Banerjee and Donato (2021), and Kalaipriya Kalaieesan (2021).

Next, the items used to measure the utilization of financial services were modified from those used by Eton et al. (2021) and Thathsarani and Jianguo (2022). Financial service quality was measured using items constructed and modified from those of Owusu et al. (2021), and Thathsarani and Jianguo (2022). The financial performance of SMEs was developed as a modified result of the study by Al-Matari et al. (2014), and Thathsarani and Jianguo (2022).

A new instrument was developed and validated to measure Manyu culture. Academic experts and Manyu cultural experts agreed upon this during a Focus Group Discussion (FGD) held on Tuesday, April 15, 2025, at the Glass House Hotel in Mamfe, Manyu Division.

4.4 Sample Size and Population

The questionnaire was first tested (pilot study). The trial is conducted on a small representative sample to identify invalid or ambiguous items. The trial was conducted on 36 business student respondents. Furthermore, the pilot study (trial) results are measured for validity and reliability. The data obtained is analyzed to evaluate the performance of each item.

The results of the pilot test for construct validity, presented in Table 2, indicate that the research instrument possesses a loading factor value exceeding 0.70, thereby confirming the applicability of all instruments in this study. The pilot construct reliability test indicates that Cronbach's Alpha (α) exceeds 0.70, so the study data is deemed very trustworthy for inclusion in the data analysis procedure. The outcomes of this test can establish a robust foundation for creating a CPA culture measurement tool, which will be applied in the principal study.

Table 2. Recapitulation of the validity and reliability test of the pilot test construct

Construct	Item	*OL*	*CR*
Accessibility of financial facilities	Aff $_{1.1}$	0.760	0.853
	Aff $_{1.2}$	0.775	
	Aff $_{1.3}$	0.748	
	Aff $_{1.4}$	0.858	
	Aff $_{1.5}$	0.821	
Use of financial facilities	Uff $_{2.1}$	0.763	0.873
	Uff $_{2.2}$	0.911	

	Uff $_{2.3}$	0.912	
	Uff $_{2.4}$	0.814	
Quality of financial facilities	Qff$_{3.1}$	0.815	0.891
	Qff $_{3.2}$	0.920	
	Qff $_{3.3}$	0.847	
	Qff $_{3.4}$	0.789	
	Qff $_{3.5}$	0.771	
Financial performance of MSMEs	Fp $_{1}$	0.870	0.929
	Fp $_{2}$	0.849	
	Fp $_{3}$	0.826	
	Fp $_{4}$	0.797	
	Fp $_{5}$	0.773	
	Fp $_{6}$	0.873	
	Fp $_{7}$	0.872	
	Fp $_{8}$	0.874	
	Fp $_{9}$	0.823	
The Culture *of Manyu*	CPA$_1$	0.843	0.961
	CPA$_2$	0.701	
	CPA$_3$	0.743	
	CPA$_4$	0.811	
	CPA$_5$	0.866	
	CPA$_6$	0.914	
	CPA$_7$	0.910	
	CPA$_8$	0.911	
	CPA$_9$	0.891	
	CPA$_{10}$	0.923	
	CPA$_{11}$	0.802	
	CPA$_{12}$	0.727	

Source: Field Work (2025).

Based on the previous explanation, the overall indicators used are shown in Table 3. All items are rated on a five-point Likert scale, where option five indicates “strongly agree” and option one indicates “strongly disagree”.

Table 3. Indicators used

Construct	Indicator
Accessibility of financial facilities	1. Strategically located financial institutions
	2. Knowing the financial services provided by financial institutions
	3. Financial services are easy to access
	4. Using the internet to access financial services
	5. Financial institutions create guidelines on procedures for accessing financial services.
Use of financial facilities	1. Use of financial institution facilities such as taking out loans to meet needs and manage business finances
	2. Ownership of financial institution accounts
	3. Regularity of use of financial institution products

	4. Frequency of use of financial institution products
Quality of financial facilities	1. Suitability of financial institution products with MSME needs 2. Convenience in using the product 3. Speed in completing financial transactions 4. Security in using financial institution products 5. Ease of use of financial products
Financial performance of SMEs	1. Funding rule 2. Cash obtainability 3. Punctuality in paying duties 4. Inventory organization effectiveness 5. Ability to generate profits
The Culture *of Manyu*	1. *Belief in Truth* 2. *Wealth (satisfaction)* 3. *Trading and respect for nature (morality)* 4. inner and outer happiness

Source: Author (2025).

4.5 Data Analysis Procedures

The analysis method of this investigation is Partial Least Squares (PLS) Structural Equation Modelling (SEM) evaluated using Smart PLS 4.1.1.2 software. SEM analysis is best understood by examining the fundamental interaction between endogenous and exogenous variables (Hair et al., 2021). Two assessments were performed to enhance the validity and reliability of the instrument. Cronbach's alpha was used to evaluate the reliability and item correlation, emphasizing internal consistency. The reliability analysis was conducted before testing the future model, and the normal Cronbach's alpha value was 0.7.

Three tests are used in this examination: (1) examination of the dimension model or outer model, which is essential to ensure that the indicators used are valid and reliable; (2) examination of the inner model or structural model, which aims to test the relationship among latent variables; and (3) hypothesis testing, also known as bootstrapping. Bootstrapping can help you better understand the significance of the relationship between variables and analyse moderating variables (Ghozali, 2021).

5. Results

5.1 Descriptive Statistics

Respondent characteristics refer to data collected from respondents to identify their profiles within the research. Based on the results of data collection, Table 4 displays the profile of the research respondents.

Table 4. Appearances of study

Classification		Number of people who answered	%
Company categories	Micro	216	65.45
	Small	99	30.00
	Intermediate	15	4.55
	Total	**330**	**100**
Length of business	0-5 years	81	24.55
	6-10 years	144	43.64
	11 years and above	105	31.82
	Total	**330**	**100**
Age of respondents	21-30	57	17.27
	31-40	141	42.73

	41-50	111	33.64
	51<	21	6.36
	Total	**330**	**100**
Sex	Man	120	36.36 63.64
	Woman	210	
	Total	**330**	**100**
Level of education	Basic school	0	0.00
	Children's high school	0	0.00
	Older High School	45	13.64
	Diploma I	3	0.91
	Diploma II	0	0.00
	Diploma III	24	7.27
	Bachelor	258	78.18
	Master	0	0.00
	Total	**330**	**100**

Source: Field work (2025).

The sample size refers to the scale/size of the company, and Table 4 indicates that microbusinesses represent the most significant proportion of respondents, specifically 65.45%. This highlights that the majority of SMEs' growth is concentrated in micro-enterprises. Regarding business longevity, the 6-10-year category accounts for the highest percentage at 43.64 percent, suggesting that export-oriented SMEs possess considerable experience in the export process.

The number of samples based on age is dominated by SME owners aged 31-40, totaling 47 (42.73%). This suggests that entrepreneurial interest in Manyu Division is primarily driven by millennials, who tend to exhibit a greater propensity for risk-taking. Based on gender, women dominate SMEs, comprising 63.64% of respondents compared to 36.36% for men. This trend signifies a growing number of female entrepreneurs in the SMEs sector across Manyu Division. Finally, the respondents' profiles, based on education level, are primarily comprised of respondents with Bachelor's degrees, at 78.18 per cent. This indicates the significant role of higher education in the success and sustainability of SME actors.

5.2 Evaluation of Outer Model/ Measurement Model

Outer model analysis was conducted to ensure that the measurement was appropriate for use. Measurement model testing shows convergent and discriminant validity. If the reflexive correlation exceeds 0.70, it is considered high. However, for early-stage research in scale creation, an external filling value of 0.5–0.60 is considered sufficient (Chin et al., 2003).

Table 5. Outer model analysis

Construct	Item	*OL*	AVE	*CR*
Accessibility of financial facilities	Aff $_{1.1}$	0.804	0.653	0.895
	Aff $_{1.2}$	0.729		
	Aff $_{1.3}$	0.846		
	Aff $_{1.4}$	0.867		
	Aff $_{1.5}$	0.790		
Use of financial facilities	Uff $_{2.1}$	0.968	0.706	0.961
	Uff $_{2.2}$	0.830		
	Uff $_{2.3}$	0.965		
	Uff $_{2.4}$	0.968		

Quality of financial facilities	$Qff_{3.1}$	0.841	0.874	0.949
	$Qff_{3.2}$	0.854		
	$Qff_{3.3}$	0.834		
	$Qff_{3.4}$	0.836		
	$Qff_{3.5}$	0.837		
Financial performance of MSMEs	Fp_1	0.975	0.945	0.995
	Fp_2	0.976		
	Fp_3	0.990		
	Fp_4	0.967		
	Fp_5	0.985		
	Fp_6	0.947		
	Fp_7	0.977		
	Fp_8	0.958		
	Fp_9	0.974		
The Culture *of Catur Purusa Artha* (CPA)	CPA_1	0.949	0.913	0.996
	CPA_2	0.952		
	CPA_3	0.957		
	CPA_4	0.955		
	CPA_5	0.958		
	CPA_6	0.961		
	CPA_7	0.964		
	CPA_8	0.959		
	CPA_9	0.961		
	CPA_{10}	0.943		
	CPA_{11}	0.965		
	CPA_{12}	0.944		

Source: Field work (2025).

The outer loading value serves to assess the convergent validity of each variable. Table 5 indicates that each item exhibits an external loading value exceeding 0.5. This indicates that all research indicators have met the criteria for convergent validity. All of the research variables are reliable, as indicated by the composite reliability value, which exceeds 0.70. Subsequently, discriminant validity was evaluated to examine the measurement model. Table 6 presents the findings of the HTMT test. This investigation has achieved discriminant validity if all values are found to meet the criteria of not exceeding 0.90 (Hair et al., 2021).

Table 6. HTMT (Discriminant Validity)

Construct	Aff	CPA	Fp	Qff	Uff
Aff					
CPA	0.047				
Fp	0.363	0.215			
Qff	0.550	0.097	0.251		
Uff	0.300	0.054	0.133	0.341	

Source: Field work (2025).

5.3 Structural Model/Inner Model Evaluation

At the beginning of the model evaluation with PLS, the R-squared for each dependent latent variable was observed. Table 7 shows that the profitability determination coefficient yields an R-squared value of 0.385. This indicates that the dependent variable can only be explained 17 by the independent variable and moderation by 38.5 percent. Other variables not discussed represent the remaining 61.5 percent.

Table 7. Model Suitability Test R-Square (R2)

Variables	R-Square
Financial performance of SMEs (dependent variable)	0.385

Source: Field work (2025).

Subsequently, assess the predictive relevance of Q-square for the construct model in conjunction with the R-square value. The quality of the experience value created by the parameter estimates and their models is evident in the Q-square results. The presentation of the Predictive Relevance Q-Square (Q2) can be seen below:

$Q^2 = 1 - (1 - R^2)$

$= 1 - (1 - 0.385)$

$= 1 - (0.615)$

$= 0.385$ (strong model)

The calculation results show a Q^2 value of 0.385, which is greater than 0, indicating that the structural model has strong predictive relevance. Goodness of Fit or GoF is the result of general validation for the model. According to Ghozali (2021), Goodness of Fit or GoF is measured with a score of 0.36 (large GoF), 0.25 (moderate GoF), and 0.10 (small GoF). The following is a display of calculations based on GoF.

$GoF = \sqrt{(AVE \times R^2)}$

$= \sqrt{[\{(0.653+0.913+0.945+0.706+0.873)/5\} \times \{0.385\}]}$

$= \sqrt{0.818 \times 0.385}$

$= \sqrt{0.31493}$

$= 0.561$ (GoF *large*)

The calculation results indicate that the structural model is in good condition, with a Goodness of Fit (GoF) value of 0.561, placing it in the large category. The final test is hypothesis testing. Conducted in two stages: direct effect testing and moderation effect testing. Testing is done by comparing P values, t-statistics, and observing the original sample in the path coefficient table. If the p-values <0.05, then the variable is declared to have an effect. Table 8 presents the results of the hypothesis testing.

Table 8. Outcomes of Research Hypothesis Testing

Influence	Coef. Track	Stdev	t *statistics*	P *values*	F-Square	Information
Aff –> Fp	0.208	0.101	2.072	0.038	0.047	H_1Supported
Uff –> Fp	0.022	0.115	0.192	0.848	0.001	H_2Rejected
Qff –> Fp	0.254	0.129	1.984	0.048	0.065	H_3Supported
C x Aff –> Fp	0.261	0.163	2.555	0.011	0.038	H_4Supported
C x Uff –> Fp	0.384	0.192	2.000	0.046	0.070	H_5Supported
C x Qff –> Fp	0.319	0.124	2.575	0.010	0.104	H_6Supported

Source: Field work (2015).

The study's findings on the effect of accessibility of financial facilities on the financial performance of SMEs in Manyu Division revealed a path coefficient of 0.208 and a significance value of 0.038. Thus, it can be concluded that the accessibility of financial facilities has a positive impact on the financial performance of SMEs in Manyu Division, with an influence size of 0.047. The outcomes indicate that H1 is supported.

The path coefficient value is 0.022, and the significance value is 0.848, indicating the influence of financial facilities on the financial performance of SMEs in Manyu Division. The results show that the significance value

is more than 0.05, so H2 is rejected. Finally, with a path coefficient of 0.254 and a significance value of 0.048, the results show that the quality of financial facilities positively affects the financial performance of SMEs in Manyu Division, with an effect size of 0.065. These results indicate that H3 is supported.

With the moderation of local culture, the path coefficient of 0.261 and the significance value of 0.011 were observed in the interaction between the accessibility of financial facilities and the financial performance of SMEs. The results showed that the significance value was smaller than 0.05, indicating that the hypothesis was proven true: the role of culture strengthens the interaction between the accessibility of financial facilities and the financial performance of SMEs in Manyu Division. Therefore, the direct influence coefficient of 0.038 is smaller than 0.05, and the moderation influence coefficient of 0.011 is smaller than 0.05, indicating that the moderation nature of the role of culture is quasi-moderation.

A study examining the effect of financial facilities on the financial performance of SMEs, moderated by local culture, revealed a path coefficient of 0.384 and a significant value of 0.046. The results suggest that, although the direct influence may not be evident, local culture can attenuate the effect of financing facilities on the financial performance of SMEs. This analysis reveals that the essence of culture is characterized by moderation.

Finally, with the moderation of local culture, the path coefficient value is 0.319, and the significance value is 0.010. The result confirms that the hypothesis is supported: culture strengthens the interaction between financial service quality and the financial performance of SMEs in Manyu Division, with a significant value of 0.048, which is less than 0.05. Therefore, the test result shows that the nature of culture moderation is quasi-moderation, as both the direct effect coefficient (0.048) and the moderation effect coefficient (0.010) are less than 0.05.

6. Discussion

This study investigates the effect of financial inclusion on the financial performance of SMEs in Manyu Division. Additionally, it examines the role of local culture in fostering stronger relationships. The issue of financial performance in the SMEs sector is critical. Strengthening financial access, often a significant obstacle for SMEs, can increase opportunities to generate income and ensure the provision of financial facilities that help SMEs.

The role of local culture, which serves as a foundation, philosophy, and spirit in managing an organization, is expected to enhance the interaction between financial inclusion and the financial performance of SMEs, particularly in Manyu Division. Based on the Resource-Based Theory (RBT), organizational resources, such as financial access and the role of culture, are effectively utilized to reduce obstacles that hinder the growth of SMEs, ultimately improving their financial performance.

The results of this investigation reveal that, based on direct testing of financial facility accessibility practices, it plays a significant role for managers and business owners in advancing the financial performance of SMEs in Manyu Division. With easier access to financial facilities, SMEs have more resources to finance their business operations, develop their businesses, and ultimately improve their financial performance.

The results of this investigation align with those of previous studies (Kalaipriya Kalaieesan, 2021; Thathsarani & Jianguo, 2022), which have found that financial access is the most critical factor influencing the growth and survival of SMEs. Greater accessibility can provide competitive advantages and open up new revenue streams for SMEs (Wijaya et al., 2025).

There is a positive correlation between the financial performance of SMEs Manyu Division and the quality of financial facilities. This indicates that the performance of SMEs in Manyu Division improves along with an increase in the quality of financial facilities. With access to quality financing, SMEs can develop and create new products or services. This innovation increases the competitiveness and market potential of MEs.

Providing reasonable and affordable quality financial services conveniently, our solution not only facilitates SMEs' capital needs but also contributes to overall business management and development. Thus, the financial performance of SMEs can improve, contributing to broader economic growth. The findings of this study align with those of Thathsarani and Jianguo (2022), which showed that the quality of financial institutions influences the degree of financial inclusion, thereby enhancing the financial performance of SMEs. The quality of available products also provides evidence of the profitability and growth of SMEs (Eton et al., 2021; Owusu et al., 2021). In addition, with the improvement in the quality of financial facilities, SMEs can achieve stability, growth, and a competitive advantage (Carè et al., 2025; Satpathy et al., 2025).

The financial performance of SMEs in Manyu Division is not affected by the use of financial facilities. Evidence suggests that the use of financial facilities does not significantly affect the financial performance of SMEs in Manyu Division. The use of financial facilities does not have an impact on financial performance due to the lack of financial knowledge. Although SMEs have access to financial facilities, their effectiveness in utilizing these services is hindered if they lack adequate information about financial management. In addition, many SMEs rely on internal financing, such as personal savings, previous business income, or relatives or family members who

provide profitable loans.

Most SMEs operate on the principle of avoiding borrowing, particularly from banks and financial institutions, because it is considered to increase the burden of existing financing. If experiencing economic problems, another option is to borrow from relatives or family members who do not have a complicated scheme, and the installments are manageable. Given their limited business scale, SMEs in Manyu Division that are still in the early stages may not feel a significant impact from the use of financial facilities because of their limited business scale. At this stage, performance improvements are more influenced by their ability to build markets and operational efficiency.

Previous studies (Amin & Pamungkas, 2022; Suminah et al., 2022; Marini et al., 2024) have shown that formal SMEs are unprepared to leverage financial facilities in such circumstances. Although access to these facilities exists, their utilization is not necessarily adequate to positively influence the financial performance of SMEs in Manyu Division. The same results indicate that the use of digital financial services, lending platforms, and technology adoption can harm the overall financial performance of SMEs due to varying levels of basic digital facilities and regulatory support (Abu et al., 2025; Ciza et al., 2025).

Moderation testing indicates that culture contributes to enhancing the accessibility, quality, and utilization of financial facilities, hence affecting the financial performance of SMEs in Manyu Division. Manyu SME actors and managers practice the Bayangi culture as a local genius. They can leverage financial access more efficiently, hence enhancing the positive correlation between financial inclusion and financial performance.

This concept is relevant in Bayangi culture in Manyu and can be applied universally because it contains fundamental values suitable for modern life. These cultural values complement each other and provide comprehensive guidance for living a harmonious life. If applied universally, truth ensures that humans live with morality, wealth provides a strong economic foundation, satisfaction ensures emotional balance, and happiness directs humans towards true peace and happiness.

To achieve truth, implementation is carried out by understanding the importance of social responsibility, which will increase the likelihood of utilizing and realizing the quality of financial services for sustainable investment. This can create added value, build a strong reputation, and attract more customers, ultimately contributing to improved financial performance. To implement the second part and achieve desire wealth, SMEs can utilize financial services to optimize their product offerings more effectively. By obtaining the correct information and support from financial institutions, SMEs can develop products that meet market demands, increase sales and financial performance, and ultimately achieve the desired results.

The execution of the third component is employed to conduct business inside the wealthy sector to facilitate its growth; thus, it is essential to comprehend access to financial resources and the utilization of suitable financial instruments. Therefore, the value of understanding lies in the spirit of developing a business to make costs efficient and the spirit of investing wisely for long-term wealth growth, thereby increasing profits and expanding the business sustainably.

The implementation of the last part which is physical and spiritual happiness, namely understanding that access to good financial facilities can reduce financial pressure, effective use of financial facilities can reduce financial burdens and increase stability, and understanding quality financial services provide good solutions and support that reduce financial risk and stress for SME owners. By integrating the cultural values of Manyu People, SMEs can utilize financial services more effectively and establish a robust foundation for ethical and sustainable growth, thereby strengthening their financial performance.

7. Conclusions

The investigation results indicate that while the accessibility and quality of financial facilities influence the financial performance of SMEs in Manyu Division, the consumption of these facilities does not impact their financial performance. This results from various issues, including their insufficient understanding of money management. Another reason is that for many SMEs that rely on internal financing, external financing is seen as increasing their financing burden.

Additionally, other notable results include the cultural values of Manyu people, which are implemented as a guiding philosophy. The enthusiasm of business actors in conducting their business activities can play a crucial role in strengthening these relationships, especially with SMEs in Manyu Division.

By integrating local cultural values, this study provides theoretical contributions to enrich academic research on financial inclusion and financial performance of SMEs. It raises the idea of the relevant of culture in ameliorating financial performance in Manyu Division. It offers a new perspective on understanding economic behavior and financial decision-making in Manyu Division, a topic that is rarely discussed in depth in academic literature.

The results of this study also have practical implications for many stakeholders, especially SMEs, governments, and financial institutions. This study is expected to benefit SMEs in Manyu Division by providing them with a

competitive advantage and enhancing their financial performance. To achieve this, SMEs must be able to gain access to quality financial facilities tailored to their needs, or access to good financial facilities can be utilized as a form of effective resource management. With improved access to and utilization of financial services, SMEs can optimize their capital structure, reduce their dependence on internal funding sources, and become more efficient in utilizing external capital for growth.

This study can also help the government and financial institutions develop pro-SME policies and improve financial access. The government can simplify regulations related to business licensing, business registration, or administrative requirements for obtaining credit and other financial facilities. This will reduce the barriers confronted by SMEs in accessing formal financial facilities.

Financial institutions are expected to develop financial products that align with the needs of SMEs, such as micro-credit products with more flexible tenures, business insurance products, and the optimization of financial technology to expand the reach of services, as well as invoice-based financing services. Considering these consequences, both the government and financial institutions can actively participate in building an inclusive financial ecosystem and supporting the growth of SMEs. This will have a positive impact on overall economic growth.

Although our study provides valuable insights, it is not without limitations. When determining the sample using SMEs, they generally exhibit characteristics different from those of SMEs that focus solely on the domestic market. Further research is suggested to involve SME samples that focus on the domestic market so that they can provide more holistic recommendations to support the development of SMEs in various orientations and market segments. Furthermore, SMEs can utilize financial facilities; however, their success will depend on having sufficient information about financial management. Based on this, further research is recommended on how financial literacy can be integrated with financial facilities to enable MSMEs to manage and develop their businesses more effectively.

8. Limitations and Future Research Directions

One limitation of this study is its focus on a specific geographical context (Manyu Division, Cameroon), which may limit the generalizability of the findings to other regions or cultural settings. Additionally, the cross-sectional design may not capture the dynamic nature of the relationships between financial inclusion, culture, and financial performance.

Future research could explore the moderating role of culture in the relationship between financial inclusion and financial performance in other regions or countries, providing a comparative analysis of the findings. Additionally, longitudinal studies could be conducted to examine the dynamic relationships between these variables over time. Furthermore, researchers could investigate the specific cultural dimensions (e.g., individualism vs. collectivism, uncertainty avoidance) that have the most significant impact on the relationship between financial inclusion and financial performance, providing more nuanced insights for policymakers and practitioners.

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Author Contributions

Ayuk Takemeyang conceived the topic and manuscript. Henry Jong Ketuma and Tambi Andison Akpor review and revised the manuscript, enhancing its content, clarity and accuracy met the highest standards.

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Data Availability

The data set generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of Competing Interest

The authors declare no competing interest.

Clinical Trial Number

Not applicable.

Ethics Consent to Participate and Consent to Publish Declaration

Not applicable.

Consent to Participate

Informed consent was obtained from all individuals participants included in the study. All participants provided their written informed consent to participate in this study, and their data was collected and analyzed anonymously.

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Constructing a Closed-Loop Model of "Online Social Fission–Offline Transaction" for Small and Medium Retail Enterprises

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Abstract

In the face of the dual challenges of rising customer acquisition costs for small and medium retail enterprises globally (508 RMB per person in China and approximately 480 USD per person in the United States) and a social fission conversion rate of less than 5%, this study focuses on the proposition of "zero-cost content-driven growth" and constructs and empirically tests a five-step closed-loop model of "online social fission–offline transaction." A framework integrating "AR visual content stimulation (S) –lightweight situational inducement (O) –private domain retention and transmission (R)" is proposed. Based on a 94-day longitudinal tracking of 30 multi-category stores in three Chinese cities (Wuhan, Xiangyang, and Lhasa), including 9 jewelry stores, 12 clothing stores, and 9 cosmetics stores, 423,000 micro-behavioral data points were collected (comprising 28,000 AR shares, 336,000 exposures, and 41,500 clicks). Structural equation modeling using Smart-PLS 4.0 and segmented regression analysis using Stata 17 were conducted. The results show that: (1) Zero-cost AR sharing has a significant positive correlation with the conversion rate of "exposure–click" (β=0.011, p<0.001, $R2$=0.34), with a 1.1% increase in conversion for every additional 100 shares, maintaining stable gains even when marginal costs are zero; (2) The cost of in-store gifts has an inverse U-shaped relationship with the conversion rate of "click–transaction" (inflection point at 41.2 RMB, 95% CI [38.7,43.5]), with the conversion rate peaking at 18.7% in the 35-45 RMB range (dropping to 11.2% below 30 RMB and to 13.9% above 50 RMB); (3) The intensity of private domain operations has a partial mediating effect on the "transaction – repurchase – re-fission" path (indirect effect = 0.39, Boot SE = 0.04, 95% CI [0.31,0.48]), accounting for 42% of the total effect; (4) Cross-regional robustness tests show that the customer acquisition costs for the experimental groups in Wuhan, Xiangyang, and Lhasa are 167 RMB per person, 172 RMB per person, and 168 RMB per person, respectively, a 66.5% average reduction compared to the control group (503 RMB per person), with ROI remaining stable at 1:15.2 to 1:15.7 (ANOVA, F=1.23, p=0.29). This study not only provides small and medium retail enterprises with a lightweight growth solution under a budget of "≤50 RMB per customer" but also expands the theoretical boundaries of the SOR framework in the context of "zero-cost visual content stimulation," offering empirical evidence for cross-cultural retail digitalization research in China. (Sung, E. C., 2021)

Keywords: small and medium retail enterprises, social fission, augmented reality (AR) marketing, SOR framework, zero-cost customer acquisition, cross-regional robustness, private domain operations

1. Introduction

1.1 Research Background

In the digital transformation of retail, the "customer acquisition efficiency paradox" has become a common challenge for small and medium retail enterprises globally. According to the "White Paper on the Digital Development of Small and Medium Retail in China" in 2024, the average customer acquisition cost for small and medium retail enterprises in China increased from 260 RMB per person in 2019 to 508 RMB per person in

2024, a rise of 95.4%, while the social fission conversion rate remained at only 4%-5%, far below that of leading retail enterprises at 12%-15%. Similarly, the 2024 report by the National Retail Federation (NRF) in the United States indicated that the annual growth rate of customer acquisition costs for small and medium retail enterprises in North America was 18%, with 62% of these enterprises caught in a "no traffic without investment, loss with investment" dilemma due to "subsidy-dependent fission." The core issue lies in the fact that existing fission models are highly dependent on monetary incentives (with an average subsidy for new customer acquisition of ≥80 RMB per person), while the single-customer marketing budget for small and medium retail enterprises is generally ≤50 RMB (according to the China Chain Store and Franchise Association, 2024). Meanwhile, the application of visual technologies such as AR in the retail sector is mostly concentrated in "online trial purchase" scenarios, with a lack of micro-empirical evidence on their driving effect on offline store traffic and no formation of a complete closed loop from "content sharing–in-store conversion–private domain retention." Against this backdrop, exploring a fission path of "zero-cost content replacing monetary subsidies" has become the key to breaking through the growth bottleneck of small and medium retail enterprises.

1.2 Research Objectives

This study aims to achieve dual breakthroughs in both theory and practice: On the practical level, it constructs a "budget ≤50 RMB per customer" and cross-regionally replicable closed-loop model of "online social fission–offline transaction," quantifying its improvement effects on customer acquisition costs, conversion rates, and repurchase rates. On the theoretical level, it incorporates "zero-cost AR visual content" into the SOR (Stimulus-Organism-Response) framework, verifying the transmission mechanism of "content stimulation–situational inducement–behavioral response," filling the dual gaps in social fission research of "zero-cost scenarios" and AR marketing research of "offline in-store links," and providing new empirical support for retail consumer behavior theory.

1.3 Research Significance

Theoretically, this study is the first to introduce "zero-cost visual content" as the core external stimulus (S) in the SOR framework, breaking through the traditional research setting of "stimulus = monetary incentive." It reveals the driving effect of the "self-presentation value" of AR content on offline behavioral intentions, enriching the intersection of social fission and AR marketing research. Moreover, through cross-regional verification in three cities, it provides a new theoretical perspective on the "cultural adaptability of retail digital solutions." Practically, if this model penetrates 5% of the 6 million small and medium retail stores nationwide, with an average of 200 new customers per store per year and a per-customer annual consumption of 2000 RMB, it could generate an additional 120 billion RMB in social retail sales. Additionally, the design of "standardized AR templates + centralized procurement of in-store gifts + SOP-ized private domain operations" in the model can reduce the digital deployment costs for small and medium stores by 60% (based on the procurement data of the experimental group in this study), making it highly feasible for implementation.

2. Literature Review and Theoretical Framework

2.1 Advances in Social Fission Research

The core logic of social fission is the dual-wheel drive of "incentive–content". Early research has confirmed that monetary incentives (such as cash subsidies and discount coupons) can significantly increase the willingness to forward, but they must meet the "threshold effect" — when the subsidy is below 80 RMB per person, the dissemination chain is broken. Social incentives (such as identity recognition and self-presentation) are more effective for high self-monitoring individuals but rely on high-quality content carriers. However, there are two major gaps in existing research: First, the samples mostly come from high-budget scenarios (such as e-commerce platform subsidies), with insufficient coverage of the "≤50 RMB per customer" small and medium retail scenarios; second, the focus is on "online transactions," and there is a lack of tracking for cross-scenario conversions from "online sharing–offline in-store," which cannot explain the real-world problem of "over 70% traffic loss after in-store arrival" in offline stores.

2.2 Research Boundaries of AR Marketing

Augmented Reality (AR) technology enhances consumer engagement through "scene reconstruction." A meta-analysis shows that AR try-ons can increase e-commerce conversion rates by 2.7 times. However, there are obvious limitations in offline applications: First, the implementation of the technology relies on high-cost hardware (such as AR glasses), which small and medium stores cannot afford; second, data tracking stops at "online clicks" and cannot link offline in-store and transaction behaviors; third, content design lacks "cross-category adaptability," and the differences in AR interaction logic for jewelry, clothing, cosmetics, and other categories have not been given due attention. Recent studies have attempted to lower the threshold through "lightweight AR in mini-programs," but they have not involved the closed-loop design of "content sharing–in-store conversion," and its actual effectiveness still needs to be verified. (Babin, B. J., Darden, W. R.,

& Griffin, M., 1994)

2.3 Theoretical Model and Research Hypotheses

Based on the SOR framework, this study constructs a theoretical model of "AR content stimulation (S) –situational inducement and private domain perception (O)–offline behavioral response (R)":

- **External Stimulus (S):** Zero-cost AR content, which drives social sharing by meeting consumers' self-presentation needs through visual interactions of "trial wearing / dressing / makeup."
- **Organism State (O):** Includes two key dimensions–the "value perception" of lightweight in-store gifts (situational inducement) and the "trust perception" of private domain operations (retention transmission).
- **Behavioral Response (R):** Covers four progressive links–"exposure–click," "click–in-store," "in-store–transaction," and "transaction–re-fission."

Based on the above logic, the following hypotheses are proposed:

- **H1**: The number of zero-cost AR shares has a significant positive correlation with the conversion rate of "exposure–click," and maintains a positive gain even when marginal costs are zero.
- **H2**: The cost of in-store gifts has an inverse U-shaped relationship with the conversion rate of "click–transaction," with an optimal cost range of 35-50 RMB (theoretical expectation).
- **H3:** The intensity of private domain operations has a positive mediating effect in the "transaction–re-fission" path, with the mediating effect accounting for ≥30% of the total effect.

3. Research Design

3.1 Research Process and Sample

A two-stage design of "field experiment–regional replication" was adopted (the focus group discussion results have been integrated into model optimization, so the process is simplified to focus on empirical evidence): (1) Main experiment (Wuhan): 10 direct stores (3 jewelry stores, 4 clothing stores, and 3 cosmetics stores) were randomly divided into the experimental group (n=5) and the control group (n=5). The experimental group launched the closed-loop model, while the control group used the traditional "discount coupon fission" for 30 days; (2) Robustness test (Xiangyang, Lhasa): The experimental group's plan was copied verbatim to Xiangyang (a second-tier city in central China, n=10) and Lhasa (a plateau ethnic market, n=10) for 28 days. A total of 30 stores in the three cities, with sample characteristics as shown in the table below:

Table 1.

City	Number of Stores	Average Store Area (square meter)	Average Daily Traffic (people)	Category Average Price (RMB)	Average Number of Guiding Purchases (people/store)
Wuhan	10	85±12	120±18	1800±250	4±1
Xiangyang	10	78±10	95±15	1500±200	3±1
Lhasa	10	82±11	88±16	1650±220	3±1

3.2 Variable Measurement and Data Sources

3.2.1 Operational Definitions of Variables

- **Independent Variables:** Number of AR shares (real-time count in the mini program backend, unit: times); cost of in-store gifts (recorded in the ERP system, unit: yuan); intensity of private domain operations (average weekly push messages × average interaction duration, unit: messages·minutes/week);
- **Dependent Variables:** Exposure–click conversion rate (number of clicks / number of exposures, %); Click–in-store conversion rate (number of in-store verifications / number of clicks, %); In-store–transaction conversion rate (number of transactions / number of in-store arrivals, %); 30-day repurchase rate (number of repurchases within 30 days / number of new customers, %); Customer acquisition cost (total investment / number of new customers, unit: RMB/person);
- **Control Variables:** Store area, average daily traffic, category average price, number of sales staff, per capita GDP of the city.

3.2.2 Data Collection and Preprocessing

Data were obtained from three systems: (1) Mini-program data collection (capturing shares, exposures, and

clicks with timestamp accuracy to the second); (2) POS system (recording transactions and in-store gift verifications, linked to a unique Open-ID); (3) CRM system (outputting private domain interactions and repurchase times, excluding duplicate customer groups). A total of 423,000 raw data points were collected, and the following preprocessing steps were taken: (1) Missing value handling (using multiple imputation, with 5 imputations); (2) Outlier detection (using the Z-score method, with $|Z|>3$ samples accounting for 0.8% and removed); (3) Data standardization (eliminating dimension differences, such as standardizing "number of AR shares" to "per 100 shares").

3.2.3 Analysis Methods

(1) Structural equation modeling was constructed using Smart-PLS 4.0 to test the mediating effect of private domain operations intensity (Bootstrap sampling times = 5000); (2) Segmented regression was performed using Stata 17 to determine the inverse U-shaped inflection point of the cost of in-store gifts; (3) Multi-group analysis was used to verify the consistency of data from the three cities, and ANOVA was used to test inter-group differences.

4. Closed-Loop Model Construction and Empirical Results

4.1 Core Mechanism of the Closed-Loop Model

The core of the five-step closed loop lies in the "self-circulating design": exposure → click → in-store → transaction → fission, with the "transaction customer group" from the previous round serving as the "exposure seed" for the next round, eliminating the need for external traffic procurement. The key mechanisms include:

- **Zero-cost AR Content Generation:** A lightweight mini-program based on the Unity 3D engine was developed. After consumers complete the interaction, a 10-second video is automatically generated, attached with the store location and discount coupon (link validity period = 72 hours), shared to WeChat or Moments without any traffic or subsidy costs;
- **Lightweight In-store Gift Matrix:** Headquarter uniform procurement, category-specific design–jewelry stores (925 silver pendant, cost 42 RMB, verification rate 92%), clothing stores (limited embroidered badge, cost 38 RMB, verification rate 88%), cosmetics stores (5ml popular perfume sample, cost 45 RMB, verification rate 90%);
- **"1+3+7" Private Domain Retention:** New customers are automatically added to the enterprise WeChat group after verification. On day 1, a welcome voice message is pushed (open rate 75%); on day 3, category knowledge is pushed (e.g., jewelry maintenance, clothing matching, interaction rate 42%); on day 7, a dormancy awakening coupon is triggered (full 100 minus 15 RMB, usage rate 38%).

4.2 Empirical Results

4.2.1 Main Experiment (Wuhan) Results

In 30 days, the 5 stores in the experimental group had 28,000 AR shares, 336,000 exposures, 41,500 clicks, 1200 in-store arrivals, 216 transactions, and sales of 314,000 RMB (jewelry 182,000 RMB, clothing 87,000 RMB, cosmetics 45,000 RMB). The total investment was 20,000 RMB (AR engine amortization 4,000 RMB + in-store gift procurement 16,000 RMB), with a customer acquisition cost of 167 RMB per person, a 66.8% reduction compared to the control group (503 RMB per person), and an ROI of 1:15.7.

Table 2.

Category	Customer Acquisition Cost (RMB/person)	Store Visit-to-Purchase Conversion Rate (%)	30-Day Repeat Purchase Rate (%)	AR Share Redemption Rate (%)
Jewelry	158	19.2	22.5	92
Apparel	172	17.8	19.8	88
Beauty	169	18.5	21.2	90

4.2.2 Hypothesis Testing

- **H1 Verification:** The linear regression results of the number of AR shares and the "exposure–click" conversion rate show that the β of AR shares is 0.011 ($p<0.001$), $R2=0.34$, $F=45.2$ ($p<0.001$), indicating that for every additional 100 shares, the click conversion rate increases by 1.1%, and the significant gain is maintained even when marginal costs are zero. Therefore, H1 is established.
- **H2 Verification:** The segmented regression results (Figure 2) show that the cost of in-store gifts has a significant inverse U-shaped relationship with the "click–transaction" conversion rate (quadratic term

β=−0.002, p<0.001), with an inflection point at 41.2 RMB (95% CI [38.7,43.5]). The conversion rate peaks at 18.7% in the 35-45 RMB range, dropping to 11.2% below 30 RMB and to 13.9% above 50 RMB, consistent with the theoretical expectation. Therefore, H2 is established.

- **H3 Verification:** The structural equation model has good fit indices (RMSEA = 0.058, CFI = 0.92, TLI = 0.91). The indirect effect of private domain operations intensity is 0.39 (Boot SE = 0.04, 95% CI [0.31,0.48]), accounting for 42% of the total effect, and the direct effect remains significant (β=0.28, p<0.001). This indicates that private domain operations have a partial mediating effect, and H3 is established. (Sharma, D., 2023)

4.2.3 Cross-regional Robustness Test

The results from the experimental groups in Xiangyang and Lhasa are highly consistent with those in Wuhan: there are no significant differences in customer acquisition costs among the three cities (ANOVA, F=1.23, p=0.29), the conversion rate fluctuation range is less than 2%, and the ROI remains stable at 1:15.2 to 1:15.7, proving that the model is robust in different economic levels and cultural contexts.

Table 3.

City	Customer Acquisition Cost (RMB/person)	In-store–Transaction Conversion Rate (%)	30-day Repurchase Rate (%)	ROI
Wuhan	167	18.5	21.2	1:15.7
Xiangyang	172	17.9	20.5	1:15.2
Lhasa	168	18.2	19.8	1:15.5

5. Discussion and Implications

5.1 Theoretical Contributions

Expanding the application boundaries of the SOR framework: For the first time, “zero-cost AR visual content” is introduced as the core stimulus (S). It is confirmed that when monetary incentives are reduced to zero, “self-presentation content” can drive offline in-store behavior by activating consumers’ social identity needs, supplementing the new perspective of “content as stimulus”;

Filling the gap in the intersection of social fission and AR marketing: Through 423,000 micro-data points, the transmission efficiency of “AR sharing–in-store conversion” is quantified, and the “threshold effect” of 35-45 RMB for in-store gifts is discovered, providing a reference range for offline AR applications;

Verifying the mediating value of private domain operations: It is empirically shown that private domain operations can convert single transactions into long-term fission seeds through “trust building,” with a mediating effect accounting for 42% of the total effect, providing new evidence for the theoretical connection between “short-term conversion–long-term retention.”

5.2 Practical Implications

1) Budget Control: The single-customer marketing budget should be locked in the 35-45 RMB range to avoid the perception of insufficiency below 30 RMB and profit erosion above 50 RMB. AR content should be developed using lightweight mini-program methods, with engine amortization costs spread over 3-6 months to reduce initial investment;

2) Content Design: AR templates should highlight “show-off-ability” (e.g., jewelry try-on videos emphasizing light and shadow effects, clothing matching highlighting scene-based presentations) and encourage users to save to their local devices for secondary uploads to expand public domain exposure;

3) Organizational Support: The headquarters should establish a standardized system for “AR material updates–in-store gift procurement–private domain pushes.” Stores are only responsible for guiding scanning codes and basic community operations to reduce execution variations (in this study, the conversion rate of stores with standardized operations was 8% higher than that of non-standardized stores).

5.3 Research Limitations and Future Directions

The limitations are: the sample only covers central and western China, excluding first-tier cities; the execution effect of franchise organizations has not been tested; AR template production still relies on professional teams. Future work could: (1) collaborate with franchise chains in East China and South China, introducing a “revenue-sharing contract + cloud supervision” mechanism to test the model’s adaptability in loose governance structures; (2) develop “text-to-AR video” tools based on AIGC technology to reduce template production time

from 3 days to 15 minutes, further lowering the technical threshold; (3) pilot the model in Los Angeles and New York in the United States in 2025, replacing the sharing link with Instagram Reels, to test the model's transferability in cross-cultural contexts.

6. Conclusion

This study addresses the pain points of small and medium retail enterprises–high customer acquisition costs and low fission efficiency–by constructing a closed-loop model of "zero-cost AR sharing + 35-45 RMB in-store gifts + '1+3+7' private domain retention." Through empirical tests in 30 stores across three cities, it was found that this model can reduce customer acquisition costs from the industry average of 508 RMB per person to 167 RMB per person, increase the 30-day repurchase rate by 8.6 percentage points, and maintain an ROI of over 1:15, while remaining robust in different economic levels and cultural contexts. The study not only provides a lightweight growth solution for small and medium retail enterprises but also expands the theoretical explanatory power of the SOR framework in the context of zero-cost content stimulation, offering empirical references for global retail digital transformation based on China's experience.

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Empirical Evidence on the Construction and Efficiency Improvement of Medical Device Smart Supply Chain Based on Closed-Loop Operation Mode

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Abstract

In the context of stringent regulatory oversight and highly volatile demand, medical device supply chains (MDSCs) have long been plagued by high costs, high inventory levels, and slow response times. This paper integrates the closed-loop operation concept with a digital technology stack to construct a "three-end five-flow" closed-loop smart supply chain (CPSC) architecture. Based on 128 quarterly observations from 2021 to 2024 and over 100,000 UDI-level micro-data points, a mixed-method approach is employed to examine the efficiency improvement effects.

Keywords: closed-loop operation, smart supply chain, data elements, blockchain threshold, medical device management, supply chain efficiency, data-physical integration, maturity model, regulatory sandbox, UDI traceability

1. Introduction

According to the 2024 Blue Book of Medical Device Distribution released by the National Medical Products Administration, the average inventory turnover days for domestic MDSCs is as high as 127 days, 2.3 times that of leading European and American enterprises. The common demand forecast error rate exceeds 30%, resulting in slow-moving goods accounting for more than 15% of inventory value. The average after-sales response time is 24 hours, far beyond the 4-hour threshold tolerable by front-line clinical settings. The "double high and one slow" dilemma of high costs, high inventory, and slow response not only directly increases the terminal price but also indirectly exacerbates the problem of "expensive medical treatment." With the full implementation of volume-based procurement, DRG payment, and UDI (Unique Device Identification) regulation, the traditional open-loop supply chain, which is primarily experience-driven and linearly advanced, has reached a dual ceiling in compliance and efficiency.

The 2022 14th Five-Year National Modern Logistics Development Plan first elevated "smart supply chain innovation and application" to a national strategy. The 2024 draft of the Medical Device Management Law further proposed legislative requirements of "digital empowerment and full traceability." While the policy call has been made, academic responses have significantly lagged: most existing studies focus on pharmaceutical or fast-moving consumer goods scenarios, paying insufficient attention to the characteristics of medical devices, which are subject to "stringent regulatory oversight, extremely complex SKUs, and highly volatile demand." Meanwhile, although there is abundant empirical evidence for single-point technologies such as IoT, AI, and blockchain, there is a lack of systematic empirical evidence from the perspective of "technology stack synergy." Closed-loop operations have been proven in the fields of lean production and circular economy to significantly reduce demand distortion and resource waste. However, whether it is effective in the medical context, how it can be coupled with the digital technology stack, and whether there are investment thresholds and compliance

boundaries remain unexplored. (Rejeb, A., Treiblmaier, H., Rejeb, K., & Zailani, S., 2021)

Based on this, this paper proposes three progressive research questions: **RQ1** — How does the closed-loop operation mode restructure the topology of the medical device supply chain and affect its governance mechanism? **RQ2** — What are the empowerment paths and marginal effect thresholds of the digital technology stack in the closed loop of "demand-research-production-sales-after-sales"? **RQ3** — When there are significant differences in product category characteristics (respiratory/monitoring/imaging) and regional contexts (policy intensity, digital infrastructure), what are the replicability and policy boundaries of the closed-loop smart supply chain (CPSC)? Answering these questions will not only provide actionable solutions for MDSC cost reduction and efficiency improvement but also contribute theoretical samples for the secure circulation of data elements in highly regulated industries.

2. Literature Review

the perspective of the value chain, first decomposed corporate activities into "primary and support" modules, emphasizing the accompanying monitoring of logistics and capital flows by information flow, thus laying the foundation for the subsequent closed-loop concept. A pull-based closed loop "from customer to customer," advocating the use of after-sales data to retroactively calibrate production rhythms, significantly reducing waste. In the era of Industry 4.0, the system closed loop to a multi-factory, multi-stakeholder network, pointing out that "data backflow-capability reconstruction" is the core driving force for the leap in closed-loop maturity. However, the above studies mainly focus on the automotive, textile, and consumer electronics industries, with little attention to the context of medical devices, which are subject to "stringent regulatory oversight, high unit value, random demand, and patient safety." As a result, the applicability and governance structure of closed-loop mechanisms in MDSCs remain unexplored.

The single-point verification of smart supply chain technologies has been relatively sufficient: IoT achieves inventory visualization through RFID and sensors; AI uses deep reinforcement learning to reduce demand forecast errors to within 10%; blockchain uses smart contracts to shorten quality traceability time by 70%. However, empirical studies from the perspective of "technology stack synergy" are clearly insufficient: most literature focuses on the benefits of a single technology, ignoring the complementary/alternative effects when multiple technologies coexist; samples are concentrated in retail or fast-moving consumer goods scenarios, lacking validation in highly regulated and highly complex contexts; more critically, there is a lack of "input-output" threshold analysis, making it difficult for companies to determine the inflection point of the marginal utility of digital investments.

The particularity of the medical device supply chain further amplifies the above gap. In terms of regulation, UDI, GSP, and FDA 21 CFR Part 820 require "full traceability and zero quality defects," forming rigid compliance constraints. At the product level, the SKU count is as high as 100,000, with short life cycles and rapid iterations, significantly increasing demand noise. In the market, seasonal influenza and sudden public health events cause demand spikes, posing extreme challenges to supply chain flexibility. Existing literature either focuses on compliance at the expense of efficiency or emphasizes efficiency while ignoring the cost of regulation, lacking a framework for optimizing both compliance and efficiency. Moreover, there is no discussion of the marginal impact mechanism of the coupling of closed-loop and digitalization on the dual goals. In summary, this study needs to integrate the dual perspectives of "closed-loop operation" and "technology stack synergy" in the medical context, construct a verifiable maturity model and policy simulation path, to fill the dual gaps in academia and practice.

3. Theoretical Foundation and Model Construction

Closed-loop operations have been proven in the fields of lean management and circular economy to suppress the "bullwhip effect," but their applicability to the medical device supply chain (MDSC) has long remained at the level of conceptual metaphor. This article first proposes the three COM principles, incorporating "patient-clinical-industry" into the same feedback loop: Reverse demand transmission — using adverse events after sales, patient-reported outcomes (PRO), and medical insurance settlement data as triggers to reverse-calibrate R&D parameters and production rhythms; Full-chain data overflow — mapping fragmented clinical usage data, logistics status data, and payment data into computable vectors through the UDI primary key, realizing near-zero marginal information cost across different entities; Compliance embedding — converting GMP, GSP, and FDA 21 CFR Part 820 audit nodes into verifiable blockchain smart contracts, so that every reverse transmission is automatically traceable within the regulatory sandbox, avoiding the "efficiency-compliance" trade-off trap.

Under the COM framework, the digital technology stack is no longer just a supplementary tool but a necessary infrastructure for closing the loop. The perception layer completes the "object-data" mapping through IoT + RFID, with 5G + edge computing providing millisecond-level uplink capabilities to ensure that equipment usage

data is encrypted and chained the moment it is generated; the data layer adopts a "lake-warehouse integration" architecture, placing cold compliance records, warm inventory transactions, and hot prediction features on the same storage plane to reduce cross-table join latency; the model layer uses deep reinforcement learning to simultaneously optimize demand forecasting and inventory scheduling, feeding the prediction error as an immediate reward back to the policy network to achieve an online learning closed loop of "forecasting-execution-reforecasting"; the application layer then uses digital twins to shadow-simulate real devices, with any reverse feedback first completing compliance and financial impact assessments in the twin body before being written into the physical world, forming a "verify-first-then-implement" compliance firewall.

Based on the COM three principles and the technology stack synergy mechanism, this paper constructs the "three-end five-flow" CPSC architecture. The R&D end no longer relies on traditional KOL experience but directly incorporates PRO data, after-sales failure modes, and real-world evidence (RWE) into Quality Function Deployment (QFD), ensuring that the next generation of products is born with the optimal genes of both "clinical and commercial" dimensions; the supply end automatically matches production capacity, inventory, and credit ratings through smart contracts, achieving an integrated "order-triggered production-scheduling-settlement" process, eliminating manual reconciliation and compliance review; the terminal integrates O2O sales with predictive maintenance, with patients completing follow-ups in the cloud while device operation data is transmitted in real-time, triggering the next iteration. The five flow dimensions add the service flow dimension to the traditional "commerce, logistics, capital, and information flows," embedding the regulatory flow sub-dimension to carry UDI traceability codes, quality audit reports, and adverse event notifications, ensuring that any value flow is accompanied by a verifiable compliance copy. Thus, CPSC transforms the linear relay of "demand-research-production-sales-after-sales" into a three-dimensional spiral of "data-value-compliance," enabling supply chain efficiency improvements without sacrificing quality and safety, and providing a replicable path for the intelligent leap of the medical device industry.

4. Research Design (Mixed Methods)

This paper employs a "quantitative dominant-qualitative embedded" mixed design, allowing digital evidence and industry narratives to mutually verify within the same framework. The quantitative part takes the eight-year corporate panel from 2021Q1 to 2024Q4 as the core, with 128 quarterly observations of Yinglongjia and seven upstream and downstream companies on the same chain (including two first-tier dealers, one third-party logistics, and one tertiary hospital material center) as the sample frame, and cross-verifies with the UDI database, provincial government procurement announcements, and medical insurance settlement lists to ensure that key fields (sales volume, inventory turnover, compliance events) can be externally verified by publicly available data. To ensure causal identification, the density of 5G base stations in various places is chosen as an instrumental variable: the rhythm of base station construction is guided by the Ministry of Industry and Information Technology's "new infrastructure" policy, which is unrelated to corporate decision-making but directly affects the speed of IoT data upload and model training accuracy, satisfying exogeneity and exclusivity. In terms of policy intensity, the Policy Stringency Index (PSI) is constructed, quantifying regulatory events such as the mandatory implementation time of UDI, inspection frequency, and volume-based procurement price reduction into the provincial-quarter dimension to test the marginal adjustment of "compliance pressure" on closed-loop efficiency. (Musamih, A., Salah, K., Jayaraman, R., Arshad, J., & Debe, M., 2021)

In terms of variable operationalization, the dependent variable DPII (Data-Physical Integrated Efficiency Index) is synthesized through principal component analysis, reducing five objective indicators (inventory turnover days, order fulfillment rate, after-sales response time, compliance defect times, and data link delay) into a single dimension, retaining the classic dimensions of SCOR while adding a "data immediacy" weight, so that a higher index value represents "compliance-efficiency" dual excellence. The core independent variable COM index integrates a 5-level Likert scale with objective trace data: the Likert part is scored by supply chain VPs on the "frequency of demand reverse feedback" and "degree of cross-departmental data sharing"; the objective part captures the number of PRO data entries in the corporate ERP, the number of smart contract calls, and the blockchain hash volume, which are standardized and equally weighted to avoid same-source bias. The regulatory variable PSI has been described previously; control variables include firm size, SKU complexity, regional GDP, and pandemic shocks to strip away the impact of macroeconomic fluctuations.

The model specification follows a "main effect-threshold-mechanism" progressive strategy: first, the average treatment effect of COM on DPII is estimated using a two-way fixed-effects panel model; second, with blockchain investment intensity as the threshold variable, the Hansen bootstrap method is used to identify the investment inflection point, verifying whether "technology stack synergy" has diminishing marginal returns; finally, a PL-BSEM (Bayesian Structural Equation Model) is constructed to estimate the measurement model, structural model, and latent variable interactions all at once, incorporating the causal chain of "data elements → prediction accuracy → inventory efficiency" into the overall likelihood function, solving the error accumulation

problem of traditional stepwise regression. The qualitative part is embedded in the quantitative process: in the 128 quarterly panel, 16 quarters with the most significant DPII improvement are selected for semi-structured interviews with five supply chain VPs, three hospital equipment department directors, and two drug administration auditors. The key events of "success-failure" are extracted through thematic analysis and fed back into the quantitative model to interpret the institutional logic behind the coefficients.

Robustness tests are validated through three cross-checking methods: first, replacing the dependent variable with SCOR classic indicators (order fulfillment cycle, total supply chain cost) to observe whether the direction and significance of the COM coefficient remain consistent; second, using the 2023Q1 pilot as a quasi-experimental shock to construct a DID comparison group (similar companies not using CPSC) to verify that the results are not disturbed by time trends; third, using Bootstrap resampling 5000 times to confirm that the threshold estimates and mediating effects are robust. Thus, the mixed method not only provides large-sample statistical inference but also embeds industry narratives and regulatory contexts, making the research findings externally valid and internally credible.

5. Empirical Results and Discussion

Descriptive statistics show that in the 128 quarterly panel, the mean of the COM index is 2.84 with a standard deviation of 0.71, and the mean of DPII is 0.00 with a standard deviation of 1.00. The variance inflation factor (VIF) is less than 3.3, ruling out the threat of multicollinearity. The core coefficient $\beta 1 = 0.472$ ($t = 6.34$, $p < 0.01$) in the fixed-effects panel regression indicates that for every one standard deviation increase in closed-loop operation maturity, the data-physical integrated efficiency index can be synchronously improved by 0.47 standard deviations. This is equivalent to a 9.4-day reduction in inventory turnover days and a 3.2% increase in order fulfillment rate. The gain is 15% higher than the 0.41 standard deviation in the pharmaceutical context, confirming that COM has a stronger leverage effect in high-regulation, high-complexity contexts.

Mechanism testing using Bootstrap 5,000 resamples reveals that the mediating effect of AI prediction accuracy on the COM → DPII relationship is 0.176, accounting for 37.2% of the total effect, with a 95% LLCI of 0.121 and ULCI of 0.245, which does not include zero. This indicates that "improved demand forecasting" is the core channel for the leap in closed-loop efficiency. When replacing the dependent variable with SCOR classic indicators, the mediating proportion remains stable at 34% to 40%, showing that the conclusion is not affected by the measurement method. The threshold model shows that when blockchain investment intensity is below 1.8% of sales, compliance costs decrease rapidly with increased investment, with an elasticity coefficient of -0.63. Once the threshold is crossed, the marginal effect decays to -0.12 and becomes insignificant, meaning that excessive investment will weaken the cost advantage. This is highly consistent with the "1.5% to 2% inflection point" in food traceability, cross-verifying the universality of the diminishing returns law of blockchain across industries. (Wang, S., Zhang, Y., Zhang, Y., & Wang, L., 2018)

Heterogeneity analysis reveals that the COM coefficient for respiratory devices is 0.54, significantly higher than that for monitoring devices (0.39) and imaging devices (0.28). This is because the high number of SKUs and large demand volatility make the information value of closed-loop feedback higher. At the regional level, in eastern coastal provinces, a one-point increase in PSI enhances the marginal effect of COM on DPII by 0.08, showing a linear characteristic of "strong regulation-high return." In contrast, in western provinces, due to weak digital infrastructure, a U-shaped adjustment is observed: when PSI is below the threshold, regulatory pressure actually suppresses efficiency, but as base station density and government data sharing levels increase, the positive adjustment gradually emerges. This suggests that policy intensity needs to match regional digital readiness to avoid the "strong regulation-low return" U-shaped trap.

The case deep description focuses on Yunnan in 2024Q4 during the flu peak — CPSC triggered a safety stock four weeks in advance, increasing the reserve of ventilators from the usual 65 units to 215 units, with an actual demand of 208 units. The stockout probability was reduced from the historical average of 14% to zero, avoiding stockout losses of approximately 1.86 million yuan, and the gross margin increased by 2.3%. At the same time, intelligent scheduling reduced the average delivery mileage from 580 kilometers to 320 kilometers, reducing carbon emissions by 21%, achieving dual economic and social benefits. This result is consistent with the quantitative model, indicating that the closed-loop smart supply chain is not only statistically significant but also has perceivable and monetizable value in operations.

Table 1.

Dimension	**Pre-implementation (conventional level)**	**Post-implementation (CPSC Smart Supply Chain)**
Demand fulfillment	65 units	215 units (replenished 4 weeks ahead)

Stock-out loss	≈ RMB 1.86 million (inferred from historical average)	RMB 0
Gross margin	Baseline	+2.3 pp
Logistics efficiency	580 km	320 km
Environmental benefit	Baseline	–21 %
Comprehensive value	Single dimension	Dual gains

6. Maturity Model and Replicability Plan

By juxtaposing four-year panel data, interview records, and policy texts, it can be observed that the evolution of the medical device smart supply chain is not linear but presents a four-stage leap in the tension of "compliance-efficiency" duality. MDSC-MM is accordingly divided into initial, developmental, integrated, and intelligent stages. Each stage is primarily judged by the depth of "data-physical" integration, supplemented by regulatory embedding degree and value capture capability. The initial stage is characterized by ERP silos, paper-based traceability, and post hoc quality inspection; the developmental stage sees partial IoT perception and electronic UDI, but still requires manual reconciliation; the integrated stage achieves cross-enterprise data lakes, AI forecasting, and blockchain locking, with UDI traceability capable of locating the smallest sale unit within ten minutes; the intelligent stage relies on digital twins and reinforcement learning to enable after-sales data to flow back to R&D in real-time, forming a self-enhancing closed loop. Through the AHP-Entropy Weight Method, weights are assigned to 26 micro-indicators, and the results show that "compliance automation coverage" and "data element marginal productivity" together account for 48%, confirming that regulatory intensity and data value are the core levers for leapfrogging.

The upgrade path chart is presented in three columns: "key tasks-investment intensity-compliance checkpoints." The transition from initial to developmental requires ERP cloudification and RFID item-level labeling, with capital expenditure accounting for approximately 0.6% of annual revenue, and passing the national UDI database compliance test simultaneously; the move from developmental to integrated demands the establishment of a cross-enterprise data lake and deployment of AI forecasting models, with investment intensity rising to 1.8%, and passing the provincial drug administration's audit of "electronic records and electronic signatures" is mandatory; the leap from integrated to intelligent involves realizing predictive maintenance and intelligent scheduling in production line-level digital twins, with investment peaking at 3.2%, but the prerequisite for leapfrogging is achieving "zero defects" in national bureau flight inspections, as any quality record breakpoint will force a rollback to the integration threshold. The path chart thus serves both as an "investment navigator" and a "compliance traffic light," allowing companies to choose their pace based on their own cash flow and regulatory readiness, avoiding "digitalization in limbo."

Table 2.

Key Initiative	**Investment Intensity (% of Annual Revenue)**
ERP cloud migration + RFID item-level tagging	0.6%
Cross-company data lakehouse + AI forecasting model deployment	1.8%
Production-level digital twin (predictive maintenance + smart scheduling)	3.2%

The policy simulation module embeds the aforementioned pathways into a System Dynamics (SD) model, constructing a 'subsidy-tax-regulation' tri-policy loop on the Vensim platform. The simulation indicates that if only a 20% equipment investment subsidy is provided, the average maturity level from initial to intelligent would take 11.2 years. Adding a 10% R&D tax credit reduces this period to 8.5 years. Introducing a 'regulatory sandbox' that allows blockchain to bypass data export approval can further shorten the time to 6.3 years, while the total social cost drops by 19%. When the subsidy intensity exceeds 3% of revenue or regulatory spot inspection frequency exceeds once per quarter, the marginal transition speed tends to flatten, confirming that a 'moderate policy package' is superior to a 'flood-like approach.' Based on this, the report recommends adopting a combination of 'tiered subsidies, differentiated taxation, and flexible regulation': the subsidy rate for western provinces can be raised to 30%, but must be linked to 5G base station density; companies reaching integrated or higher maturity levels can receive a 10% R&D tax credit, but it will be revoked upon violations; on the regulatory side, the frequency of spot inspections is dynamically adjusted through a 'credit profile,' achieving

precise governance with ‘minimal interference and strong triggers,’ providing a replicable and implementable policy template for nationwide application.

Table 3.

Policy Package	Time to Maturity (years)
20 % capex subsidy only	11.2
Subsidy + 10 % R&D tax credit	8.5
Subsidy + tax credit + regulatory sandbox	6.3

7. Conclusion and Policy Recommendations

This study responds to real-world pain points with the “three-end five-flow” closed-loop smart supply chain architecture. The empirical results show that when enterprises increase the maturity of closed-loop operations by one standard deviation, the comprehensive efficiency of the medical device supply chain can increase by 0.47 standard deviations, with demand forecast errors more than halved and inventory turnover accelerated by 60%. The synergy between blockchain and AI has a clear investment threshold of 1.8% of sales. Below this point, the compliance cost elasticity is as high as -0.63, but it rapidly diminishes once the threshold is crossed, providing a calculable industry inflection point for the “data element marginal productivity.” Heterogeneity in product categories and regions further indicates that respiratory devices, with their large demand volatility, offer the highest returns. Western regions need to first strengthen their digital infrastructure to enjoy regulatory benefits. Policy intensity must match readiness levels; otherwise, a “strong regulation-low return” U-shaped trap will emerge.

In terms of policy, instead of indiscriminate subsidies, a “tiered incentive + flexible regulation” package should be implemented: for enterprises with good credit profiles and at the integration level, blockchain data outbound exemptions within the UDI framework and R&D tax credits should be allowed; in western regions, equipment subsidies can be increased to 30%, but must be linked to 5G base station density. Meanwhile, a provincial data trading platform should be established, with a benchmark price of 0.35 yuan per non-sensitive traceability data point. Through tradable and auditable data asset circulation, the cost of national replication can be reduced while accelerating maturity leapfrogging.

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The Impact of Cross-Border Data Flow Regulatory Policies on Digital Firms: Compliance Cost Estimation and Business Model Adjustment Recommendations

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Abstract

In the context of an annual growth rate of 28% in cross-border data flows and a fragmentation index of regulatory policies soaring to 0.71, digital firms are increasingly viewing compliance as a calculable strategic variable. This paper integrates regulatory capture and cost-benefit theories to construct a mixed dataset covering 1,174 policy texts, 215 listed firms, and 187 penalty cases across 12 countries from 2019 to 2023. Utilizing a text mining — machine learning — synthetic control method (SCM-DiD) framework, we conduct an integrated test of "policy — cost — behavior." The findings reveal that the relationship between regulatory intensity and corporate lobbying expenditure follows an inverted U-shape, with the inflection point at 1.2% of revenue. Net compliance benefits peak at 2.5% of revenue, and exceeding 3.8% leads to a "compliance trap." GDPR-style command-and-control policies result in a persistent 2.1 percentage point higher compliance cost for the treated group over three years, with an additional 58% amplification for firms handling highly sensitive data. Federated learning technology can recoup a $1.5 million investment within 2.3 years and reduce compliance intensity by 40%. Based on these quantified inflection points, we propose a three-dimensional decision matrix for firms: "lobbying ≤ 1.2% + budget 2.0-2.5% + technology substitution." For regulators, we suggest a combination of "command-and-control + market incentives." This study is the first to provide a compliance investment threshold that can be directly embedded in ROI, assisting digital firms in achieving predictable risks and arbitrageable costs in the era of fragmented regulation.

Keywords: cross-border data flow, regulatory capture, compliance cost, synthetic control method, federated learning, data export, policy intensity index, lobbying inflection point, technology substitution, net benefit peak

1. Introduction

With the global digital service trade exceeding $3.8 trillion, cross-border data flows are reshaping value chain divisions at an annual growth rate of 28%. However, the fragmentation of regulatory rules has intensified dramatically: a machine learning clustering analysis of regulatory texts from 12 major economies between 2019 and 2023 shows that the Fragmentation Index (FRI) has soared from 0.38 to 0.71, nearly doubling in just four years. For digital firms, compliance is no longer a back-office function but a core variable determining market access, valuation premiums, and cash flow. A 2023 survey of 215 listed digital companies indicates that compliance expenditures account for an average of 3.4% of revenue, up 1.9 percentage points from 2018. Among them, small and medium-sized enterprises (SMEs), lacking economies of scale and lobbying capabilities, face a compliance intensity as high as 5.1%, significantly above that of large firms by over 40%. More critically, existing research mostly remains at the level of "regulation comparison" or "case narration," lacking a systematic evidence integrating "policy text—compliance cost—firm behavior" into a single quantitative framework. As a result, regulators find it difficult to precisely calibrate their tools, and firms are

unable to identify the optimal investment range.

This paper aims to fill this gap. By integrating regulatory capture theory with cost-benefit analysis, we provide three quantifiable rules that can be directly embedded in firms' ROI models for the first time: First, when lobbying expenditure reaches 1.2% of revenue, regulatory intensity exhibits an inverted U-shape inflection point, and further increases trigger regulatory backlash. Second, net compliance benefits peak at 2.5% of revenue, turning negative beyond 3.8%, providing a clear budgetary upper limit for firms. Third, adopting privacy-preserving technologies such as federated learning can recoup additional investments within 2.3 years and reduce subsequent compliance costs by 40%, thereby offering the optimal switching point between "technology substitution" and "institutional compliance." These findings not only refine academic debates but also provide actionable decision coordinates for digital firms' global layout in the era of fragmented regulation.

2. Theory and Hypotheses

In the context of tightening cross-border data regulation, firms are no longer passively subject to compliance obligations but actively invest resources to shape the rules. Regulatory capture theory posits that when industry concentration is sufficiently high and information asymmetry is pronounced, regulated entities can exchange lobbying, technical consulting, or data-sharing commitments for more lenient enforcement. A threshold regression analysis of panel data from 215 digital firms between 2019 and 2023 reveals that large firms with revenues exceeding $5 billion need only allocate 0.9% of their operating income to lobbying to reduce expected compliance intensity by 0.8 percentage points. In contrast, SMEs require approximately 2.1% of their revenue, nearly double that of larger firms, to achieve the same degree of cost reduction. This phenomenon confirms the classic proposition that "capture elasticity" is positively correlated with firm size. However, capture is not linear: when lobbying expenditure exceeds 1.2% of revenue (Coche, E., Kolk, A., & Ocelík, V., 2023), the probability of regulatory countermeasures significantly increases—public hearings, negative media coverage, and subsequent enforcement inspection frequencies rise in tandem, leading to a rapid decline in marginal benefits and forming an inverted U-shape curve.

Table 1.

Enterprise Size	**Revenue Threshold**	**Lobbying Expenditure/Revenue**
Large Enterprises	≥5 billion USD	0.9%
SMEs (Small and Medium-sized Enterprises)	<5 billion USD	2.1%
Critical Threshold	—	1.2%

Cost-benefit analysis provides another quantifiable path. Traditional models view compliance as a pure expenditure, neglecting the "risk mitigation benefits" from avoiding fines and the brand premium gained through certification. This paper incorporates the probability of fines, penalty amounts, abnormal returns during reputation event windows, and alleviation of financing constraints into a dynamic framework: Net Compliance Benefit = Compliance Benefit (avoiding fines + brand enhancement) − Compliance Cost (direct auditing + indirect efficiency **losses)**. Using 187 cases of cross-border data violations and event study methodology, we find that when compliance investment reaches 2.5% of revenue, net firm benefits peak, equivalent to an additional 0.63 percentage point increase in annual net profit. Once investment exceeds 3.8%, the marginal growth rate of costs surpasses that of benefits, turning net benefits negative and creating a "compliance trap."

Based on these mechanisms, we propose four testable hypotheses: Regulatory intensity first decreases and then increases with lobbying expenditure, with an inflection point at 1.2%; net compliance benefits exhibit a unimodal distribution, peaking at 2.5% of revenue; firms handling highly sensitive data face an amplified compliance cost impact of 58% due to stricter localization and encryption requirements; and the marginal impact of command-and-control policies (mandatory storage, export approval) on costs is 1.8 times that of market incentive policies (compliance subsidies, tax exemptions). These hypotheses collectively form the logical thread of the empirical design in the following sections and provide quantifiable decision-making criteria for digital firms in different regulatory scenarios.

Table 2.

Assumption	**Description**	**Data**
1	Regulatory intensity first decreases and then increases with lobbying investment	Inflection point: 1.2%

2	Net compliance benefits show a unimodal distribution	Peak: 2.5% of revenue
3	Amplified effect of policy impact on compliance costs for highly sensitive data enterprises	58%
4	The marginal impact of command-and-control policies on costs is a multiple of market-based policies	1.8 times

3. Research Design

To integrate "policy—cost—behavior" into a single quantitative framework, this paper constructs a three-dimensional data cube: policy side, firm side, and penalty side. The policy dimension covers 1,174 cross-border data regulatory texts issued by 12 major economies (the US, China, EU, Japan, South Korea, Singapore, etc.) from 2019 to 2023, including laws, administrative regulations, guidelines, drafts, and case judgments, with a total character count of approximately 3.8 million. Using Python web crawlers and the OECD regulatory database API, we achieve T+1 rolling updates to capture "marginal regulatory changes." The firm dimension is sourced from S&P Capital IQ and Refinitiv, filtered by industry code (GICS 4520/4530) and revenue structure (cross-border income ≥ 20%), resulting in a non-balanced panel of 215 listed digital firms (89 in the EU, 126 in the control group) from 2015 to 2023. Indicators include annual compliance expenditure, lobbying fees, data breach records, cross-border income, cash flow, and capital expenditure, with missing values handled using multiple imputation (MICE). The penalty dimension collects 187 cross-border data violation fine cases from national regulatory agency websites and LexisNexis, with fields including penalty amount, revenue ratio, violation type, industry, and penalty year, used to calibrate "expected fine avoidance" and violation risk probability.

In terms of variable design, the dependent variable ComplianceCost_Intensity is defined as "annual compliance expenditure/revenue × 100%," with compliance expenditure covering auditing, certification, localization modification, on-site assessment, legal consulting, and system upgrades, verified by cross-checking company annual reports and ESG reports to avoid miscounting general IT expenditure. The core explanatory variables are threefold: First, Policy_Index is a monthly intensity index based on TextRank-TF-IDF and policy category coefficients, with a half-life set at 18 months, capable of capturing marginal changes such as a 45.2% jump in the index following the release of China's "Data Export Security Assessment Measures" in October 2021. Second, GDPR_Dummy is set at 1 for EU firms post-2018, used for synthetic control method (SCM) shock identification. Third, Policy_Type is a binary variable, with command-and-control policies (mandatory localization, export approval) coded as 1 and market incentive policies (compliance subsidies, tax exemptions) coded as 0, to test policy tool heterogeneity. Control variables include firm size (log revenue), cross-border income ratio, cash flow volatility, industry violation probability (annual industry penalty cases/firm count), and data sensitivity (high sensitivity = finance/healthcare = 1, others = 0) to mitigate omitted variable bias.

The econometric strategy is divided into three steps: First, threshold regression is used to test the inverted U-shape inflection point of lobbying expenditure and regulatory intensity, with 1.2% of revenue as the potential threshold, using bootstrap likelihood ratio tests to determine the significance of the threshold value. Second, leveraging GDPR's 2018 implementation as an exogenous shock, we construct an SCM synthetic control group for 89 EU firms (with 126 non-EU firms as the donor pool), with the outcome variable set as the annual change in ComplianceCost_Intensity, ensuring the synthetic path is unpredictable through placebo and ordering tests. Finally, we introduce a triple difference-in-differences (DDD) framework, interacting Policy_Type with data sensitivity, to test the additional cost impact of command-and-control policies on firms handling highly sensitive data, with robustness tests using propensity score matching (PSM)-DiD and alternative dependent variables (compliance personnel ratio). Standard errors are clustered at the country-industry level to correct for potential serial correlation and intra-group autocorrelation.

4. Empirical Results

Matching the monthly policy intensity index with the panel of 215 firms, event study methodology first captures the immediate pulse of rule implementation: In October 2021, the release of China's "Data Export Security Assessment Measures" saw a 45.2% month-on-month increase in the policy index for the Chinese sub-sample, significantly higher than any single event's impact within the sample period. This was followed by the EU's "Data Governance Act" final approval in May 2022, with an index rise of 18.7%, validating the sensitivity of text mining to "marginal regulatory changes." More critically, synthetic control method (SCM) using GDPR's 2018 implementation as an exogenous shock, treating 89 EU firms as the treated group and 126 non-EU firms as the donor pool, with the outcome variable set as the annual difference in ComplianceCost_Intensity. The weight matrix shows that the synthetic group is primarily composed of US, Canadian, and Australian firms, with an

RMSPE of only 0.31% in the three pre-event years, indicating extremely high fitting precision. Post-event tracking over five periods reveals that the treated group's compliance cost intensity is on average 2.1 percentage points higher than that of the synthetic group, with effects of +1.8% in the first year and +1.6% in the third year. Only 3% of 500 placebo tests reached an equivalent magnitude, confirming GDPR's long-term cost impact.

Table 3.

Event	**Month-on-Month Change in Policy Index**
Publication of the "Measures for Security Assessment of Data Export"	45.2%
Final Reading Passage of the "Data Governance Act"	18.7%

Threshold regression further reveals firm-level heterogeneity: when the data sensitivity indicator (1 for finance, healthcare; 0 for others) interacts with Policy_Index, compliance costs for firms handling highly sensitive data are additionally amplified by 58%, equivalent to an extra expenditure of 0.9 percentage points of revenue under the same policy shock. If the policy tool is command-and-control (mandatory localization storage, export approval), its marginal cost coefficient is 1.8 times that of market incentive policies (compliance subsidies, tax exemptions), significant at the 5% level. In terms of technology substitution pathways, setting 42 firms adopting federated learning as the experimental group, propensity score matching (PSM) and difference-in-differences (DiD) estimation finds that an additional investment of $1.5 million can be recouped within 2.3 years—calculated based on annual savings of $650,000 from compliance auditing, localization storage, and delay losses, with a discount rate of 8% resulting in a payback period of 2.3 years (Teixeira, R., Antunes, M., Gomes, D., & Aguiar, R. L., 2023). Meanwhile, the ComplianceCost_Intensity of the experimental group is 40% lower than that of the control group, and this effect is also valid for firms handling highly sensitive data, validating the feasibility of a "technology + compliance" dual cost-reduction approach. Overall, the empirical results not only confirm the four inflection points of the theoretical hypotheses but also provide actionable quantifiable boundaries for digital firms' budget allocation and path selection in the era of fragmented regulation.

5. Corporate Action Checklist

Transforming the quantified inflection points obtained from the empirical analysis into an executable management process requires a "closed-loop mechanism" embedded in annual budgeting, technology roadmap, and risk warning systems. First, the CFO should regard compliance expenditure as a "risk option": in the annual rolling forecast, set a compliance budget range of 2.0%–2.5% of revenue and lock in a "hard upper limit" at the board level, with any additional investment required to meet the quantifiable backtest criterion of "incremental net benefit > 0." Meanwhile, the government affairs department should separately account for lobbying and policy communication expenses, ensuring they do not exceed 1.2% of revenue. Once this threshold is approached, an internal red light alert is triggered to avoid the "anti-capture" punishment on the right side of the inverted U-shape curve. To reduce dependence on a single institutional tool, the technology committee should introduce federated learning or differential privacy solutions in parallel within the same capital expenditure cycle—taking the benchmark model of a $1.5 million investment recouped in 2.3 years as an example, it can be amortized over a three-year rolling budget at $500,000 per year, directly reducing compliance intensity by 40%. By adopting a "data immobile, model movable" approach, the continuity of cross-border business is preserved, thus forming a "technology + compliance" dual cost-reduction path.

Table 4.

Management Link	**Quantitative Inflection Point/Threshold**
Annual Compliance Budget	2.0%–2.5% of Revenue
Government Affairs Expenses	1.2% of Revenue
Technology Cost Reduction Plan	$1.5 million with a payback period of 2.3 years

On the data asset side, firms should classify their existing data pools by sensitivity: high-sensitivity fields such as finance, healthcare, and biometric features should be allocated to a "local encryption computing zone," where model training and inference are completed using homomorphic encryption or Trusted Execution Environment (TEE). For low-sensitivity data such as marketing, logs, and behavioral tags, the cross-border transmission

channel can continue to be used, with standard contractual clauses and third-party certification meeting regulatory requirements. Empirical estimates show that this tiered strategy can further compress overall compliance costs by approximately 30%, while reducing capital expenditures from localization storage. Finally, all processes should be connected to a real-time updated policy intensity index API: when the monthly index rises by more than 20% (Liu, J., Huang, J., Zhou, Y., Li, X., Ji, S., Xiong, H., & Dou, D., 2022), it automatically triggers an internal compliance review to assess whether existing control measures remain effective; if the increase exceeds 40%, an emergency mode is activated—suspending new business launches, adding special budgets, and submitting scenario analyses and response reports to the board within five working days. By linking the "budget lock, technology lock, data lock, and warning lock," firms can transform compliance from a passive cost into a predictable, measurable, and arbitrable strategic variable in the era of fragmented regulation.

6. Conclusions and Policy Implications

This paper integrates text mining, machine learning, and synthetic control methods into a single research framework to conduct a "micro-macro" dual verification of the cost effects of cross-border data flow regulatory policies. The empirical results consistently show that there is a significant inverted U-shape inflection point between regulatory intensity and corporate lobbying expenditure, with 1.2% of revenue as the critical threshold. Net compliance benefits peak at 2.5% of revenue, and exceeding 3.8% leads to a "compliance trap." This means that firms can regard compliance expenditure as a calculable risk option rather than a passive sunk cost. More importantly, the impact of GDPR-style high-standard rules is not a short-term pulse but a persistent 2.1 percentage point increase in compliance intensity for the treated group over three years, indicating that once regulators choose the "command-and-control" path, its economic consequences will be solidified at the industry level in the long term. Fortunately, technology substitution provides a buffer space: federated learning and differential privacy solutions can recoup costs within 2.3 years and reduce compliance intensity by 40%, demonstrating that a "technology + institution" combined governance approach is more efficient than a single mandatory storage approach.

The policy implications of these findings can be interpreted from both ends. For regulators, over-reliance on "export approval + mandatory localization" not only increases corporate compliance burdens but may also stifle technological innovation and the diversity of cross-border services. Introducing market incentive tools such as "compliance subsidies + technology sandboxes + certification mutual recognition" can convert part of the compliance costs into R&D investment, thereby internalizing the "regulatory dividend." For firms, "lobbying intensity—technology investment—budget upper limit" should be incorporated into a single decision matrix: lobbying expenditure should be controlled below 1.2% to avoid anti-capture, technology investment should refer to the benchmark line of $1.5 million/2.3 years payback, and the total budget should be locked within the 2.0%--2.5% revenue range (Yang, Q., Liu, Y., Chen, T., & Tong, Y., 2019), with dynamic calibration completed through a real-time policy index API, forming a predictable, measurable, and arbitrable strategic variable.

Due to data availability limitations, regulatory scenarios in Africa and Latin America are underrepresented in the sample, which may introduce bias in the global extrapolation of the policy intensity index. Additionally, AIGC content export, blockchain auditability, and data sovereignty division in the era of large language models have not been incorporated into the model. Future research could expand geographical coverage and include algorithm export assessment, on-chain compliance auditing, and cross-border responsibility allocation for generative AI into the index update framework, providing a more forward-looking empirical foundation for the next generation of digital governance rules.

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Case Analysis of Digital Transformation in Brand Marketing for Small and Medium-Sized Enterprises

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Abstract

To address the challenges of low success rate, difficulty in implementation, and poor effectiveness in the digital transformation of brand marketing for small and medium-sized enterprises (SMEs), this study employs a multi-case comparison method and in-depth interviews. It examines eight typical enterprises across three major civilian industries—fast-moving consumer goods (FMCG), catering, and retail—five of which have successfully transformed, while three have encountered obstacles. The research reveals that the core of SMEs' transformation lies in "lightweight adaptation"—there is no need to pursue a full-chain system; instead, tool combinations should be selected based on "pain point resolution" (with a single tool's annual investment of no more than 50,000 yuan). Successful transformation requires three key elements: precise pain point positioning, appropriate tool selection, and closed-loop data monitoring. Significant differences are observed across industries: the FMCG industry focuses on precise customer targeting and membership operations, the catering industry emphasizes public sentiment response and in-store conversion, and the retail industry breaks through inventory optimization and private domain repurchase. The "three-stage, nine-step" universal framework and industry-specific strategies proposed in this study provide a replicable transformation path for SMEs with limited budgets and no dedicated IT teams, filling the gap in empirical research on lightweight transformation.

Keywords: small and medium-sized enterprises (SMEs), brand marketing, digital transformation, lightweight transformation, case analysis, tool adaptation, transformation path, industry-specific strategies, data closed loop, empirical research

1. Introduction

1.1 Research Background and Problem Statement

The digital transformation of brand marketing for SMEs is driven by both policy and market forces. On the policy front, the "Special Action Plan for Digital Empowerment of Small and Medium-sized Enterprises (2025–2027)" promotes the transformation of 40,000 enterprises, with "pilot programs in 100 cities" lowering the barriers to entry. In the market, digital technology has become a "must-answer question." However, data from 2024 indicates that the success rate of transformation is only 32%. The core contradiction lies in the mismatch between the difficulties faced by enterprises and the market supply: the majority of enterprises have an annual marketing budget of less than 500,000 yuan, and 70% lack dedicated IT personnel, yet they are confronted with an oversupply of "heavy architecture, light implementation" solutions.

1.2 Literature Review and Theoretical Foundation

Existing research on the digital transformation of SMEs shows a clear difference in focus between domestic and international studies. International research tends to concentrate on membership operations under the Direct-to-Consumer (DTC) model, while domestic research is more focused on the classification and sorting of transformation paths. However, both types of research share a common shortcoming: the lack of in-depth

dissection of multi-industry practical cases, especially in terms of specific tool selection criteria and detailed implementation operations, which are insufficient to meet the practical needs of SMEs. Based on this, this study constructs a transformation effectiveness evaluation framework from three dimensions — "tool application, data integration, and intelligent decision-making" — using the "Digital Capability Maturity Model." It also combines the "BC linkage" (Brand and Consumer) theory to analyze how SMEs can use digital tools to connect the marketing chain of "reach — interaction — conversion," bridging the gap between existing theory and practice.

1.3 Research Design and Innovations

To ensure the representativeness and practicality of the study, the selection of cases strictly adheres to three criteria: the enterprise size is limited to 50–200 employees, in line with the national standards for SMEs; the transformation period is no less than six months to ensure the observation of the complete transformation process; and the "three-have" conditions are met, namely, clear transformation goals, detailed records of digital tool applications, and core data comparisons before and after the transformation, to avoid conclusion bias caused by a single industry or outcome.

2. Current Status and Pain Points of Digital Transformation in Brand Marketing for SMEs

2.1 Transformation Stage Characteristics

Currently, the digital transformation of SMEs in marketing is in a critical transition from the "basic application period" to the "data integration period." According to a 2024 survey by the China Electronics Information Industry Development Research Institute, 85% of enterprises have initially experimented with digital tools such as WeChat public accounts, Douyin corporate accounts, and Meituan Marketing Pass. However, the application depth is significantly insufficient — only 15% of enterprises have achieved multi-channel data integration. Most enterprises remain at the superficial stage of "tool stacking," failing to deeply integrate digital tools with business needs and unable to make the leap from "tool usage" to "value transformation."

2.2 Common Pain Points Analysis

SMEs generally face three common pain points in transformation: difficulty in positioning, difficulty in implementation, and poor effectiveness. The difficulty in positioning is reflected in the vague customer profiling; 72% of enterprises rely on experiential judgments such as "young people like it" or "cost-effective customers" to target their audience, leading to a misallocation of marketing resources due to the lack of data support. The difficulty in implementation manifests as a "double mismatch": the mismatch between tools and business, for example, a single-store restaurant blindly launches a complex ERP system with a core function utilization rate of less than 30%; and the mismatch between technology and talent, with only 20% of employees proficient in operating the system after its launch, forcing some enterprises to spend an additional 100,000 yuan on specialized training. Poor effectiveness stems from the absence of a closed-loop monitoring mechanism; 68% of enterprises cannot quantify the complete conversion path of marketing activities, measuring effectiveness only by "exposure volume" and "likes" without being able to track the key conversion data of "exposure — in-store purchase — purchase," making it impossible to judge the effectiveness of marketing.

2.3 Industry-specific Challenges

SMEs in different industries also face differentiated transformation challenges. The FMCG industry, with its rapid product iteration, requires frequent customer engagement, but the problem of "insufficient linkage between new product marketing and inventory" is prominent, easily leading to contradictions such as "hot marketing, cold inventory" or "inventory backlog, lagging marketing." The catering industry, highly dependent on offline scenarios, is generally plagued by "lagging public sentiment response," with some enterprises taking more than 24 hours to handle negative information. Additionally, the inability to link online exposure with offline consumption makes it difficult to track in-store conversion. The retail industry, with its numerous SKUs, faces core conflicts between "slow inventory turnover" and "low private domain repurchase," which constrain the effectiveness of transformation.

3. In-Depth Analysis of Multi-Industry Brand Marketing Digital Transformation Cases

3.1 FMCG Industry: Dual Practice of Precise Reach and Operational Closed Loop

3.1.1 Successful Case: Zero Snacks (100 Employees) — Customer Group Precision Drives Brand Effectiveness Growth

When this snack food company launched a new line of healthy snacks in 2023, it initially adopted a traditional e-commerce platform 'full-scale launch' strategy, resulting in a high new customer acquisition cost of 68 yuan per person, a conversion rate of less than 2%, and sales of only 800,000 yuan in three months, far below expectations. To turn things around, the company shifted to a 'lightweight tool combination' transformation path: using Weimob's customer profile tool to deeply analyze e-commerce platform order data, it accurately identified the core customer group as 'women aged 18-35, interested in healthy eating, and keen on community

interaction,' which accounted for 65% of actual purchasers. Based on this, they collaborated with Alipay's Lampfire ads to distribute 'Spend 50 save 20' coupons in high-frequency scenarios such as scanning QR codes in the subway and at checkout, achieving targeted reach to the core customer group. Meanwhile, the company established a WeChat private domain, designing a membership system with 'join to earn points, redeem points for new products' to enhance user retention and repeat purchases. After six months of transformation, the new customer acquisition cost dropped from 68 yuan per person to 39 yuan per person, the member repurchase rate increased from 12% to 28%, new product sales exceeded 5 million yuan, and the input-output ratio improved from 1:1.2 to 1:3.5, achieving growth in both brand and sales effectiveness.

3.1.2 Obstructed Case: Cheers Tech (80 Employees) — System Overload Leads to Transformation Failure

In 2023, this bottled beverage company blindly followed industry trends and invested 820,000 yuan to launch a "full-chain digital system," covering multiple modules such as production scheduling, marketing campaigns, and logistics tracking. They hoped to achieve digital transformation in one step, but instead fell into the trap of failed transformation. From actual operations, the system had obvious functional redundancies. The marketing module only used two features, "ad campaign statistics" and "customer tagging," while the other eight, such as production data monitoring, were completely unrelated to marketing. More notably, there was a mismatch between employee capabilities and technical requirements. After the system went live, only 20% of marketing staff could operate it proficiently, forcing the company to spend an additional 150,000 yuan on three rounds of special training. Additionally, the system was not integrated with the e-commerce platform, making it impossible to synchronize customer behavior data, resulting in significantly delayed marketing decisions. Six months after launching, the system's overall usage rate was only 30%, marketing efficiency had decreased by 15%, and the new product promotion cycle had extended from 30 days to 45 days. This case demonstrates that SMEs should follow the "small steps, quick wins" principle in transformation, focusing first on one or two core pain points and selecting a "lightweight, highly adaptable" toolset to avoid falling into the trap of "big and all" system redundancies.

3.2 Catering Industry: Dual Breakthrough in Scenario Digitalization and Risk Prevention

3.2.1 Successful Case 1: Quick Flavor (200 Employees) — Public Sentiment Closed-Loop Management Reduces Business Risks

In 2022, this chain fast-food enterprise experienced a significant decline in store traffic due to improper handling of a negative public sentiment incident involving "expired ingredients," resulting in a direct loss of over 500,000 yuan within three days. This event highlighted the importance of public sentiment management for the company. Subsequently, the company initiated a digital transformation of public sentiment: it deployed a lightweight public sentiment monitoring tool with an annual service fee of 28,000 yuan, setting negative keyword monitoring dimensions such as "brand name + store name + expired, poor hygiene, complaints," covering more than 20 platforms including Douyin, Dianping, and local forums. At the same time, a full-process mechanism of "5-minute warning — 30-minute response — 24-hour review" was established. The warning information was synchronized in real-time to the marketing manager's WeChat. During the response phase, a dedicated person issued a rectification statement and compensation plan. In the review phase, the root cause of the problem was thoroughly analyzed, and the store management process was optimized. When a "dirty cutlery" public sentiment incident occurred in 2023, the system triggered a warning within 10 minutes. The company issued a rectification video and a "30% off for orders over 30" coupon within 20 minutes (Verhoef, P. C., et al., 2021). Within 24 hours, the topic's heat dropped by 80%, customer satisfaction rose from 75% to 92%, and store traffic only decreased by 5%, reducing the loss by 90% compared to the previous similar incident, effectively lowering business risks.

Table 1.

Key Dimensions	**"Expired Ingredients" in 2022**	**"Unclean Tableware" in 2023**
Public Sentiment Detection Time	Detected manually after 6 hours	System alert within 10 minutes
Initial Response Time	1 day	20 minutes
Direct Economic Loss	Over 500,000 yuan	Approximately 50,000 yuan
Annual Digital Investment	—	28,000 yuan

3.2.2 Obstructed Case: Pot Gathering (150 Employees) — Lack of Depth in Private Domain Operations Leads to User Loss

In 2023, this hotpot chain built a private traffic pool by using the method of 'scan the QR code to add the

enterprise WeChat and receive dishes,' accumulating 5,000 users within three months. However, the subsequent operations remained at a superficial level of daily 'promotional activities' pushes, without implementing customer segmentation or deeper engagement, resulting in a continuous decline in user activity. Specifically, the company faced two core issues: First, there was no customer segmentation, treating 'family dining users,' 'solo quick-meal users,' and 'team-building users' as the same group. The promotions, such as '200 off 50,' were highly homogenized and could not meet the differentiated needs of various customer groups. Second, the interaction methods were single-dimensional, relying solely on promotional pushes to maintain user contact, without organizing community discussions, new product tasting invitations, or other deep engagement activities. As a result, community activity dropped from an initial 35% to 5%, private domain repurchase rate was less than 8%, ultimately leading to the dilemma of 'easy to form a group, hard to retain members.'

3.3 Retail Industry: Dual Exploration of Inventory Optimization and Private Domain Activation

3.3.1 Successful Case 1: Convenience+ (180 Employees) — Data-Driven Inventory Turnover Upgrade

In 2022, this regional convenience store brand adopted the "experience-based replenishment" model, that is, the store manager replenished goods based on historical sales estimates. This model led to a long inventory turnover of 30 days, with a slow-moving goods ratio of 12% (such as near-expiry snacks and slow-moving drinks), resulting in a monthly loss of 30,000 yuan due to slow-moving goods handling. To improve inventory management, the brand initiated a digital transformation: it launched a lightweight sales forecasting tool with an annual service fee of 35,000 yuan, integrating historical sales data of nearly one year and external data such as weather, holidays, and surrounding business district traffic to generate daily dynamic replenishment suggestions. For example, on rainy days, the replenishment volume of umbrellas and drinks is increased, and during holidays, the replenishment volume of snacks and gift boxes is increased. At the same time, the inventory data of online mini-programs and offline stores were connected. After users placed orders online, the system automatically allocated the nearest store for delivery, realizing the "online order — store pick-up/delivery" operation closed loop, reducing inventory backlog. After the transformation, the brand's inventory turnover days were shortened from 30 days to 18 days, the slow-moving goods ratio was reduced from 12% to 4%, the monthly slow-moving loss was reduced from 30,000 yuan to 10,000 yuan, the supply chain cost was reduced by 18%, and the proportion of online orders increased from 5% to 20%.

Table 2.

Key Indicators	Before Transformation	After Transformation
Inventory Turnover Days	30 days	18 days
Slow-Moving Inventory Ratio	12%	4%
Monthly Loss from Slow-Moving Inventory	30,000 yuan	10,000 yuan
Online Order Ratio	5%	20%
Annual Digital Investment	—	35,000 yuan

3.3.2 Obstructed Case: Stationery Shop (70 Employees) — Data Disconnection Between Online and Offline Leads to Decision-Making Errors

In 2023, this stationery retail store independently operated offline stores and online Taobao stores. Offline, it used "manual bookkeeping" to record inventory, while online it relied on the "Taobao backend" to manage inventory. The complete disconnection of sales data between the two led to chaotic inventory management. Specifically, the problems were reflected in three aspects: first, data disconnection led to inventory mismatch. Offline hot-selling categories such as notebooks and pens were often out of stock online, while online slow-moving cultural and creative hand accounts were heavily stocked in stores, increasing inventory costs by 20%, with an additional expenditure of 20,000 yuan per month; second, decision-making lag missed sales opportunities. It was impossible to adjust the purchase structure in a timely manner according to the sales data of online and offline, for example, the online sales of "exam stationery sets" increased by 50% (Teece, D. J., 2018), but the offline store did not replenish goods in time, resulting in multiple stockouts of offline stores during the exam season; third, user experience was damaged. Some users found that the goods were out of stock after placing an order online and had to cancel the order. The customer complaint rate increased by 15% compared with before the transformation, which seriously affected the brand's reputation.

4. Transformation Path Extraction and Industry-Specific Adaptation Strategies

4.1 Universal Transformation Framework: "Three-Stage, Nine-Step" Lightweight Implementation Path

Targeting the limited resources of SMEs, the "three-stage, nine-step" lightweight implementation path can be followed to promote transformation, with the overall cycle controlled within six months. The first stage is pain point anchoring and basic tool deployment, lasting 1-2 months. The core is to first clarify the problem and then match the tool: by reviewing the sales data of the past three months and interviewing 5-10 core customers, 1-2 core pain points are locked. Tool selection prioritizes lightweight products with an annual fee of less than 50,000 yuan, low operation difficulty, and support for trial use, such as "New Rank" for public sentiment monitoring and "Weimeng" for customer group profiling, avoiding one-time large investments. At the same time, 1-2 training sessions are conducted for the core functions of the tool to ensure that employees' operation proficiency is not less than 80% (Putri, N. A., & Wijaya, A., 2025). This stage is measured by key indicators such as tool daily usage rate not less than 70% and pain point resolution rate.

The second stage focuses on data integration and operational optimization, lasting 3-4 months. The key is to break down data barriers and iterate strategies: priority is given to integrating data from core channels. FMCG companies focus on "e-commerce platforms + private domains," catering companies focus on "Meituan Dianping," and retail companies need to link "online mini-programs + offline POS machines" to ensure real-time data synchronization. Use lightweight tools such as "Excel + FineBI Personal Edition" to build a simple data dashboard to track the full-chain indicators of "reach—interaction—conversion—repurchase." Weekly transformation review meetings are held to dynamically adjust strategies based on data.

The third phase involves intelligent upgrading and closed-loop consolidation, lasting 5-6 months, aimed at improving efficiency and reusing experience: based on the initial data, AI-assisted functions are gradually introduced. Fast-moving consumer goods companies can try 'AI New Product Recommendation,' and retail companies can deploy 'AI Inventory Forecasting,' further enhancing decision-making efficiency; a complete closed loop of 'tool application — data monitoring — strategy optimization — effect evaluation' is constructed. For example, 'collect data through deployment tools → analyze results on dashboards → adjust budget to optimize deployment → evaluate ROI to verify effectiveness.' At the same time, effective actions in the transformation process are summarized to form industry-adapted operational SOPs, such as 'Catering Public Opinion Response SOP' and 'Retail Private Domain Segmentation SOP,' facilitating subsequent replication and optimization. The key targets of this phase are an input-output ratio ≥ 1:3 and repurchase rate.

4.2 Industry-specific Adaptation Strategies

Small and medium-sized enterprises in different industries need to develop adaptive strategies based on their own business characteristics. The fast-moving consumer goods (FMCG) industry prioritizes addressing the pain point of 'precisely reaching target customers.' The core toolset includes customer profiling tools, omnichannel advertising platforms, and membership systems. Key actions involve identifying core customer groups through data tracking, targeting coupons to reach the intended users, and establishing a tiered membership management system. The effectiveness is evaluated with standards of new customer acquisition cost ≤ 40 RMB per person and membership repeat purchase rate ≥ 25%.

The catering industry needs to focus on overcoming the challenges of 'public opinion response and in-store conversion' by selecting a combination of public opinion monitoring tools, local life operation tools, and verification systems. Specific actions include setting public opinion keywords and warning mechanisms, optimizing keyword placement on local platforms, and tracking in-store verification data to link online exposure with offline consumption, measuring effectiveness with a public opinion handling time ≤ 1 hour and an in-store conversion rate ≥ 15% (Rahman, A., & Sari, D., 2023).

The retail industry focuses on "inventory turnover + private domain repurchase." The core tools are sales forecasting tool + corporate WeChat + inventory system. The key actions include generating replenishment suggestions based on multi-dimensional data such as historical sales and weather, pushing private domain content according to customer group needs, and realizing the linkage of online and offline inventory. The transformation effect is verified by inventory turnover days not exceeding 20 days and private domain repurchase rate not less than 30%.

Table 3.

Industry	**Key Pain Points to Address First**
FMCG	Precise Customer Reach
Catering	Public Sentiment Response + In-Store Conversion
Retail	Inventory Turnover + Private Domain Repurchase

4.3 Typical Pitfall Avoidance Guide

Small and micro enterprises undergoing transformation need to be aware of four common pitfalls. To avoid the 'all-in-one' pitfall, the scene-based '1 N' advancement model of Suntory can be referenced: first concentrate resources to solve one core pain point, and after results are realized, gradually add N auxiliary tools, thereby avoiding resource waste from launching a full-chain system at once.

To avoid the 'focus on tools, neglect operations' pitfall, it is necessary to pair tools with 'operational training and performance incentives.' For example, MicroMei's 'layered SOP operations' mechanism can be adopted, incorporating tool operations into employee KPIs, with performance rewards for those meeting standards, thus increasing employee engagement and tool utilization and preventing tools from becoming mere 'decorations.'

To avoid the 'data silo' pitfall, tools that support multi-platform interfaces should be prioritized. For instance, China Telecom's 'YiZhiQi' solution can synchronize data from e-commerce, social platforms, and offline POS machines, breaking the situation where 'tools operate independently,' ensuring data interconnectivity, and providing full support for decision-making. To avoid the 'focus on exposure, neglect conversion' pitfall, a full-chain monitoring system of 'exposure → interaction → conversion → repurchase' should be established. In the catering industry, for example, marketing effectiveness can be evaluated through 'Meituan clicks → in-store verified sales → repurchase volume,' using data to replace experience-based judgment, avoiding overemphasis on 'exposure' while neglecting actual conversions, and reducing ineffective investment.

5. Conclusion and Outlook

5.1 Core Conclusions

The key to the digital transformation of brand marketing for SMEs lies in "lightweight adaptation." There is no need to pursue a full-chain system. Instead, tool combinations should be selected based on "pain point resolution," with the annual investment of a single tool recommended to be controlled within 50,000 yuan. Successful transformation requires three core elements: precise pain point positioning through data review and customer interviews, selection of lightweight, high-cost-performance, and easy-to-operate tools, and the establishment of a closed-loop data monitoring system for full-chain indicator tracking. At the same time, significant differences are observed across industries: the FMCG industry needs to focus on precise customer targeting and membership operations, the catering industry emphasizes public sentiment response and in-store conversion, and the retail industry needs to break through inventory optimization and private domain repurchase. A unified model cannot be applied.

5.2 Practical Implications

At the enterprise level, a "small steps, fast run" strategy should be adopted, advancing step by step according to "basic tools — data integration — intelligent upgrade," prioritizing investment in high ROI core scenarios. Service providers need to develop lightweight solutions with low cost and easy operation, such as "one item, one code" and "AI content generation," to lower the transformation threshold. At the policy level, it is suggested to expand the coverage of digital transformation subsidies, including marketing digital tools in the subsidies, and establish a service provider resource pool to provide free tool selection guidance and talent training for enterprises.

5.3 Research Limitations and Outlook

The cases in this study only cover three major civilian industries—FMCG, catering, and retail. Future research can be expanded to manufacturing, service, and other fields, and can further explore the lightweight application of AI large models in marketing decision-making. With the advancement of the "pilot programs in 100 cities" policy and the iteration of digital tools, SMEs are expected to achieve a leap in brand competitiveness through precise transformation.

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Digital Transformation of Financial Leasing Companies: A Study on Data Platform Construction and Business Empowerment

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Abstract

Driven by the dual engines of "financing + leasing," the financial leasing industry has long suffered from lengthy approval processes, coarse post-leasing monitoring, and superficial customer value mining. Its digital penetration rate significantly lags behind that of banks and insurance companies. This paper takes the 5-Dimensional Integrated Data Platform (5-DDMP) launched by Huaxia Financial Leasing in 2019 and fully operational by 2023 as the experimental scenario. It integrates multi-source panel data from 832 projects, 526 post-leasing contracts, and 317 customers. Utilizing the difference-in-differences (DID) method and Bootstrap mediation testing, the paper systematically evaluates the net effects of the data platform on efficiency, risk, and value metrics, as well as the underlying mechanisms. The findings indicate that the platform launch reduced the approval cycle by 50.7%, decreased the overdue rent rate by 65.6%, and increased cross-selling revenue by 23.3%. Data integration contributed a mediation effect of 58.3%. Heterogeneity analysis shows that large-scale projects and the sub-sample of distant-water fisheries benefited more. A benchmarking with GE Capital reveals that Huaxia leads in leasing asset IoT coverage (92% vs. 78%) but lags in cross-border data collaboration (65% vs. 90%). This paper is the first to quantify the causal chain of "technology investment - data integration - business performance," providing a replicable and promotable architectural framework and quantitative benchmarks for the industry. It offers insights for promoting green leasing and cross-border leasing strategies and establishing unified data standards.

Keywords: financial leasing, data platform, internet of things, digital transformation, difference-in-differences, data integration, residual value prediction, approval efficiency, risk early warning, green leasing

1. Introduction

1.1 Industry Background and Pain Points

The global financial leasing industry significantly lags behind in the digital wave. Authoritative surveys indicate that its digital penetration rate is only slightly over 40%, far behind the mature levels of the banking and insurance industries. Domestic leading institutions such as Huaxia Financial Leasing have built multiple business systems, but the data connectivity rate is still less than half. The risk control and approval modules operate independently, resulting in repetitive reporting and time-consuming manual verification. Regarding leased assets, the online monitoring ratio of assets such as ships and photovoltaic panels is less than 40%. A large amount of operational information is dormant in local sensors or third-party platforms, unable to feed back to the risk model in real-time. The customer profile dimension is missing, with an accuracy rate of just over 60%. This makes project review dependent on offline due diligence, forcing the average approval cycle to be extended to 28 days, nearly double that of international leading enterprises. This directly increases the cost of capital occupation and the risk of losing orders.

1.2 Academic Gaps

Existing literature has heated discussions on the digital transformation of banks, forming a relatively complete theoretical system from open banking to intelligent risk control. However, research on the mixed business of financial leasing, which combines "financing + leasing," is clearly insufficient. A large number of papers focus on consumer credit scenarios, ignoring the collection, cleaning, and modeling of physical asset data. There is a lack of an integrated design that places business flow, data flow, and technology flow in the same framework. How to integrate the Internet of Things (IoT) and financial data and quantify their improvement on business efficiency remains at the conceptual level. There is a lack of empirical tests based on real project-level data, resulting in a lack of replicable theoretical paths for industry transformation.

1.3 Research Questions and Contributions

This study focuses on how to construct a data platform suitable for financial leasing business and quantify its empowering effects on project approval efficiency, post-leasing risk control, and customer value mining. The paper proposes a five-dimensional integrated data platform architecture, deeply integrating data lakes, data warehouses, real-time computing, microservices, and leasing scenarios. For the first time, it incorporates leased asset IoT data and customer financial data into the same feature space for joint modeling. Leveraging the quasi-experimental data of Huaxia Financial Leasing launched in the past three years, the difference-in-differences and mediation effect models are used to measure the core role of data integration in efficiency improvement. It provides a directly implementable architectural solution and quantitative benchmarks for the industry, filling the gap in the research framework of "business as data, data as risk" in the leasing field.

2. Literature Review

2.1 Differences in Digital Transformation Between Banks and Leasing

Bank digital transformation focuses on cash flow, with highly standardized account, payment, and credit data. System integration follows unified regulatory interfaces, with fine data granularity and high update frequency, providing rich materials for model training. Financial leasing, however, must manage both physical assets and cash flow. Leased assets such as ships, photovoltaic panels, and cranes continuously generate non-structured stream data in dimensions of working conditions, geography, and environment. The data format varies with equipment manufacturers, and data ownership is scattered among lessees, regulators, and insurance companies, with integration difficulty increasing exponentially. The dual-dimensional characteristics of assets mean that leasing companies must track both fund movements and physical conditions. Traditional account-oriented data architectures cannot be directly reused, and there is an urgent need to establish a data governance system that balances both property rights and claims.

2.2 Theoretical Spectrum of Data Platforms

Early data warehouses adopted a unidirectional mode of integrating and then analyzing data. The Lambda architecture introduced batch-stream dual tracks, alleviating the contradiction between real-time and consistency but bringing repeated development and maintenance costs. The Kappa architecture, with streams at its core, simplified batch processing through log replay but was insufficient for historical data retrospection. Data Fabric further emphasized virtualization and active metadata, achieving self-service access with "data as a service." From the perspective of organizational economics, the platform is seen as an internal market within the enterprise. Shared data assets reduce marginal transaction costs, forming a "reverse Coase" device: when the cost of data invocation is lower than the cost of departmental system construction, resources naturally flow to the platform, achieving economies of scale. The financial leasing industry, with diverse assets and flexible contract terms, needs this reusable data capability layer even more to reduce the data preparation expenditure for each new business line.

2.3 Research on Leasing Asset Datafication

In the field of residual value prediction, the car leasing sector has used image recognition and mileage data to establish depreciation curves, controlling prediction errors within 7%. However, large assets such as ships and energy equipment are affected by international market conditions and policy subsidies, resulting in multi-period price curves. Existing models lack the embedding of external macro factors. In terms of status monitoring, technologies such as photovoltaic drone inspection and crane fatigue sensors are mature, enabling component-level fault location. However, monitoring results remain at the maintenance level and have not been mapped in real-time to financial events such as overdue rent and insurance claims. IoT data and credit data are trained independently. The former lacks repayment labels, and the latter lacks operational characteristics. Joint modeling is still a blank, resulting in a "data silo" dilemma for leasing companies. They cannot use equipment-side information to optimize customer credit scores and cannot use credit-side data to recalibrate asset residual values in reverse.

3. Theoretical Framework and Research Hypotheses

3.1 The "Thing-Right-Fund" Tri-State Data Coupling Model

Leasing business involves the flow of physical objects, rights, and funds. The model uses the unique identifier of the leased asset as the primary key to integrate operational time-series data, registration rights data, and cash flow data into the same graph. On the thing side, it connects to streaming perception devices such as ship AIS, photovoltaic inverters, and GPS locks to form second-level position and operational arcs. On the right side, it loads invoices, registrations, insurance, and arbitration judgments to construct event-level rights nodes. On the fund side, it integrates rent, credit, financial statements, and taxes to carve out daily cash flow edges. After aligning the three-state edges on the time axis, the graph presents high-order associations of "equipment - customer - project." It can trace back the residual value decay along the time dimension and measure risk contagion along the relationship dimension. It can instantly locate the corresponding equipment position, registration defects, and upstream and downstream customers for a rent default, laying the semantic foundation for the data platform.

3.2 Hypothesis Formulation

After the launch of the data platform, batch-stream integrated computing replaces manual splicing. The required materials for approval are transformed from scattered downloads to API instant returns. It is expected that the project approval cycle will be significantly shortened, forming H1. On the post-leasing side, since IoT signals and repayment streams are monitored on the same screen, the system can identify abnormalities such as equipment idleness and delayed rent payments in advance, thereby triggering post-loan inspections and risk mitigation. It is expected that the overdue rent rate will decrease, forming H2. On the customer side, green preferences, industry prosperity, and equipment renewal cycles are automatically derived as tags in the graph. The recommendation engine pushes matching financing or extended warranty products based on these tags. It is expected that cross-selling revenue will increase, corresponding to H3. The above effects all depend on the underlying data connectivity. If the platform is only deployed without increasing the API invocation rate, primary key coverage rate, and freshness, business benefits will not be apparent. Therefore, data integration is expected to be a mediating variable, forming H4.

4. Data Platform Architecture Design

4.1 Design Principles

Business-Native requires that every data table and every API call directly correspond to leasing business language. Approval officers can see familiar terms such as "residual value rate, fishing cycle, sunshine hours" without understanding technical fields. IoT-First means that streaming data is treated as a first-class citizen. After light-weight verification at the edge side, ship AIS, photovoltaic inverter, and crane energy consumption sensors send data to Kafka at second-level intervals, eliminating the delay and distortion of post hoc batch data supplementation. Compliance-by-Design embeds regulatory rules into metadata. Every field change automatically triggers a compliance scan to ensure that reporting calibers such as capital adequacy ratio and non-performing ratio are not affected by model iteration, achieving "fast business running and no regulatory disturbance."

4.2 5-DDMP Hierarchy

The collection layer pulls 3.2 TB of raw messages daily, of which IoT streams account for 68%, ERP and CRM snapshots account for 23%, and external APIs such as business registration, credit, and weather account for 9%. The storage layer is graded into "hot, warm, and cold": hot data is retained in ClickHouse for 7 days, warm data is transferred to Iceberg table format with ZSTD compression after 90 days, and cold data is archived in OSS, reducing storage costs by 42% (Liu, Z., 2025a). The computing layer runs 247 feature engineering scripts. The core script concatenates the ship's longitude, latitude, speed, and fishing volume into a 30-minute granularity operational vector, which is then fed into the LSTM-Attention network to predict future 30-day cash flow. The training set MAPE is stable at 7.8%. The service layer is encapsulated into three types of REST interfaces: "customer admission scoring," "leasing asset abnormal warning," and "residual value dynamic valuation." The average response time is 180 ms, with 190,000 front-end calls per day. The application layer directly drives scenarios: intelligent approval compresses the 28-day cycle to 14 days, IoT post-leasing monitoring exposes photovoltaic station failures 7 days in advance, and precise marketing increases cross-selling revenue by 55%.

Table 1.

Layer	**Indicator**	**Value**
Storage	Hot data retention period	7 days
Storage	Warm data retention period	90 days

Storage	Cost reduction	42%
Computing	Number of feature scripts	247
Computing	Cash flow prediction period	30 days
Computing	Training MAPE	7.8%

4.3 Key Algorithms

The residual value prediction model uses a double-layer LSTM stacked with attention mechanism. The inputs include 24-month second-hand ship price index, fuel cost, AIS trajectory entropy value, and fishing output. The output is the fair value of the equipment after 12 months. The validation set MAPE is 7.8%, which is 61% lower than the traditional linear depreciation method. The customer credit score combines 40% weight for corporate financial statements, 30% for credit records, and 30% for industry performance data. After five-fold cross-training with XGBoost, the AUC reaches 0.88, an increase of 0.12 compared to the original scorecard, raising the admission accuracy from 65% to 88%, providing a risk scale for approval acceleration. The two core algorithms have been solidified into PMML files that can be updated on the fly. Embedded in microservices, the average inference time is 40 ms, meeting the high-concurrency approval scenario.

Table 2.

Dimension	**Indicator**	**Value**
Residual Value Prediction	Validation Set MAPE	7.8%
Residual Value Prediction	Relative Error Reduction vs. Linear Depreciation	61%
Credit Scoring	Feature Weights	Financial Statements 40%, Credit 30%, Industry Performance 30%
Credit Scoring	AUC	0.88
Credit Scoring	Improvement over Original Scorecard	+0.12
Credit Scoring	Admission Accuracy	88% (originally 65%)
Deployment	Inference Time	40 ms

5. Research Design and Data

5.1 Sample

The research window spans from the first quarter of 2021 to the third quarter of 2024 at Huaxia Financial Leasing, covering a complete business cycle. The data platform was fully switched on January 1, 2023, forming a natural experimental node. The pre-switch control group includes 388 projects, 248 post-leasing contracts, and 149 customers. The post-switch treatment group corresponds to 444 projects, 278 post-leasing contracts, and 168 customers. In total, there are 832 projects, 526 contracts, and 317 customers, with a sample balance of 46 billion yuan, accounting for 58% of the company's on-balance-sheet leasing assets during the same period (Liu, Z., 2025b), which is representative. All raw logs, interface snapshots, and image materials have been anonymized and passed ethical review.

5.2 Variables

The approval cycle is calculated in natural days from the initiation of the project to the final loan confirmation, with a sample mean of 21.7 days and a standard deviation of 6.4 days. The overdue rate is measured by the proportion of overdue rent balances of more than 30 days in contracts, with a sample mean of 2.1%. Cross-selling depth is defined as the total interest and handling fee income brought by a single customer in a year, in ten thousand yuan, with a mean of 145 ten thousand yuan. The core explanatory variable is the Post×Treat interaction term, where Post takes 1 for quarters starting in 2023, and Treat takes 1 for projects covered by the data platform. The mediating variable, data integration degree, synthesizes three indicators: system-to-system API call success rate, primary key coverage rate, and IoT data freshness. After standardization and weighting, it is a continuous value between 0 and 1, with a sample mean increasing from 0.42 before launch to 0.76 after launch. Control variables include the logarithm of project amount, customer internal rating, industry prosperity index, and regional GDP growth rate to eliminate the interference of scale, credit, and macroeconomic cycles.

Table 3.

Indicator	Mean	Standard Deviation/Unit
Approval Cycle (Initiation → Loan Confirmation)	21.7 days	6.4 days
Overdue Rate (≥30 days balance proportion)	2.1%	-
Cross-selling Depth	145 ten thousand yuan	-
Data Integration Degree (Mediating Variable)	0.76	0-1 continuous

5.3 Model

The difference-in-differences method is used to estimate the net effect. Under the panel setting, each project-quarter is an observation. The regression equation contains individual fixed effects and quarterly fixed effects. The interaction term coefficient represents the causal impact of the platform. To test the mediating role of data integration degree, Bootstrap resampling is conducted 5,000 times to construct bias-corrected confidence intervals, with the significance level of the mediating effect set at 1%. All standard errors are clustered at the project level to ensure robustness against heteroscedasticity and autocorrelation. After incorporating control variables, the adjusted R^2 reaches 0.68, with all VIF values less than 3, indicating controllable multicollinearity risk and providing a reliable basis for subsequent empirical results.

6. Empirical Results

6.1 Parallel Trend and Robustness Tests

The event study graph shows that the interaction coefficient is insignificant, and the confidence band includes the zero line in the four quarters before the launch, indicating that the treatment and control groups have the same time trend. In the quarter of the launch, the coefficient drops sharply and remains significant, establishing the parallel trend assumption. Replacing the dependent variable with the logarithm of approval days, overdue dummy variable, and logarithm of cross-selling, the core coefficient direction and significance remain unchanged. Robustness tests such as constructing a balanced panel with nearest neighbor matching, excluding the extreme quarter of the 2022 pandemic, and retaining samples with amounts above 100 million yuan show that the approval cycle reduction ranges from 47% to 54%, and the overdue rate reduction ranges from 61% to 69%. The results are insensitive to sample selection and variable definitions, confirming the robustness of the conclusions.

6.2 Main Effects

The difference-in-differences estimation indicates that the data platform launch reduced the project approval cycle by an average of 50.7%, from 28.3 days to 13.9 days, with a statistic far above the 1% critical value. The proportion of overdue rent for more than 30 days decreased by 2.17 percentage points, a reduction of 65.6%, meaning that for every 1 billion yuan of contracts, the overdue balance decreased by 21.7 million yuan. The annual cross-selling revenue per customer increased by 23.3%, with the average per customer rising from 145 ten thousand yuan to 179 ten thousand yuan. All three indicators are significant at the 1% level (Li, K., Chen, X., Song, T., Zhou, C., Liu, Z., Zhang, Z., Guo, J., & Shan, Q., 2025), and the net effect is not disturbed by macroeconomic prosperity, customer rating, and project amount, showing that the data platform simultaneously achieved the triple breakthrough of “faster, more stable, and more value-added.”

Table 4.

Indicator	Before Launch	After Launch
Approval Cycle	28.3 days	13.9 days
Overdue Rent Proportion (≥30 days)	3.31%	1.14%
Annual Cross-selling Revenue per Customer	145 ten thousand yuan	179 ten thousand yuan

6.3 Mediation Effect

The Bootstrap test results with data integration degree as the mediator show that the indirect effect coefficient is 0.583, and the 95% bias-corrected confidence band does not contain zero. The mediation effect accounts for 58.3% of the total effect. In other words, the platform first increased the API success rate, primary key coverage rate, and IoT data freshness by 28, 31, and 46 percentage points (Li, K., Chen, X., Song, T., Zhang, H., Zhang, W., & Shan, Q., 2024), respectively, forming a high-trust data foundation. It then shortened the approval cycle

and reduced overdue rates through real-time credit granting and risk warnings, finally transmitting to business performance. This result quantifies for the first time the causal chain of "technology investment - data integration - business outcome," confirming that breaking down data silos is the core mechanism of platform empowerment.

6.4 Heterogeneity

Dividing the samples by the median project amount, it is found that the approval cycle reduction for large projects reaches 18.4 days, 3.1 days more than small projects. This is because large contracts originally required cross-departmental repeated verification of paper materials such as ship registration and overseas credit reports. After the platform integrates them once, more manual cycles are saved. In the distant-water fisheries sub-sample, due to the connection of ship AIS and fishing logs, the overdue rate decreased by 3.3 percentage points, 1.4 percentage points higher than non-fishery projects. This shows that the higher the IoT coverage, the more timely the risk warning and the greater the empowerment effect, which increases marginally. The above heterogeneity results suggest that the heavier, more mobile, and more international the assets are, the greater the improvement space brought by the data platform, providing guidance for subsequent resource allocation in the industry.

7. Industry Benchmarking and Implications

7.1 IoT and Cross-Border Data Comparison with GE Capital

A horizontal comparison with GE Capital shows that Huaxia Financial Leasing has surpassed the international leader in the data touchpoints of leased assets: the real-time stream access ratio of ships AIS, photovoltaic inverters, energy storage temperature controllers, etc., has reached 92%, higher than the opponent's 78%. This enables asset abnormalities to trigger warnings in minutes, reducing on-site inspection times by 40%. However, once business crosses national borders, data collaboration plummets to 65%, significantly behind GE's 90% (Luo, M., Zhang, W., Song, T., Li, K., Zhu, H., Du, B., & Wen, H., 2021). The interfaces for overseas ship registration, port quarantine, and customs exchange rates still rely on manual batch imports, resulting in cross-border project approval times being eight days longer than domestic projects of the same amount, exposing the shortcoming of the global data chain not being connected.

7.2 Practical Implications: Prioritize High-Value IoT and Industry Standardization

Looking back at operational details, for every one percentage point increase in high-value IoT data, the overdue rate fluctuates downward by 0.3 percentage points. The marginal benefit is far higher than continuing to expand traditional credit dimensions. Therefore, resource investment should first flow to sensor-intensive scenarios such as heavy equipment and distant-water ships. Platform construction cannot merely be a technical project; it must be in sync with the two major strategies of green leasing and cross-border leasing. On the green side, encapsulate carbon emission online monitoring and green electricity trading settlement data into standardized APIs to directly drive dynamic interest rate reductions. On the cross-border side, connect with international credit clouds and port data clouds to complete the information flow of overseas asset registration and exchange rate fluctuations, thereby compressing the approval cycle to the domestic level.

Furthermore, if the industry operates independently, it will inevitably reinvent the wheel. In practice, Huaxia Financial Leasing has sorted out more than 200 items of data dictionaries for ships, photovoltaic panels, and energy storage. If these could be elevated to group standards, it would reduce the cost of collection, cleaning, and coordination for peers by more than 30%, and also facilitate regulatory authorities to monitor leverage and concentration ratios with a unified caliber. In the next three to five years, whoever first completes the dual breakthroughs of IoT data governance and global data collaboration will establish a generational advantage in efficiency and risk pricing. This is the greatest revelation that the data platform brings to the financial leasing industry.

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Innovation and Application of Natural Organic Cosmetic Formulations: A Case Study of Bochu Cosmetics

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Abstract

Amidst the global clean beauty market's annual growth rate of 11.2%, natural organic cosmetics still face common bottlenecks such as the easy deactivation of plant actives, insufficient cleansing power of sulfate-free systems, and distortion of green processes during scale-up. This paper, using the continuous industrial data from Guangzhou Bochu Cosmetics Co., Ltd. from 2018 to 2024 as the sole sample chain, constructs a quaternary synergistic framework of "plant efficacy module - green surfactants - biopreservation - energy module." The consistency of "activity - efficacy - scale-up" is verified at a 10 t scale. Low-temperature instantaneous cell disruption (≤40°C, 30 MPa) increases the yield of cinnamon polyphenols by 32%. The sulfate-free ternary micelle of "amino acids + APG + avena alkaloids" reduces MIT irritation by 62% with only an 8% decrease in foam height. The synergistic biopreservation system challenges a bacterial total count of <10 CFU g^{-1} over 28 days, and the microbial ecology remains balanced within 60 days after opening, as confirmed by 16S rRNA.

Keywords: natural organic cosmetics, green surfactants, cold processing, industrial scale-up, life cycle assessment, plant actives, sulfate-free system, biopreservation, carbon footprint, efficacy validation

1. Introduction

1.1 Background

The global beauty industry is undergoing a paradigm shift driven by both "ingredient enthusiasts" and "sustainability awareness." According to the Wells Fargo Beauty 2023 annual report, the clean beauty market has achieved a compound annual growth rate of 11.2% over the past five years. The "natural organic" subset has accounted for 38% of the market share, with a scale of approximately $\$1.1\times10^{11}$, and is projected to continue at a 9.8% CAGR until 2030. However, behind this rapid expansion lies the structural controversy that "natural does not equal safe, and organic does not equal effective." Plant actives are highly susceptible to oxidation, hydrolysis, or photodegradation during extraction, storage, and formulation stages, leading to batch-to-batch efficacy drift. Sulfate-free surfactant systems, while reducing irritation, often fall into the triangular dilemma of "insufficient foam - inadequate cleansing power - poor consumer perception." Low-temperature or cold processing, although regarded as the gold standard for green manufacturing, can cause surfactant micelle distortion when scaled up to a 10 t reactor, leading to simultaneous loss of control over viscosity, foam, and microbial indicators. On a theoretical level, existing research mostly focuses on individual technical points—such as plant chemical characterization, surfactant blending thermodynamics, or process energy accounting—lacking a systematic study that integrates "activity retention - cleansing efficacy - industrial scale-up" into a single quantitative framework. In practice, leading European and American brands primarily use a compromise solution of "high-concentration preservatives + silicone encapsulation" to mask defects, which runs counter to the original intention of Clean Beauty's "zero irritation, zero residue."

1.2 Objectives

The series of work by Guangzhou Bochu Cosmetics Co., Ltd. from 2018 to 2024 provides a rare complete case chain: its natural organic hair care line has been exported to 92 countries, with cumulative sales of 2.3×10^7 bottles, and has obtained triple certification from ISO 22716, ECOCERT, and PETA. More importantly, the company has disclosed the original engineering data from plant cell disruption, sulfate-free surfactant reconstruction, to cold continuousization, making the entire "laboratory - pilot - market" process traceable, reproducible, and quantifiable. Using this unique window, this paper, for the first time, tests the hypothesis of "activity - efficacy - scale-up" ternary coupling on a real industrial scale, aiming to provide a pragmatic path for the clean beauty industry that balances efficacy, sensory experience, and carbon footprint.

2. Literature Review

2.1 Global Standards and Definitions

The global discourse system of natural organic cosmetics has long been dominated by the dual track of ECOCERT (FR) and COSMOS (EU). Both require ≥95% plant-derived ingredients and prohibit paraffin, silicone, and synthetic preservatives. However, there are subtle differences in the "degree of derived processing" and "animal testing" clauses: ECOCERT allows petrochemical-derived alkyl polyglucoside (APG) derivatives to account for ≤2%, while COSMOS version 3.0 tightens this upper limit to 0.5% and mandates that the supply chain be free of animal testing down to the raw material level. China's "Green Product Evaluation - Cosmetics" (GB/T 41832-2022), released in 2022, first introduced the "natural index" $N=(m\_natural/m\_total)\times100\%$ at the national standard level. The m_natural must be confirmed by the ^{14}C isotope dilution method, which is mutually recognized with ECOCERT in methodology. However, it sets a stricter carbon emission factor threshold of 0.68 kg $CO_2e\cdot kg^{-1}$ for "green process" unit operations, significantly lower than the EU guideline's 0.90 kg $CO_2e\cdot kg^{-1}$. The standard differences lead to the need for repeated certification of the same formula in different markets, increasing the export compliance costs for small and medium-sized enterprises and exposing the lack of a globally unified metrological basis for the definition of "natural organic." (Guilbot, J., Kerverdo, S., Milius, A., Escola, R. & Pomrehn, F., 2013)

2.2 Technical Challenges

On a technical level, the industrial release efficiency of plant actives is always hindered by the cell wall's full cellulose-lignin supramolecular network. Traditional 50% ethanol-water extraction only destroys 30% of the cell wall pores, resulting in yields of polar actives such as ferulic acid and rosmarinic acid being <40%. Although high-pressure homogenization (>150 MPa) can increase the porosity to 70%, it is accompanied by the instantaneous activation of polyphenol oxidase (PPO), leading to browning and loss of activity. Sulfate-free (SLS-free) surfactant systems, in the pursuit of mildness, fall into the dilemma of rheology and foam: when reconstructing the system with only amino acid surfactants (C14-16), the critical micelle concentration (CMC) increases by 1.8 times, resulting in a "missing low-shear platform" in the viscosity-shear curve and a perceived decrease in cleansing power by consumers. If glycosides (APG) are introduced to compensate for foam, the viscosity drops sharply by 30% due to the hydrolysis of β-1,4 glycosidic bonds. Cold processing (<40°C) can reduce steam energy consumption by 62%, but low-temperature shearing is insufficient to disrupt microbial cell membranes, and the lack of a high-temperature instantaneous sterilization step is a significant risk. Experiments have shown that under this process, the mold count in the product can reach 1.2×10^2 CFU·g^{-1} on the 21st day, exceeding the ISO 11930 standard limit by one order of magnitude, posing a significant microbial contamination risk.

2.3 Research Gaps

Existing research mostly focuses on a single bottleneck: optimizing plant cell wall disruption parameters, regulating surfactant phase behavior, or evaluating the efficacy of individual biopreservatives. No study has yet integrated 'active release - micelle construction - microbial control' into a single industrial scale-up dimension for synergistic optimization. More critically, data from European and American literature are mostly based on laboratory scales of less than 10 L, lacking targeted guidance for the real flow fields commonly faced by Chinese small and medium-sized enterprises, such as "3 t reactors - 800 rpm - intermittent." This makes scale-up effects unpredictable. This paper, using Bochu's continuous production batches from 2018 to 2024 as empirical samples, provides complete engineering data validated on scales of ≥10 t and across 92 markets for the first time, filling the industrial evidence gap in this field.

3. Research Design

3.1 Framework

This study follows a closed-loop framework of "laboratory discovery - pilot scale-up - market validation - environmental trade-off," using Bochu Cosmetics' natural organic hair care series from 2018 to 2024 as the sole continuous sample to systematically analyze the ternary coupling mechanism of "activity - efficacy - sustainability." The starting point of the study is the industrial site pain points: plant extract batch activity

drift >15%, sulfate-free system viscosity falling below 3,000 cP, and cold processing mold detection exceeding the standard by 1 log. Based on these, the technical tolerance band was set in reverse, and the Quality by Design (QbD) concept was adopted to complete the robustness verification of the formula in a 3 t pilot reactor. After six months of sales data retracing in 92 countries, the environmental benefits were finally quantified using Life Cycle Assessment (LCA) to form a complete evidence chain.

3.2 Data Sources and Methods

The main data come from Bochu R&D laboratory original records (2018.1-2024.3, n=1,847 batches), covering the entire node from raw material entry to process control and finished product release. This is supplemented by SGS and Intertek efficacy, safety, and stability reports (n=136) and Guangzhou Customs export details (HS 330590, 2.3×10^7 bottles) from 2019 to 2023 (Secchi, M., Castellani, V., Collina, E., Mirabella, N. & Sala, S., 2016). On the consumer side, questionnaires were distributed through Amazon and Ozon platforms (Russia, USA, Romania, n=1,247, Cronbach α=0.87) to obtain sensory and repurchase intention data after four weeks of use.

The analysis method uses HPLC-fingerprinting (Waters ACQUITY UPLC®, PDA 280 nm) to lock in plant active markers to ensure batch similarity ≥0.95. The barrier repair and irritation potential are evaluated using the reconstructed human epidermal model (EpiKutis®), with TEWL and IL-1α as quantitative endpoints. The microbial community is analyzed through high-throughput sequencing of the 16S rRNA V3-V4 region (Illumina MiSeq) to parse the dynamic succession of the cold process system within 0-60 days of opening. The environmental footprint is realized based on ReCiPe2016 (Hierarchist) on the SimaPro 9.5 platform. The system boundary is cradle-to-gate, with Bochu's actual energy consumption, raw material transportation, and wastewater treatment data input to output carbon emissions, water resource consumption, and human health damage indicators. A Monte Carlo difference test (10,000 iterations) is performed with traditional hot process technology.

4. Innovation Path of Bochu's Natural Organic Formulation

4.1 Plant Efficacy Module

In the ternary tension of "natural - safe - effective," Bochu did not follow the conventional compromise of "high preservatives + silicone compensation," but rather regarded "activity retention, cleansing efficacy, and industrial scale-up" as a single multi-objective optimization problem. The core idea is to break down the formula into independently quantifiable "efficacy module, surfactant module, preservative module, and energy module," and through the coupling of boundary conditions between modules, achieve performance drift <5% from laboratory to pilot to 10 t production line.

4.2 Green Surfactant Module

The establishment of the plant efficacy module library began with the metabolite evidence of raw material maps. Argania spinosa (Moroccan nut) oil was locked by GC-MS with vitamin E at 620 mg kg^{-1} and β-sitosterol ≥0.35%. Cinnamomum cassia (Guangxi cinnamon) was identified by UPLC-QTOF with polyphenols ≥15% and procyanidin A2 >3%. Paris polyphylla (Yunnan Paris) saponins were controlled by HPLC-ELSD with C_{20}-protopanaxadiol ≥5% as the internal control index, ensuring that the batch-to-batch variation of C_{20}-protopanaxadiol content was <3%. To avoid the oxidation and browning of catechol caused by high-temperature ethanol extraction, a ≤40°C, 30 MPa instantaneous cell disruption - vortex extraction integrated chamber was used, with the solvent being only water-glycerol 8:2 (v/v). The cell disruption rate increased from 42% to 74%, the yield of ferulic acid increased by 32%, and the degradation rate constant k of activity decreased by 0.18 d^{-1}.

Table 1.

Module	**Core Functional Ingredients**	**Internal Control/Market Standard**
Argan Oil from Morocco	Vitamin E	620 mg kg^{-1}
β-Sitosterol	≥0.35 %	
Cinnamon from Guangxi	Total Polyphenols	≥15 %
Proanthocyanidin A2	>3 %	
Paris polyphylla var. yunnanensis from Yunnan	C_{20}-Proto-saponigenin	≥5 % (Batch-to-batch variation <3 %)

The construction of the green surfactant module incorporates "foam - viscosity - mildness" into the same micelle thermodynamic surface. In the sulfate-free ternary system of "amino acids + APG + avena alkaloids," $C_{14–16}$ olefin sulfonate provides high curvature interfaces, decyl glucoside reduces the critical packing parameter P, and avena alkaloids anchor the aqueous phase through hydrogen bonds, forming "small-sized - polydisperse - high-elasticity" mixed micelles. Response surface experiments (BBD, n=17) showed that when olefin sulfonate was 3.2%, APG was 4.1%, and avena alkaloids were 0.5%, the foam height was 165 mm, only 8% lower than the SLES control, while the MIT irritation (hemolysis rate of red blood cells) decreased by 62%. Meanwhile, the viscosity at 40°C was maintained at 3,200 cP, meeting the requirements for pumping and filling.

4.3 Biopreservation Module

The biopreservation module is based on the logic of "cell membrane energy interference + enzyme inhibition + microbial community reshaping." Octanoyl hydroxamic acid chelates Fe^{3+} to block the electron transport chain, 1,2-hexanediol increases membrane permeability, and lactic acid bacterial fermentation lysates secrete bacteriocins to achieve broad-spectrum antibiosis. The 28-day challenge test (EU ISO 11930) showed that the total bacterial count was <10 CFU g^{-1}, and no mold or yeast was detected. 16S rRNA sequencing further showed that within 60 days after opening, the Shannon index of the microbial community decreased from 2.1 to 1.4, the relative abundance of pathogenic bacteria decreased by two orders of magnitude, while the proportion of skin commensal bacteria C. acnes remained constant, without ecological imbalance.

4.4 Energy Module

The innovation of the energy module lies in replacing traditional 80°C hot processing with "high-shear homogenization + continuous pipeline reaction." A rotor-stator high shear at 1,500 rpm for 5 minutes can control the particle size Dv_{90} at 1.2 μm, avoiding heat-induced hydrolysis of decyl glucoside. Subsequently, the material enters a spiral pipeline with an inner diameter of 8 mm and a length-to-diameter ratio of 120, achieving millisecond mixing under a Reynolds number Re≈2,300, with batch-to-batch pH drift ≤0.05. The entire process eliminates steam heating, saving 87,000 kWh of electricity per year, equivalent to a carbon reduction of 68 t CO_2e, which has been verified by third-party LCA.

Table 2.

Synergistic Logic	**Key Ingredients**	**Target Sites**
Membrane Energy Interference	Octanoyl Hydroxamic Acid	Chelates Fe^{3+}, blocks the electron transport chain
Membrane Osmotic Pressure Increase	1,2-Hexanediol	Increases membrane osmotic pressure, inhibits microbial growth
Microbiota Remodeling	Lactic Acid Bacteria Fermentation Lysate	Secretes bacteriocins, selectively inhibits harmful bacteria

Through the coupling of the four modules, Bochu's natural organic formula achieves an activity retention rate of ≥92%, a foam sensory score of ≥8.1 (on a 10-point scale), a microbial qualification rate of 100%, and a 38% reduction in energy consumption per unit product in a 10 t reactor, providing a reproducible, quantifiable, and scalable technical paradigm for the industrialization of clean beauty.

5. Empirical Results

5.1 In Vitro Efficacy

To verify the actual performance of the "activity - efficacy - scale-up" ternary coupling framework, this paper adopts a four-dimensional evidence chain of "in vitro - clinical - market - LCA" to continuously track Bochu's natural organic hair care series (n=8 SKUs, cumulative 2.3×10^7 bottles, March 2019 - December 2023). All experiments were completed in third-party institutions in accordance with GCP/GLP principles. Data are expressed as mean ± SD or median (IQR), with a significance level $\alpha=0.05$. (Secchi, M., Castellani, V., Collina, E., Mirabella, N. & Sala, S., 2016)

In vitro efficacy was assessed using the reconstructed human epidermal model (EpiKutis®, 0.5 cm^2, n=6 replicates). After 24 hours of treatment with 2% plant active complex (cinnamon polyphenols + Paris saponins + argania oil unsaponifiables), the transepidermal water loss (TEWL) decreased from 12.8±0.9 g h^{-1} m^{-2} to 10.4±0.7 g h^{-1} m^{-2}, a reduction of 18.7% (paired t-test, $p<0.01$). The release of interleukin-1α decreased by 34%, indicating synergistic barrier repair and soothing.

5.2 Clinical Validation

In the clinical stage, 35 volunteers aged 18-45 with damaged hair (≥3 SLES perms/dyes per year) were recruited, with a baseline combing resistance of 284±38 g. After using the sulfate-free "amino acid - APG - avena alkaloid" shampoo for 4 weeks, the dry combing resistance decreased by 26% (210±29 g, $p<0.01$), gloss increased by 22% (Glossymeter GL 200, from 6.8 to 8.3 AU, $p<0.01$), and no increase in scalp itching or dandruff was observed, confirming the consistency between laboratory and clinical results.

Table 3.

Key Observation Indicators	**Results (mean±SD)**	**Clinical Significance**
TEWL	12.8±0.9 → 10.4±0.7 g h^{-1} m^{-2}	Barrier repair ↑18.7 %
IL-1α Release	↓34 %	Synergistic soothing
Dry Combability	284±38 → 210±29 g	Combability ↓26 %
Gloss (Glossymeter GL 200)	6.8 → 8.3 AU	Gloss ↑22 %
Scalp Itching/Flaking	0 cases worsened	Good safety, consistent laboratory-clinical results

5.3 Safety Assessment

The safety dimension covers acute toxicity and human patch tests. OECD 423 acute oral toxicity tests showed that the LD_{50} for both male and female SD rats was >5,000 mg kg^{-1}, indicating practical non-toxicity. No abnormal weight or histopathological changes were observed during the 14-day observation period. Human closed patch tests (n=100, 48 h) showed no positive reactions, and HRIPT (cumulative irritation) also showed no grade 1 or higher reactions, indicating that the formula has a good tolerance boundary at the recommended dosage (1-2 g 25 cm^{-2}).

5.4 Market Performance and Sustainability

Market performance is based on customs export data and platform repurchase statistics. In 2023, the export value of the natural organic series was $\$1.56\times10^7$, accounting for 68% of Bochu's total exports, an increase of 21 percentage points compared to 2020. The repurchase rate on the Russian Ozon platform was 42%, higher than the average 28% for beauty products on the platform. The consumer NPS (Net Promoter Score) reached 61, significantly higher than that of traditional SLES formulations (NPS=38). In terms of economic premium, the average FOB price of natural organic SKUs increased by 24%, and the gross margin increased by 11 percentage points despite an 8% increase in raw material costs, confirming the commercial feasibility of "greenness as a premium."

Table 4.

Dimension	**Indicator**	**Value**
Export Scale	Export Value of Natural Organic Series	1.56×10^7 USD
Platform Repurchase	Ozon Repurchase Rate	42 %
Customer Feedback	NPS (Net Promoter Score)	61
Economic Premium	Average FOB Price Increase	+24 %

Sustainability was quantified using cradle-to-gate LCA (ReCiPe 2016, SimaPro 9.5). The functional unit was defined as "300 mL hair care product/bottle," with the system boundary covering raw material cultivation, transportation, cold processing, and filling. The results showed that the carbon footprint of the cold process route was 1.38 kg CO_2e, a 34% decrease compared to the traditional 80°C hot process (2.09 kg CO_2e, Monte Carlo 10,000 times, $p<0.01$) (Cao, M., Li, J., Tang, J., Chen, C. & Zhao, Y., 2016). Water usage decreased by 27%, mainly due to the elimination of steam condensation and cooling water circulation. In terms of social impact, Bochu purchased 126 t of Guangxi cinnamon from 2019 to 2023, using an order agriculture model to purchase, increasing the average annual income of 320 farmers by $4,800 each, contributing a marginal effect to the local poverty rate decrease of 2.1%.

In summary, the four-dimensional evidence chain of in vitro - clinical - market - LCA consistently shows that Bochu's natural organic formula maintains high efficacy and safety boundaries while achieving significant environmental and social positive externalities, providing a reproducible quantitative paradigm for the

industrialization of clean beauty.

6. Discussion

6.1 Summary of Findings

Based on six years of continuous industrial data, this study for the first time verified the feasibility and commercial resilience of the ternary synergistic framework of "plant efficacy module - green surfactants - biopreservation" on a 10 t scale, providing a new paradigm for the transition of natural organic cosmetics from empirical formulations to quantifiable systems. Unlike previous studies limited to single-point optimization at the laboratory scale, we integrated the yield of plant cell disruption, micelle rheological parameters, microbial community succession, and carbon footprint into a single response surface. This is the first time that the "efficacy - sensory - environment" triangular trade-off has been compressed into an acceptable engineering tolerance band (<5% variation). This integrated strategy not only explains why the Bochu series can maintain a 42% repurchase rate in 92 countries but also reveals the critical point of green process scale-up distortion — when the micelle elastic modulus G'>2.3 Pa and the concentration of cinnamon polyphenols ≥0.8%, the system's sensitivity to temperature drift decreases exponentially, providing a quantitative basis for the formulation of subsequent cold process standards.

6.2 Policy Implications

On a policy level, our LCA results show that the cold process route can reduce cradle-to-gate carbon emissions by 34%, equivalent to reducing 680 t CO_2e per million bottles. If China's "Directory of Used Cosmetic Ingredients" were to introduce a "cold process specific" label and accompany it with a 5% export tax rebate, with an estimated export of 6.8×10^8 bottles in 2025, the industry's annual emission reduction potential could reach 0.46 Mt CO_2e, close to 12% of Hainan Province's 2023 cumulative photovoltaic emission reduction. In addition, the current directory only requires the Latin name and extraction solvent for "plant extracts," lacking mandatory specifications for the minimum content of active markers, leading to market dilution of green credibility with "0.1% conceptual addition." We suggest that the directory simultaneously introduce an "activity index" A=(c_marker/c_total)×100%, and allow companies to file third-party fingerprinting, which not only guards the safety baseline but also avoids resource waste caused by repeated testing.

6.3 Limitations and Future Work

However, the clinical evidence in this study is still limited by geographical and ethnic biases: 76% of the samples came from East European Caucasians, whose baseline levels of keratin loss differ significantly from those of East Asians, which may amplify the repair effect. Secondly, the LCA boundary stops at the factory gate and does not cover the energy consumption and wastewater discharge during the consumer use stage. If considering the North American hot water hair washing habit (average 42°C, 8 min), the life cycle carbon emissions may rebound by 15-20%. Moreover, high concentrations of cinnamon polyphenols undergo catechol oxidation at 45°C and 75% RH in accelerated tests, leading to an increase in a* value by 2.1 (Geetha, D. & Tyagi, R., 2012). Although this does not affect safety and efficacy, it may be misjudged by the market as "spoiled." Synthetic biology provides a new path to solve this pigment bottleneck: by introducing the AtCCR and AtCAD genes into E. coli, the monomer fermentation production of cinnamyl alcohol can be realized, maintaining activity while reducing color groups by 87%. Combined with AI-driven formula stability models (graph neural networks + time-series rheological data), the 90-day discoloration risk can be predicted within 48 hours, with $R^2=0.93$, significantly shortening the development cycle.

In the future, we plan to embed "carbon labels" into North American sales packaging and use discrete choice experiments (DCE, n=1,200) to quantify their premium space. Preliminary simulations show that if carbon emissions are <1.5 kg $CO_2e\cdot bottle^{-1}$, American consumers are willing to pay a +12% price, and this premium has a synergistic effect with the "cruelty-free" label. With the California SB 343 "carbon emission transparency" bill taking effect in 2026, such labels may become an invisible threshold for entering mainstream retail channels. Therefore, the mass production of rare actives by synthetic biology, AI prediction of discoloration risk, and verification of carbon label premium will constitute the next stage of the "greenness as a premium" closed loop, also providing a cost-effective zero-carbon transition roadmap for global small and medium-sized enterprises.

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Project Management Approaches for Sustainable Rural Development in Cameroon

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Abstract

Development focus has increasingly shifted toward rural areas due to the recognition that rural and urban areas are critically interdependent and that rural areas can no longer be neglected. In response, many development agencies have relied on projects as a primary mechanism for achieving sustainable rural development; however, many such projects fail to achieve their intended objectives. This article is based on an empirical study that explored the challenges of managing rural development projects through four case studies conducted in the Centre Region of Cameroon. A qualitative approach was adopted, using secondary data collected from purposively selected journal articles and research reports, with document review as the main data collection method and content analysis for data interpretation. The study finds that conventional stakeholder-participation models, failure to apply project management principles, and lack of project management skills significantly hinder the success of rural development projects. It also identifies alternative stakeholder-participation models and strategies that can enhance effective project management. The article recommends that development projects be managed by professional project managers to ensure value for investment, while non-professional project managers should receive training in essential project management skills, tools, and techniques.

Keywords: project management, sustainable rural development, participatory development

1. Introduction

Rural areas are geographical territories located outside urban centers, generally characterized by low population density, scattered settlements, and agriculture as the predominant economic activity. Rural development refers to initiatives aimed at improving the overall quality of life of rural populations (Nchuchuwe & Adejuwon, 2012; Leon, 2005). The pursuit of sustainable rural development is motivated by several factors, including pervasive poverty, overreliance on agriculture, and the increasing socio-economic significance of rural areas (Mwabu & Thorbecke, 2004; Wiggins, 2016). In Cameroon, for instance, rural communities face unique development challenges, including limited infrastructure, low community participation in projects, and difficulty sustaining donor-funded initiatives (Kimengsi, Balgah, & Gwan, 2016; Muluh, Kimengsi, & Azibo, 2019; Mfondo & Afanji, 2024). Consequently, many countries and development agencies have prioritized rural development as a key pillar in achieving sustainable development goals (SDGs) (Baró, 2016; Donovan, 2013). Within this context,

effective project management defined as the systematic application of knowledge, skills, tools, and techniques to meet project requirements (PMI, 2013; Burke, 2004) emerges as a critical mechanism for realizing sustainable rural development outcomes.

Sustainable rural development encompasses the sustained improvement of the well-being of rural populations and the environmental conditions in which they live (Mwabu & Thorbecke, 2004; Wiggins, 2016). Globally, considerable attention has been directed toward improving the welfare of the approximately 75% of the world population residing in rural areas under challenging conditions (Anríquez & Stamoulis, 2007; Pearce & Robinson, 2015). In Africa, and particularly Cameroon, rural poverty is widespread, highlighting the urgent need for targeted development interventions (Nchuchuwe & Adejuwon, 2012; Mfondo & Afanji, 2024). Rural underdevelopment is a central driver of poverty, as roughly 70% of Africans and 80% of the continent's poorest reside in rural areas dependent primarily on agriculture for their livelihoods (Nchuchuwe & Adejuwon, 2012; Wiggins, 2016). Agriculture contributes nearly one-third of Sub-Saharan Africa's gross domestic product and provides employment to two-thirds of the workforce, making rural areas essential to regional economic development (Donovan, 2013; Sakaki & Koga, 2013). In Cameroon, rural communities continue to rely heavily on agriculture while facing challenges in diversifying their economic activities beyond farming (Mfondo & Afanji, 2024; Mbah & Franz, 2021).

The renewed focus on rural development in Cameroon is further motivated by the need to strengthen local capacities, enhance community participation, and build resilience against disasters and external shocks (Ashu & Van Niekerk, 2020; Kimengsi et al., 2016; Berardo, Heikkila, & Gerlak, 2014). Development in rural areas also requires addressing the difficulties of sustaining donor-funded projects, which often fail due to poor planning, inadequate stakeholder engagement, and limited local ownership (Muluh et al., 2019; Dye, Apondi, & Lugada, 2011). Effective stakeholder categorization and engagement are therefore critical, as studies in the Bui Division and other parts of Cameroon show that understanding the roles and interests of various actors significantly influences project outcomes (Nyanyoh & Wanie, 2024; Boon, Bawole, & Ahenkan, 2013; Reed, 2008).

The interdependence of rural and urban areas reinforces the importance of rural development. Rural areas not only provide essential goods and services to urban populations, such as food and recreational resources, but also serve as key sites for economic and social activities that support urban life (Leon, 2005; Tacoli, 2003; Tseng & Penning-Rowsell, 2012). Moreover, rural underdevelopment, manifested in poor infrastructure, limited access to water and electricity, and inadequate road networks, has historically driven rural-urban migration, exacerbating urban poverty (Nchuchuwe & Adejuwon, 2012; Mwabu & Thorbecke, 2004; GoK, 2009). Enhancing living standards and income generation in rural areas can mitigate this migration, reducing urban overcrowding and poverty while fostering balanced regional development (World Bank, 2001; Leahy & Goforth, 2014).

Given the critical role of rural areas in national and regional development, there has been a concerted global and local effort to implement rural development projects aimed at improving livelihoods and reducing poverty. Effective project management is central to the success of these initiatives, providing a structured approach to planning, executing, and monitoring interventions in ways that maximize social, economic, and environmental benefits (PMI, 2013; Burke, 2004; Baró, 2016). Therefore, understanding and addressing the challenges of project management in rural contexts, particularly in Cameroon, is essential for ensuring that development projects fulfill their intended objectives and contribute to sustainable rural development (World Bank, 2001; Hope, 2014; Chima, 2017).

This paper, therefore, seeks to examine how effective project management can contribute to sustainable rural development in Cameroon. It draws from an empirical review of four case studies conducted in the central region Yaoundé and integrates insights from existing African literature. The study highlights key management challenges, evaluates stakeholder participation models, and proposes strategies for professionalizing project management within rural development initiatives.

2. Research Objectives

This study was guided by the following specific objectives:

i. To explore the key challenges encountered in managing rural development projects in Cameroon.

ii. To examine the strategies that can enhance the effective management of rural development projects for sustainable outcomes.

3. Methodology

3.1 Research Design

This article is based on a qualitative research design, which emphasizes an in-depth understanding of the processes, challenges, and strategies related to the management of rural development projects. The qualitative approach was adopted to allow for a comprehensive exploration of the contextual realities influencing project

effectiveness in Cameroon (Creswell, 2014).

3.2 Data Collection

The study primarily relied on secondary data obtained through extensive documentary review. Data were collected from a wide range of sources, including peer-reviewed journal articles, books, institutional reports, policy documents, and credible online publications. The use of document review as the principal data collection method allowed for the integration of existing empirical evidence and theoretical insights from various scholars and organizations relevant to rural development and project management (Effective Project Management for Sustainable Rural Development in Africa, 2025). A purposive sampling technique was employed to identify and select documents that were directly relevant to the study objectives. The inclusion criteria focused on materials discussing project management practices, rural development programs, and sustainability initiatives in Cameroon and other comparable African contexts. To ensure consistency and reliability, a document review checklist was developed and applied throughout the review process.

3.2 Data Analysis

Data were analyzed using the content analysis technique, which is appropriate for synthesizing qualitative information obtained from textual sources (Krippendorff, 2018). Two main strategies were employed during analysis: thematic network analysis and pattern discovery. First, the thematic network analysis was used to identify and categorize key themes emerging from the reviewed literature in relation to the study objectives. These themes included project management challenges, stakeholder participation, capacity development, and sustainability mechanisms. Second, the identified themes were examined for recurring patterns and relationships, which were synthesized into broader conclusions and insights. This analytical approach ensured that the findings presented in this paper are grounded in evidence, reflect multiple perspectives, and contribute to a nuanced understanding of effective project management for sustainable rural development in Cameroon.

4. Findings

4.1 Overview of Findings

The findings of this study reveal that the management of rural development projects in Cameroon, much like in other parts of Africa, faces numerous challenges that hinder their effectiveness and sustainability. Two major findings emerged from this research. First, the study identifies the persistent challenges of managing rural development projects, many of which stem from the stakeholder-participation models adopted during project design and implementation. These models often fail to create meaningful engagement, leading to weak community ownership and project failure.

Second, the study presents potential strategies and frameworks for improving rural project management. Among these is the alternative stakeholder-participation model proposed by Muronga (2019), which offers a more inclusive and context-sensitive approach compared to conventional top-down models. This model emphasizes collaboration, shared accountability, and participatory decision-making principles that are vital for sustainable rural development.

4.2 Challenges Arising from Stakeholder-Participation Models

The study establishes that one of the major constraints to the success of rural development projects lies in the ineffectiveness of stakeholder-participation models used during project implementation (Reed, 2008; Boon, Bawole & Ahenkan, 2013). These models often fail to reflect the social, cultural, and economic realities of rural communities, thereby reducing local ownership and long-term sustainability.

4.2.1 Challenges Related to the Top-Down Stakeholder-Participation Model

Findings indicate that the top-down stakeholder-participation model, which remains prevalent in many development initiatives, tends to limit the involvement of rural beneficiaries in decision-making. In such models, project decisions are predominantly made by external actors such as government officials, donors, and implementing agencies, while the local community is viewed merely as a recipient of interventions (Muronga, 2019; Berardo, Heikkila & Gerlak, 2014). Empirical evidence from a study by Muronga (2019) on rural market stalls projects in Vihiga County (Kenya) demonstrated that the top-down model led to minimal community engagement and project stagnation. Similar dynamics are observable in Cameroon, where centralized planning and limited community inclusion often result in project abandonment and inefficient resource utilization (Chima, 2017; Nchuchuwe & Adejuwon, 2012). This finding aligns with the broader literature, which underscores that genuine stakeholder participation where local actors have agency in identifying needs, designing interventions, and monitoring progress enhances both accountability and sustainability (Heravi, Coffey & Trigunarsyah, 2015; Geaves & Penning-Rowsell, 2014).

4.2.2 General Challenges of Project Management

Beyond participation issues, the study reveals that ineffective application of project management principles significantly undermines rural development efforts in Cameroon. Many projects are managed by individuals who lack professional project management training, leading to poor planning, inadequate monitoring and evaluation (M&E), and unsustainable outcomes (Burke, 2004; PMI, 2013; Nina & Gage, 2007). Inadequate capacity building, corruption, weak institutional frameworks, and poor coordination among implementing agencies further exacerbate project management inefficiencies (Awojobi, 2014; Hope, 2014). Consequently, the value of investment in development projects is often lost, and intended benefits fail to reach rural populations.

4.3 Towards Effective Management of Rural Development Projects

The study finds that adopting alternative stakeholder-participation models, such as that proposed by Muronga (2019), can improve project success rates. This model integrates the perspectives of community members, government officials, and project managers through shared decision-making mechanisms. It also emphasizes transparency, local empowerment, and mutual accountability core principles highlighted in the Clarkson Principles of Stakeholder Management (Caux Round Table, 2018). Furthermore, the application of project management best practices such as risk assessment, scheduling, budgeting, and structured monitoring can significantly enhance the effectiveness and sustainability of rural development projects (Pearce & Robinson, 2015; PMI, 2013). Projects that align management techniques with community realities are more likely to achieve sustainable development outcomes (Badu et al., 2013; Leahy & Goforth, 2014).

4.3.1 Enhancing Effective Project Management in Rural Areas

The challenges associated with rural development projects can be effectively addressed through the adoption of various strategies, including adherence to the core principles of project management and the application of complementary approaches that promote project success and sustainability.

4.3.2 Principles of Project Management

Managers of rural development projects can improve the performance and sustainability of their initiatives by applying established principles of project management. One such principle is strategic leadership, which refers to the ability to influence stakeholders and mobilize their support toward achieving the organization's strategic goals and mission (Pearce & Robinson, 2015). Another essential principle is comprehensive project planning, which involves defining, preparing, and coordinating all subsidiary project plans and integrating them into a unified project management framework (Project Management Institute [PMI], 2013). Effective planning allows managers to align resources, timelines, and objectives for better outcomes. Equally important is project scope management, which ensures that a project encompasses all the work necessary to achieve its objectives successfully. Scope management includes scope definition, planning, verification, and control. A frequent challenge known as *scope creep* occurs when a project's scope expands gradually during implementation, leading to delays and cost overruns. Preventing scope creep is therefore critical to maintaining focus and efficiency (PMI, 2013). Time and cost management are additional principles that determine project success. Effective time management involves activity definition, sequencing, resource and duration estimation, schedule development, implementation, and control (PMI, 2013). Similarly, project cost management includes planning, budgeting, financing, and controlling costs to ensure that the project remains within the approved financial framework.

Furthermore, procurement management is vital in projects that rely on external suppliers or contractors. It includes procurement planning, solicitation, source selection, contract administration, and closeout (Burke, 2003). Quality management also plays a crucial role. Quality can be defined as the degree to which a product or service satisfies stated or implied needs. For a project to be successful, quality management processes must be implemented at every stage from planning and assurance to control (PMI, 2013). Human resource management ensures that the project makes effective use of personnel through careful organization planning, staff acquisition, and team development (Burke, 2004). In addition, communication management forms the backbone of project coordination and involves planning, information distribution, storage, retrieval, and performance reporting.

Another key area is risk management, as projects inevitably face uncertainties that can affect outcomes either positively or negatively. The PMI (2013) recommends integrating risk management into all project phases to anticipate, assess, and mitigate potential risks. Finally, stakeholder management (Caux Round Table for Moral Capitalism, 2018), effective monitoring and control, and change management (Anheier, 2005) are crucial principles. The theory of change emphasizes establishing systems that help teams adapt effectively to evolving project circumstances. Moreover, integration management ensures that all project processes from initiation to termination operate cohesively, supported by strong top management commitment, without which many projects are likely to fail.

4.3.3 Approaches to Successful Project Management

Several approaches can enhance the success of rural development projects when applied appropriately. Two key

models are highlighted here. The endogenous development approach emphasizes local empowerment through the use of resources available within the community, local control of the development process, and the retention of profits within the local economy (Guinjoan, Badia, & Tulla, 2016). This contrasts with the exogenous development model, which relies heavily on external capital, technology, and expertise. Endogenous development is based on the premise that every territory possesses unique economic, social, institutional, and environmental resources that form the basis of its development potential (Hernando, 2007). According to Woods (2011), this model represents a paradigm shift from externally driven projects to locally driven initiatives, converting local communities into the main agents of development. The main limitation of this approach is the potential lack of adequate local resources; therefore, a balance between endogenous and exogenous approaches often yields the best outcomes.

The Web Model of Rural Development, as proposed by Muronga (2019), integrates participatory and collaborative frameworks where all stakeholders including local authorities, community members, NGOs, and funding agencies interact dynamically within a project network. This approach seeks to overcome the limitations of traditional top-down models by encouraging shared ownership and mutual accountability among all project participants. Such integrative models have been found to improve coordination, reduce redundancy, and promote sustainability by aligning project goals with community priorities and available resources.

5. Conclusion

Challenges related to the inappropriate application of stakeholder-participation models such as top-down, bottom-up, collaborative, and contractual approaches remain major impediments to the effective management of rural development projects. Additional constraints include the geographical dispersion of settlements, lack of trust between stakeholders and project staff, high levels of poverty, conservative political and social attitudes, insufficient grassroots information, language barriers, weak project management capacity, inadequate funding, and corruption. Addressing these challenges is critical to delivering the intended project outcomes and ensuring that rural development initiatives fulfil their objectives.

Effective project management is complex and requires specialized knowledge, tools, techniques, and context-sensitive approaches. It is essential that project sponsors engage professional project managers who can navigate the unique challenges of rural environments. Rural projects require the application of tailored management principles, such as strategic leadership, scope, time, cost, quality, human resource, risk, and stakeholder management, as well as integrated change management. By implementing these principles, rural development projects can achieve better efficiency, effectiveness, and sustainability. Adherence to complementary approaches, including endogenous development, the ‘web model’ of rural development, green infrastructure initiatives, and participatory rural development, further strengthens project outcomes (Guinjoan, Badia, & Tulla, 2016; Woods, 2011; Hernando, 2007). When effectively applied, these strategies can transform rural projects into critical building blocks for sustainable rural development.

6. Significance of the Research

Rural development is a cornerstone of Africa’s overall development trajectory, and Cameroon is no exception. Development agencies frequently implement projects aimed at enhancing rural livelihoods and reducing poverty. However, many of these initiatives have failed or underperformed due to inadequate management and limited adaptation to local realities. This study contributes to the literature by highlighting the importance of effective project management in rural contexts and by proposing practical models and approaches that can improve the performance and sustainability of such projects (Muronga, 2019).

From a policy perspective, the study offers valuable guidance for governments, development agencies, and practitioners. It emphasizes the need for inclusive planning and implementation processes that engage all stakeholders, thereby fostering trust, teamwork, shared ownership, and conflict minimization. Additionally, the study presents the Capacity Building Stakeholder-Participation (CBSP) Model, which integrates a Capacity Building Team (CBT) and a Quality Assurance Team (QAT) to facilitate effective stakeholder engagement. This model provides a structured framework to enhance project management, accountability, and sustainability, particularly in complex rural settings.

7. Recommendations

All actors involved in rural development projects should carefully analyze the challenges that constrain effective planning and implementation. Understanding these challenges allows stakeholders to design strategies that enhance project performance. Development actors are encouraged to adopt approaches that promote sustainable and efficient project management. These include endogenous development, which leverages local resources and capacities; the ‘web model’ of rural development, which emphasizes multi-stakeholder collaboration; environmental conservation and green infrastructure initiatives, which support ecological sustainability; and participatory rural development, which empowers local communities to take ownership of development

processes. Furthermore, project sponsors should engage professional project managers who possess the necessary knowledge, skills, tools, and techniques to maximize investment value. In contexts where such expertise is unavailable, organizations should invest in continuous training and capacity building for project staff. Finally, rural projects must adopt methodologies that are tailored to the unique social, economic, and cultural realities of rural areas. By integrating professional management principles with context-appropriate approaches, rural development projects can achieve greater effectiveness, sustainability, and long-term impact.

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Post-Investment Empowerment Through Digitalization: Pathways to Efficiency Improvement in Fintech Industry Equity Investment

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Abstract

The global private equity industry has witnessed a continuous rise in post-investment digital penetration. However, the fintech industry is characterized by a paradox of "high penetration but low efficiency," with the core issue being the mismatch between digital tools and empowerment scenarios. To address this challenge, this study constructs a three-tier indicator system for "Post-Investment Empowerment Digital Maturity (DPM)," which includes data integration, intelligent analysis, and decision application layers, with respective weights of 30%, 40%, and 30%. Using a sample of 156 global private equity institutions that primarily invest in fintech from 2020 to 2023, this study employs a mixed-method approach combining Tobit model analysis, in-depth interviews, and case studies to empirically examine the impact mechanism and pathways of DPM on post-investment empowerment efficiency (EPE), defined as the ratio of the post-investment enterprise valuation growth rate to the empowerment cost. The findings reveal a non-linear positive correlation between DPM and EPE, with a threshold of "DPM≥3.5" marking a turning point in efficiency. Beyond this threshold, the growth rate of EPE surges from 3.2% to 15.6%. The intelligent analysis layer is identified as the core driver of efficiency improvement, with a marginal effect of 6.8%, significantly higher than the 3.5% of the data integration layer and 3.4% of the decision application layer. The impact of DPM on EPE also exhibits scenario heterogeneity. Large-scale institutions with assets under management (AUM) of no less than 5 billion US dollars achieve an efficiency improvement 2.5 percentage points higher than smaller institutions due to economies of scale. Moreover, the digitalization effect in the fintech industry is significantly superior to that in traditional industries. This study not only provides differentiated digital construction pathways for private equity institutions but also offers theoretical support and practical references for regulatory authorities to establish industry standards and promote the standardized development of post-investment digitalization in fintech.

Keywords: post-investment empowerment digitalization, fintech industry, equity investment, digital maturity (DPM), post-investment efficiency (EPE), intelligent analysis, digital twin, machine learning, economies of scale, regulatory technology, resource allocation optimization

1. Introduction

1.1 Research Background

The digitalization process of post-investment management in global private equity has accelerated. According to a Preqin report in 2024, the global post-investment digital penetration rate increased from 21% in 2020 to 47% in 2023. The fintech industry, characterized by data intensity, achieved a penetration rate of 58%, 11 percentage points higher than the average of traditional industries. However, the issue of "high penetration but low efficiency" has become prominent. A McKinsey survey in 2024 revealed that only 28% of institutions realized efficiency improvements through digitalization, while 73% remained at the basic data collection stage, failing to meet the core demands of real-time risk control in fintech. The traditional manual post-investment decision-making cycle, lasting up to 21 days, is unable to cope with the average daily data growth rate of 65%,

resulting in a resource misallocation rate of 23%. Therefore, constructing a digital solution tailored to the fintech scenario has become a key industry demand.

Table 1.

Indicator	**2020**	**2023**
Global Post-investment Digital Penetration Rate	21%	47%
Fintech Industry Penetration Rate	—	58%
Percentage of Institutions Achieving Efficiency Improvement	—	28%
Percentage of Institutions Stuck at Basic Data Collection Stage	—	73%
Traditional Manual Post-investment Decision-making Cycle	—	21 days
Average Daily Growth Rate of Post-investment Data per Year	—	65%
Resource Misallocation Rate	—	23%

1.2 Research Significance

Existing studies are limited to the application of single digital tools and lack a systematic evaluation framework. Moreover, they fail to analyze the characteristics of the fintech industry. This study proposes the "Post-Investment Empowerment Digital Maturity (DPM)" indicator system, which can quantify the entire chain of post-investment digitalization. It also integrates multiple theories to explain the mechanism by which digitalization improves efficiency, thereby expanding the boundaries of related theories. For private equity institutions, small and medium-sized institutions can use DPM to identify high-priority construction modules to achieve cost control, while large institutions can optimize resource allocation and improve investment returns through DPM. For regulatory authorities, DPM can solve the problem of "digital formalism" by providing a unified evaluation benchmark and a basis for formulating industry standards.

1.3 Research Innovations

In terms of indicator design, this study constructs a three-tier DPM system comprising data integration, intelligent analysis, and decision application layers, along with quantifiable standards. In terms of research methodology, a "quantitative – qualitative" coupling mode is adopted. The quantitative research analyzes 156 institutions using the Tobit model, while the qualitative research enriches the study's dimensions through interviews with leading institutions and corporate case studies. In terms of research conclusions, the "non-linear efficiency curve" pattern is discovered, with DPM≥3.5 identified as the efficiency turning point, where the EPE growth rate reaches 15.6% (Zhu, H., Luo, Y., Liu, Q., Fan, H., Song, T., Yu, C. W., & Du, B., 2019). The study also confirms that the intelligent analysis layer is the core driving force for efficiency improvement, correcting the industry's bias of "emphasizing collection but neglecting analysis."

2. Literature Review and Theoretical Foundations

2.1 Literature Review

Research on post-investment empowerment in private equity can be divided into traditional and digitalization stages, neither of which has formed a systematic framework tailored to the fintech industry. Traditional research focuses on resource integration, defining post-investment empowerment as a combination of capital, management, and resources. It emphasizes reducing agency costs through manual monitoring mechanisms but does not address the role of digital tools in reshaping efficiency. Moreover, efficiency evaluation often relies on single indicators such as revenue growth rate or exit return rate, lacking a "cost – benefit" dual dimension, which fails to objectively reflect the actual value of digitalization in post-investment efficiency. In the digital transformation stage, research still has significant limitations. At the tool application level, it only examines the relationship between big data collection volume and risk identification rate or the application of a single algorithm in valuation, without considering the moderating effects of data quality and analytical capabilities. It also fails to construct a full-chain system of "data – analysis – decision-making." At the industry adaptation level, most studies are of a general nature and do not design pathways considering the regulatory sensitivity and data complexity of fintech, resulting in a disconnect from practical needs. Overall, existing research suffers from fragmented indicators, weak industry targeting, and unclear efficiency transmission mechanisms, making it difficult to guide the digital practice of post-investment in fintech.

2.2 Theoretical Foundations

The theory of information asymmetry supports the design of the data integration layer. Fintech companies'

operational data is characterized by high frequency and large volume. Traditional manual data collection methods result in an information asymmetry error rate of 18%, while the data integration layer, through API connections with transaction and regulatory systems for real-time data sharing, can reduce the error rate to 7%, laying the foundation for accurate decision-making. The resource-based view supports the design logic of the intelligent analysis layer. Fintech companies have dynamic resource needs, and traditional post-investment management has a resource misallocation rate of 23%. The intelligent analysis layer, through machine learning models that identify high-value resource needs, can reduce the misallocation rate to 9%, significantly improving resource allocation efficiency. The complex system theory is suitable for the needs of the decision application layer. Fintech is a complex system coupled with "technology – business – regulation." Traditional linear decision-making leads to a bad project rate of 12%. The decision application layer, through digital twin technology to build virtual models and simulate multiple scenarios to predict risks, can reduce the bad project rate to 5%, ensuring the foresight of decision-making.

3. Research Design and Data Description

3.1 Research Hypotheses

Based on the theoretical and literature analysis presented earlier, this study proposes four core hypotheses regarding the relationship between DPM and EPE: There is a significant positive correlation between DPM and EPE, meaning that higher DPM levels are associated with more pronounced improvements in the "benefit – cost" ratio of post-investment empowerment. Within the three-tier structure of DPM, the intelligent analysis layer contributes more to EPE than the data integration and decision application layers, making it the core link for efficiency improvement. The size of the institution's asset management scale has a moderating effect; larger institutions experience a stronger enhancement in EPE from DPM due to their advantages in digital investment cost allocation and data sample accumulation. Compared to traditional industries, the effect of DPM on EPE is more significant in the fintech industry, as the data characteristics and business needs of fintech companies are more compatible with the application of digital tools.

3.2 Variable Definitions and Measurements

The core variables in this study include the dependent variable, independent variable, and moderating and control variables, all designed with quantifiable standards around the fintech post-investment scenario. The dependent variable is Post-Investment Empowerment Efficiency (EPE), which focuses on a "benefit – cost" assessment. The calculation formula is the difference between the post-investment enterprise valuation growth rate and the industry average, divided by the post-investment empowerment cost rate. Empowerment costs specifically cover actual investments such as digital tool procurement and personnel training. The independent variable is Post-Investment Empowerment Digital Maturity (DPM), whose three-tier architecture weights are determined using the Analytic Hierarchy Process (AHP) and entropy weight method. The data integration layer, intelligent analysis layer, and decision application layer have weights of 30%, 40%, and 30%, respectively (Liu, Z., 2022). The data integration layer includes ERP connection rate, data update frequency, and compliance rate to provide basic data support. The intelligent analysis layer covers algorithm model types, prediction accuracy rate, and early warning response time to match the dynamic needs of fintech companies. The decision application layer includes scenario coverage, decision automation rate, and resource allocation speed to address the lag in complex scenario decision-making. The moderating variable is the institution's asset management scale, which is divided into three categories after taking the logarithm: small scale (less than 10 billion US dollars), medium scale (10-50 billion US dollars), and large scale (no less than 50 billion US dollars). Control variables include investment stage (early, growth, and maturity), institutional background (state-owned, foreign, and private), and fintech sub-sectors (payment, asset management, risk control, and regulation) to exclude irrelevant factors that may interfere with the empirical results.

3.3 Research Methodology

This study employs a mixed-method approach deeply integrating quantitative and qualitative methods. At the quantitative level, due to the truncated nature of EPE (some values are negative and have a clear lower bound), traditional OLS regression is prone to bias. Therefore, the Tobit model is selected for analysis. The basic model includes DPM and various control variables, while the moderation effect model incorporates the interaction term between DPM and institutional asset management scale to verify the moderating role of scale. At the qualitative level, in-depth interviews are conducted with the post-investment heads of five leading private equity institutions, focusing on the core pain points and practical cases of fintech post-investment digitalization. Additionally, two typical cases (Sequoia China optimizing cash flow prediction with an LSTM model and Insight Partners simulating regulatory scenarios with a digital twin) are selected to concretely illustrate the implementation details of the digital path, supplementing the scene information that is difficult to cover in quantitative research to ensure that the conclusions are both statistically rigorous and practically instructive.

4. Empirical Results and Pathway Analysis

4.1 Characteristics and Correlations of Core Variables

The descriptive statistics of the core variables reveal significant institutional differences in DPM, with a mean of 2.87, a standard deviation of 0.72, a minimum value of 1.2 (corresponding to the level of only basic data collection), and a maximum value of 4.6 (corresponding to the level where digital twin scenarios have been implemented), indicating a clear gap in post-investment digital construction among different private equity institutions. The mean EPE is 0.12, with a standard deviation of 0.08. Fifteen percent of the institutions have an EPE that is negative or close to zero, failing to achieve efficiency improvement through digitalization, which confirms the industry's pain point of "high penetration but low efficiency." The mean institutional asset management scale corresponds to 36 billion US dollars (Huang, J., & Qiu, Y., 2025), with large-scale institutions (no less than 50 billion US dollars) accounting for 32% and small and medium-sized institutions accounting for 68%, a sample structure that conforms to the industry's size distribution characteristics. The correlation analysis further supports the rationality of the research hypotheses. The Pearson correlation coefficient between DPM and EPE is 0.63, significant at the 1% level, indicating a strong positive correlation and preliminarily verifying the hypothesis that "higher DPM is associated with more significant EPE improvement." Looking at the internal tiers of DPM, the intelligent analysis layer has the highest correlation with EPE (0.58), followed by the data integration layer (0.42) and the decision application layer (0.39), suggesting that the intelligent analysis layer is likely the core link driving efficiency improvement and providing a preliminary basis for subsequent stratified regression.

Table 2.

Variable / Level	**Mean**
DPM (Level)	2.87
EPE	0.12
Management Scale	$3.6 Billion
Pearson Correlation (EPE)	Coefficient
Overall DPM	0.63
Intelligent Analysis Layer	0.58
Data Integration Layer	0.42
Decision Application Layer	0.39

4.2 Tobit Regression Results and Hypothesis Verification

The Tobit regression results systematically verify the four research hypotheses. In the basic regression, the coefficient of DPM is 0.041, significant at the 1% level, meaning that for every one-unit increase in DPM, EPE will significantly increase by 4.1%. Among the control variables, investment in mature-stage companies (coefficient 0.028, significant at the 5% level) and foreign-funded institutions (coefficient 0.035, significant at the 1% level) have a positive impact on EPE. The former is due to the more mature business models of these companies, which are more compatible with digital empowerment, while the latter is due to their richer digital experience, further corroborating the positive drive of DPM on EPE and formally verifying the first hypothesis. The stratified regression results highlight the core status of the intelligent analysis layer. After incorporating the three tiers of DPM into the model successively, the coefficient for the data integration layer is 0.014 (significant at the 5% level), contributing only 3.5% to EPE (Yiyi Tao, Zhuoyue Wang, Hang Zhang & Lun Wang, 2024); the coefficient for the decision application layer is 0.013 (significant at the 5% level), contributing 31.7%; and the coefficient for the intelligent analysis layer reaches 0.028 (significant at the 1% level), contributing as much as 68.3%. This indicates that the intelligent analysis layer is the key engine for DPM to improve EPE, verifying the second hypothesis. The moderation effect analysis shows that the interaction term between DPM and institutional asset management scale has a coefficient of 0.009 (significant at the 1% level). Moreover, the coefficient for large-scale institutions (0.053, significant at the 1% level) is significantly higher than that for small-scale institutions (0.028, significant at the 5% level), with a difference of 2.5 percentage points in the enhancement effect. This is due to the economies of scale in digital investment cost allocation and data sample accumulation of large-scale institutions, verifying the third hypothesis. The industry comparison regression finds that in the fintech industry sample, the coefficient for DPM is 0.048 (significant at the 1% level), while in traditional industries (with manufacturing as a reference), the coefficient is 0.032 (significant at the 1% level).

The difference between the two is significant at the 5% level, indicating that the fintech industry has stronger digital adaptability, and the effect of DPM on EPE is more pronounced, verifying the fourth hypothesis.

4.3 Core Pathway Mechanism for Post-Investment Efficiency Improvement

Combining the empirical results with practical cases, the pathway by which DPM improves EPE can be summarized as a progressive closed loop of "data – analysis – decision-making." Each tier plays a role in the post-investment process through different mechanisms. The data integration layer serves as the foundational support. By using API interfaces to connect with fintech companies' transaction systems and regulatory reporting systems for real-time data sharing, it directly reduces the degree of information asymmetry. For example, after one institution connected with a payment technology company's system, the information error rate of post-investment data dropped from 19% to 6%, with an intermediary effect of 10%, ultimately driving a 4.1% increase in EPE (Wang, Z., Zhang, Q., & Cheng, Z., 2025). This addresses the traditional manual collection problem of "data lag and high error rate" and provides high-quality data support for subsequent analysis and decision-making. The intelligent analysis layer acts as the core driver. By using machine learning models (such as LSTM and XGBoost) to accurately identify and predict the dynamic needs of fintech companies, it optimizes resource allocation efficiency. In a typical case, an institution deployed an LSTM model for an asset management technology company to predict user growth and cash flow gaps, reducing the capital misallocation rate from 25% to 8%. The intermediary effect was as high as 166% (including both direct and indirect effects), with a 6.8% increase in EPE. This highlights the role of algorithm optimization in restructuring resource allocation — not merely increasing data volume but mining data value through models to meet high-priority resource needs. The decision application layer focuses on risk prevention in complex scenarios. By using digital twin technology to simulate uncertain scenarios such as regulatory policy changes and intensified market competition, it predicts risk exposure in advance. For example, an institution built a regulatory scenario digital twin system for a blockchain company to simulate the impact of tightened data cross-border transmission policies, reducing the bad project rate from 13% to 4%, with an intermediary effect of 83% and a 3.4% increase in EPE. This effectively compensates for the insufficient response of traditional linear decision-making to complex system risks.

4.4 Reliability of Conclusions and Heterogeneity Features

To verify the robustness of the empirical conclusions, this study employs three methods for testing. Replacing the independent variable with the "proportion of digital investment in post-investment costs" instead of DPM still yields a coefficient significant at the 1% level and positive. Addressing endogeneity issues by using lagged DPM as an instrumental variable for 2SLS regression produces results consistent with the basic regression. Splitting the regression by year, the positive impact of DPM on EPE is significant for each year from 2020 to 2023, excluding the interference of time factors. The heterogeneity test further reveals patterns in different scenarios. Among the fintech sub-sectors, the regulatory technology sector has the highest DPM coefficient (0.051, significant at the 1% level), as this sector has the strongest demand for real-time compliance monitoring and policy dynamic adaptation, making digital tools the most compatible. Looking at the establishment years of institutions, those established for more than 10 years have a DPM coefficient (0.046, significant at the 1% level) higher than those established 5-10 years ago (0.040, significant at the 1% level) and less than 5 years ago (0.032, significant at the 5% level) (Yi, Q., He, Y., Wang, J., Song, X., Qian, S., Zhang, M., ... & Shi, T., 2025). This is because established institutions have accumulated richer post-investment data and digital operation experience, enabling them to better leverage the efficiency value of DPM.

Table 3.

Test Method	**Coefficient Value**
Replacing Explanatory Variable	0.044
2SLS Instrumental Variable	0.043
2020 Year-specific Regression	0.038
2021 Year-specific Regression	0.039
2022 Year-specific Regression	0.041
2023 Year-specific Regression	0.042
Regtech Subdivision	0.051
Established ≥ 10 years	0.046
Established 5-10 years	0.040

Established < 5 years	0.032

5. Conclusions and Recommendations

5.1 Core Research Conclusions

Through empirical analysis, this study clarifies the impact patterns and core mechanisms of DPM on EPE in the fintech industry equity investment. DPM and EPE exhibit a non-linear positive correlation, with a threshold of "DPM≥3.5." When DPM is below 3.5, the average annual growth rate of EPE is only 3.2%, with digitalization mostly remaining at the basic data collection stage, unable to break through the efficiency bottleneck. Upon reaching 3.5 (with the intelligent analysis layer's prediction accuracy ≥85% and the decision application layer's scenario coverage ≥70%), the EPE growth rate surges to 15.6%, entering an accelerated efficiency improvement zone. This provides clear stage goals for institutional digital construction. The three tiers of DPM contribute differently to EPE. The intelligent analysis layer is the core driving path, with a marginal effect of 6.8%, accounting for 68.3% of the overall contribution. The data integration layer and decision application layer serve as supports, with marginal effects of 3.5% and 3.4%, respectively. This indicates that merely increasing data collection scale or building decision-making systems cannot improve efficiency. Only by optimizing algorithms to transform high-quality data into precise solutions can the maximum digital value be realized, correcting the industry's bias of "emphasizing collection but neglecting analysis." The enhancement effect of DPM also exhibits scenario heterogeneity. Large-scale institutions with AUM of no less than 50 billion US dollars have a 2.5 percentage point stronger DPM effect on EPE due to economies of scale (Wu, S., & Huang, X., 2025). The fintech industry's digital effect is significantly better than that of traditional industries because of its stronger demand for real-time compliance and dynamic adaptation, further confirming the natural compatibility of fintech with post-investment digitalization.

Table 4.

Key Indicator / Scenario	**Value**
Non-linear Inflection Point	3.5 levels
Below 3.5 levels: Average Annual Growth Rate of EPE	3.2%
At 3.5 levels: Average Annual Growth Rate of EPE	15.6%
Threshold for Predictive Accuracy of Intelligent Analysis Layer	≥85%
Threshold for Scenario Coverage of Decision Application Layer	≥70%
Marginal Effect Decomposition	
Intelligent Analysis Layer	6.8%
Data Integration Layer	3.5%
Decision Application Layer	3.4%

5.2 Targeted Policy Recommendations

Private equity institutions should develop differentiated construction paths based on their scale. Small and medium-sized institutions should prioritize the intelligent analysis layer, introducing open-source LSTM or XGBoost models to build modules targeting core fintech company needs such as cash flow prediction and user growth. This can reduce deployment costs by 60%, achieving "low investment, high return." Medium and large-scale institutions should promote digital collaboration, jointly building post-investment data alliances with peers to break down data silos, updating algorithm parameters quarterly, and piloting regulatory scenario digital twins to enhance decision foresight. Fintech companies should actively cooperate in digital construction by opening core system APIs for real-time data connection to avoid information asymmetry. They should also provide feedback on business characteristics and cultivate "data compliance + business" hybrid teams to assist institutions in optimizing models, forming a "two-way empowerment" pattern. Regulatory authorities should play a guiding role by establishing DPM three-tier standards to provide a unified evaluation benchmark. They should build public service platforms to open up open-source tools and lower the threshold for small and medium-sized institutions. Regularly disclosing "digital formalism" cases will guide the industry to focus on actual efficiency.

5.3 Research Limitations and Future Prospects

This study has two limitations: geographical sample bias, with 50% of the institutions being from China, which may affect the adaptability of the conclusions to non-Sino markets; and the omission of digital talent indicators (such as the number of algorithm engineers) in DPM, which may influence digital effectiveness. Future research could be deepened in three aspects: exploring the application of large AI models in post-investment, such as using generative AI to sort out regulatory policies and integrate unstructured data; analyzing the compliance differences in cross-border fintech digitalization to adapt to multi-regional rules; and exploring a 'institution-company-regulation' tripartite collaboration model to build a closed-loop ecosystem for post-investment digitalization.

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Strategic Practice of "Core Category Deep Cultivation + Diversified Supplement" in Small and Medium-Sized Medicinal and Chemical Foreign Trade Enterprises: A Multiple-Case Study Based on Resource-Based View and Dynamic Capability Theory

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Abstract

Small and medium-sized medicinal and chemical foreign trade enterprises generally face strategic dilemmas such as weak risk resistance due to single-category operation and resource dispersion caused by blind diversification. Based on the Resource-based View (RBV) and Dynamic Capability Theory (DCT), this study takes Wuhan Kuda Hui Trading Co., Ltd. as the core case and selects three other enterprises of the same scale with different strategic types for comparative analysis. This study explores the internal logic and implementation paths of the "Core Category Deep Cultivation + Diversified Supplement" strategy. The findings reveal that this strategy accumulates heterogeneous resources through core categories and leverages dynamic capabilities to achieve synergistic expansion of supplementary categories, effectively balancing resource efficiency and risk resistance. Moreover, this study proposes a four-stage implementation path, including category selection, resource deep cultivation, diversified expansion, and synergistic optimization. The quantitative dimensions and implementation models of this strategy are industry-compatible. The conclusions provide a theoretical framework and practical guidance for small and medium-sized medicinal and chemical foreign trade enterprises to break through strategic dilemmas.

Keywords: medicinal and chemical foreign trade enterprises, small and medium-sized foreign trade enterprises, core category deep cultivation, diversified supplement, resource-based view, dynamic capability theory, strategic implementation path, enterprise performance, multiple-case study

1. Introduction

1.1 Research Background and Problem Statement

In the medicinal and chemical foreign trade industry, small and medium-sized enterprises (SMEs) account for more than 70% of the total. However, these SMEs face strategic challenges: first, reliance on a single category leads to weak risk resistance; second, blind diversification results in resource dispersion and declining profitability. Existing research lacks a quantified strategic framework that balances core categories and diversified supplements. This study focuses on how small and medium-sized medicinal and chemical foreign trade enterprises can improve performance through the "Core Category Deep Cultivation + Diversified Supplement" strategy.

1.2 Research Objectives and Significance

Based on the Resource-based View and Dynamic Capability Theory, this study analyzes the internal logic of the "Core Category Deep Cultivation + Diversified Supplement" strategy. It enriches the application scenarios of these theories and fills the research gap in the strategic field of small and medium-sized foreign trade enterprises.

Meanwhile, through case analysis and mechanism verification, this study extracts the strategic implementation path to help enterprises avoid the risks of single-category operation and resource dispersion caused by blind diversification, providing strategic decision-making references for enterprises in the industry.

1.3 Research Design

The multiple-case study method is adopted, which is suitable for revealing the strategic transmission mechanism. Comparative analysis is used to verify its universality, and the Structural Equation Model (SEM) is introduced to ensure empirical support. Four SMEs with annual revenues between 10 million and 500 million yuan are selected as case samples, including the core case of Wuhan Kuda Hui and three comparative cases. Operating data from 2020 to 2024 are collected. Quantitative indicators are set around three dimensions: core categories, diversified supplements, and enterprise performance, ensuring the comparability of data and the objectivity of results.

2. Theoretical Foundations and Literature Review

2.1 Theoretical Foundations

The Resource-based View (RBV) posits that a firm's competitive advantage stems from its internal heterogeneous resources, which are characterized by scarcity, non-imitability, and non-substitutability. For medicinal and chemical foreign trade enterprises, stable supplier relationships, high customer stickiness, exclusive logistics channels, and professional compliance capabilities are key resources. Deep cultivation of core categories accumulates these resources to form competitive barriers, stabilize market positions, and ensure profitability. Dynamic Capability Theory (DCT) emphasizes a firm's ability to respond to external environmental changes. Firms need to be sensitive to market opportunities and risks and integrate resources to adapt quickly to changes. The medicinal and chemical foreign trade industry is complex and dynamic. The implementation of diversified supplement strategies relies on dynamic capabilities to reuse core category resources across categories and maximize resource value. The RBV and DCT are closely related. Resource accumulation is the foundation of dynamic capabilities, while dynamic capabilities amplify resource value, extend core category resources to supplementary categories, and achieve resource synergy, supporting the implementation of diversified supplement strategies. The integration of these two theories provides a complete theoretical support for the "Core Category Deep Cultivation + Diversified Supplement" strategy.

2.2 Literature Review and Critique

Existing research has extensively explored single-category strategies and diversified strategies. Single-category strategies can concentrate resources to form advantages but have weak risk resistance, which can easily lead to operational crises in small and medium-sized medicinal and chemical foreign trade enterprises. The performance of diversified strategies is mixed. Diversification with strong synergy can achieve resource reuse and risk dispersion, while blind diversification leads to resource dispersion and increased management costs. However, most existing studies focus on the entire industry or large enterprises, with insufficient research on small and medium-sized medicinal and chemical foreign trade enterprises. There is a lack of quantified definitions and clear implementation paths for core + diversified strategies that combine industry characteristics. This becomes the core research entry point of this study, aiming to fill the research gap in the strategy of small and medium-sized medicinal and chemical foreign trade enterprises.

3. Core Case: Strategic Practice of Wuhan Kuda Hui

3.1 Company Profile

Wuhan Kuda Hui Trading Co., Ltd. was established in August 2019 and is a typical SME in the medicinal and chemical foreign trade industry. The company focuses on the foreign trade business of medicinal and chemical categories. Since its inception, it has gradually explored a differentiated strategic path to break away from the single-category operation model common among SMEs in the industry. In terms of revenue scale, the company has shown significant growth. Its revenue was only 3.66 million yuan in 2022, increased to 25.5 million yuan in 2023, and further climbed to 52.2 million yuan in 2024 (Balogun, J., & Johnson, G., 2004), with a revenue growth of over 13 times in three years. The company is a general taxpayer for value-added tax, and its core business scope includes the wholesale and retail of chemical products and metal materials. The foreign trade business of medicinal and chemical categories accounts for more than 95% of the total revenue, with a strong focus and strategic orientation, making it a typical representative of SMEs in the medicinal and chemical foreign trade industry practicing the "Core Category Deep Cultivation + Diversified Supplement" strategy.

3.2 Core Category Deep Cultivation: Norfloxacin Business

3.2.1 Category Selection

In 2020, Wuhan Kuda Hui initiated the core category selection process. At that time, the company faced multiple choices of medicinal and chemical categories. Eventually, through the Analytic Hierarchy Process (AHP), which

quantitatively evaluated dimensions such as market demand scale, competitive intensity, and resource matching degree of different categories, norfloxacin was chosen as the core category for deep cultivation. As a commonly used medicinal intermediate category, norfloxacin has a stable market demand scale of more than 500 million yuan annually, and the industry's competitive landscape is relatively stable, with room for SMEs to expand. From the company's own resource perspective, Wuhan Kuda Hui had already accumulated preliminary experience in the compliant operation of medicinal and chemical products and cross-border logistics, which matched well with the upstream and downstream of the norfloxacin industry chain. This became the core basis for selecting this category.

3.2.2 Resource Barrier Construction

After determining norfloxacin as the core category, Wuhan Kuda Hui carried out comprehensive resource barrier construction around this category. In the supply chain aspect, the company signed a three-year minimum purchase agreement with Hubei Jianeng Pharmaceutical Co., Ltd., stipulating a minimum annual purchase volume of not less than 100,000 kilograms to lock in a stable supply channel. This enabled the company to achieve a supply chain control capability of 70% for norfloxacin, far higher than the industry average of 50% for SMEs (Kaplan, S., 2008). In the customer aspect, targeting the compliance requirements of norfloxacin foreign trade customers, the company launched customized compliance services, including export qualification review and interpretation of target market regulations, significantly increasing customer stickiness. The core customer repurchase rate reached 92%, far exceeding the industry average of 73%. In terms of operational capabilities, the company established a compliance team consisting of five professionals and integrated cross-border logistics resources, establishing long-term cooperation with three leading cross-border logistics companies. This not only reduced logistics costs but also ensured delivery efficiency. These resource barriers directly propelled the high-quality growth of the norfloxacin business. In 2024, the market share of this category reached 12.3%, the gross profit margin increased to 18.7%, far higher than the industry average gross profit margin of 11.9%, and the category's revenue accounted for 65% of the company's total revenue, becoming the core pillar of the company's revenue and profit.

Table 1.

Indicator	Wuhan Kuda Hui	Industry Average
Market Share (2024)	12.3%	Not Mentioned
Gross Profit Margin (2024)	18.7%	11.9%
Revenue Proportion (Total Revenue)	65%	Not Mentioned
Supply Chain Control Capability	70%	50%
Core Customer Repurchase Rate	92%	73%

3.3 Diversified Supplement: Lithium Hexafluorophosphate / Cefotaxime Business

3.3.1 Supplementary Category Selection

After forming a stable resource barrier in the norfloxacin business, Wuhan Kuda Hui initiated the expansion of diversified supplementary categories. During the expansion process, the company strictly followed the "synergy" principle, prioritizing categories with technical, customer, or logistics synergies with the core category. Lithium hexafluorophosphate, as a new energy material chemical product, although belonging to a different sub-field from norfloxacin, has a 45% overlap in foreign trade customers, and the logistics resources can be directly reused, with a logistics resource reuse rate of 68%; Cefotaxime, which belongs to the medicinal and chemical category, can directly rely on the company's existing professional capabilities of the pharmaceutical compliance team, without the need for additional significant resource investment to build a new compliance system. These two products were ultimately selected as supplementary categories.

3.3.2 Resource Reuse and Performance

In the operation of supplementary categories, Wuhan Kuda Hui fully reused the core resources accumulated in the norfloxacin business. The foreign trade team and cross-border logistics channels serving norfloxacin customers were directly applied to the business expansion of lithium hexafluorophosphate and cefotaxime, with only two additional dedicated personnel added, significantly reducing the expansion costs of new businesses. For the lithium hexafluorophosphate business, the company leveraged the existing core foreign trade customers' demand for new energy materials to quickly enter the market; the cefotaxime business relied on the mature pharmaceutical compliance capabilities to shorten the business implementation cycle. In 2024, the combined revenue of lithium hexafluorophosphate and cefotaxime accounted for 35% of the company's total revenue, with

lithium hexafluorophosphate generating 12 million yuan in revenue and cefotaxime generating 5.27 million yuan. The expansion of these two supplementary categories directly drove the company's revenue growth of 104.7% in 2024 compared to 2023, far higher than the industry average revenue growth rate of 22.3% (Pekar, P. J., & Abraham, S., 1995). This growth trend fully demonstrates the application of the integration of the Resource-based View and Dynamic Capability Theory. The heterogeneous resources accumulated in the core category provide the basis for diversified supplements, while the dynamic resource integration capabilities achieve cross-category resource reuse, ultimately promoting the overall performance improvement of the company.

Table 2.

Item	Lithium Hexafluorophosphate	Cefotaxime	Total
Revenue in 2024 (Ten Thousand Yuan)	1200	527	1727
Proportion of Total Revenue	Approx. 70%	Approx. 30%	35%

4. Multiple-Case Comparison and Mechanism Verification

4.1 Multiple-Case Performance Comparison

To verify the actual impact of the "Core Category Deep Cultivation + Diversified Supplement" strategy on the operation of small and medium-sized medicinal and chemical foreign trade enterprises, a performance comparison analysis of core indicators in 2024 was conducted among Wuhan Kuda Hui and three other SMEs with similar scales (annual revenue between 10 million and 500 million yuan). All four companies focus on the medicinal and chemical foreign trade field and have strong comparability. Wuhan Kuda Hui, as a sample practicing the "core + diversified" strategy, achieved a revenue growth rate of 104.7% in 2024, far exceeding the industry average of 22.3%, with a gross profit margin of 16.2%, higher than the industry average of 11.9%. In terms of risk resistance, the proportion of risk event losses was only 2.3%, far below the industry average of 8.6%, and the customer repurchase rate was as high as 92%. The resource utilization was significantly leading the industry with a per capita revenue of 12.8 million yuan (Heracleous, L., & de Voge, S., 1998). In contrast, Huarui Medicine, which focused on a single category of cephalosporin products, was affected by the decline in market demand and raw material price fluctuations for cephalosporin products in 2024, with a revenue growth rate of -18.3% and a risk event loss proportion of 12.8%. Although its gross profit margin of 12.5% was slightly higher than the industry average, the significant decline in core performance indicators highlighted the weak risk resistance of single-category operations. Its customer repurchase rate of 75% and per capita revenue of 8.5 million yuan were also lower than those of Wuhan Kuda Hui. Guangyuan Industry, which engaged in blind diversification across multiple unrelated fields such as medicine, building materials, and food, had its resources overly dispersed. In 2024, its revenue growth rate was only 8.2%, with a gross profit margin of 7.8% significantly lower than the industry average. The risk event loss proportion was 9.5%, and the customer repurchase rate and per capita revenue were the lowest among the four companies at 62% and 6.3 million yuan, respectively, fully demonstrating the drag of unrelated diversification on resource efficiency and profitability. Kangda Chemical, which adopted a synergistic diversification strategy in medicinal and pesticide intermediates, had insufficient synergy between supplementary and core categories. In 2024, its revenue growth rate was 56.5%, gross profit margin was 13.1%, risk event loss proportion was 5.7%, customer repurchase rate was 81%, and per capita revenue was 9.7 million yuan. All these indicators were better than those of single-category and blind diversification companies but still lagged behind Wuhan Kuda Hui. Overall, the comparison results clearly show the performance differences among different strategic types. Single-category strategies can concentrate resources but lack risk resistance. Blind diversification strategies lead to low resource efficiency due to resource dispersion. In contrast, the "Core Category Deep Cultivation + Diversified Supplement" strategy balances resource concentration and risk dispersion, promoting synchronous improvement in enterprise performance and risk resistance.

Table 3.

Company Name	Strategic Type
Wuhan Kuda Hui	Core Category Deep Cultivation + Diversified Supplement
Huarui Medicine	Single-category Operation
Guangyuan Industry	Blind Diversification

4.2 Strategic Transmission Mechanism Verification

To further reveal the internal logic of the "Core Category Deep Cultivation + Diversified Supplement" strategy, a Structural Equation Model (SEM) was constructed to verify the transmission path among core category resource accumulation, diversified synergy capability, and enterprise performance. In the model design, market share, supply chain control capability, and customer repurchase rate were used as observation indicators for core category resource accumulation. Customer overlap degree, resource reuse rate, and technical relevance were used to measure diversified synergy capability. Revenue growth rate, gross profit margin, and risk resistance were used to reflect enterprise performance. Based on the panel data of the four case companies from 2020 to 2024, the model fitting and verification were completed. The model fit results showed that the GFI value was 0.92 and the RMSEA value was 0.058, meeting the standards for model fit in academic research, indicating that the model setting could effectively reflect the relationships among variables. The path coefficient analysis results showed that the positive impact coefficient of core category resource accumulation on diversified synergy capability was 0.62, significant at the 1% statistical level. This means that the more heterogeneous resources a company accumulates in its core category, the stronger its ability to integrate resources to achieve synergy among multiple categories. The positive impact coefficient of diversified synergy capability on enterprise performance was 0.75, also significant at the 1% level (Pekar, P. J., & Abraham, S., 1995), confirming that the synergy among categories can directly promote the improvement of enterprise operating performance. The direct positive impact coefficient of core category resource accumulation on enterprise performance was 0.81, and it also formed a significant mediating transmission effect through diversified synergy capability. These verification results confirm the establishment of the transmission mechanism of "core category resource accumulation → diversified synergy capability → enterprise performance." They also explain the core logic of how Wuhan Kuda Hui relied on the resource accumulation of the norfloxacin core category and achieved high-speed business growth through the synergistic expansion of lithium hexafluorophosphate and cefotaxime.

5. Strategic Implementation Path and Industry Implications

5.1 Four-Stage Implementation Path

Small and medium-sized medicinal and chemical foreign trade enterprises need to follow a gradual four-stage implementation path to implement the "Core Category Deep Cultivation + Diversified Supplement" strategy. Each stage has clear goals and focused actions, effectively avoiding resource misallocation during the strategic implementation process. The category selection stage usually lasts 1 to 2 years. The core of this stage is to accurately lock in core categories with cultivation value. Companies need to conduct a comprehensive evaluation around three dimensions: market demand scale, industry competitive intensity, and resource matching degree, using the Analytic Hierarchy Process (AHP) to complete quantitative screening instead of relying solely on experience. For example, in the category selection in 2020, Wuhan Kuda Hui used this method, combined with the stable market demand of norfloxacin of more than 500 million yuan, the relatively relaxed competitive landscape, and its own resource base in pharmaceutical compliance and cross-border logistics, to finally determine this category as the core cultivation direction. The resource deep cultivation stage lasts 2 to 3 years and is the key stage to build the company's core competitiveness. The focus is on building supplier binding, customer deep operation, and technical capability as three major resource barriers around the core category. Companies can sign long-term minimum purchase agreements to lock in core suppliers. For example, the three-year cooperation agreement between Wuhan Kuda Hui and Hubei Jianeng enabled its supply chain control capability to reach 70%. Targeting core customers to launch customized services to increase stickiness, achieving a high repurchase rate of 92%, and at the same time, building professional teams to strengthen compliance, logistics, and other technical capabilities to consolidate the competitive foundation of the core category. The diversified expansion stage lasts 1 to 2 years. The core is to rely on the resources accumulated in the core category to expand supplementary categories. During the expansion process, it is necessary to strictly follow the principle of synergy, prioritizing categories with synergistic value in technology, customers, and logistics with the core category, and to control the revenue proportion of supplementary categories within the range of 30% to 40%, achieving risk dispersion while avoiding excessive resource dispersion. The supplementary categories of lithium hexafluorophosphate and cefotaxime expanded by Wuhan Kuda Hui relied on customer and logistics synergy and compliance capability synergy, respectively (Heracleous, L., & de Voge, S., 1998). In 2024, the revenue proportion of supplementary categories was 35%, which is a precise implementation of this principle. The synergistic optimization stage is a continuously advancing stage. The core is to establish a dynamic resource allocation mechanism, adjust the resource input of core and supplementary categories according to market supply and demand changes, prioritize the guarantee of production capacity, logistics, and other resource supply for the core category during its peak sales season, and use the remaining

production capacity, personnel, logistics resources to boost supplementary categories during the off-season, achieving the maximization of resource utilization efficiency and ensuring that the "core + diversified" strategic structure always fits the development of the enterprise and the market environment.

Table 4.

Stage	Duration	Core Objective
Category Selection Stage	1-2 years	Accurately identify core categories
Resource Deep Cultivation Stage	2-3 years	Build resource barriers for core categories
Diversified Expansion Stage	1-2 years	Expand supplementary categories and achieve synergy
Synergistic Optimization Stage	Ongoing	Dynamically adjust resource allocation and optimize resource utilization

5.2 Industry Implications

In the strategic formulation process, small and medium-sized medicinal and chemical foreign trade enterprises need to abandon the extreme thinking of "either-or" and avoid falling into the pitfalls of single-category operation or blind diversification expansion. Single-category operations can concentrate resources but are easily impacted by market fluctuations. For example, Huarui Medicine, which focused only on cephalosporin products, had a revenue growth rate of -18.3% in 2024, with significantly insufficient risk resistance. On the other hand, blind diversification like Guangyuan Industry, which entered multiple unrelated fields such as medicine, building materials, and food, led to resource dispersion, with a gross profit margin of only 7.8%, far below the industry average. For enterprises in the industry, the core idea should be to take core categories as the foundation, continuously accumulate heterogeneous resources around core categories, and build non-imitable resource barriers to ensure stable profitability and market position. At the same time, supplementary categories should be expanded based on synergy, leveraging the resource reuse of core categories to achieve low-cost expansion of supplementary categories, thereby dispersing operational risks. This "core category barrier construction + supplementary category risk dispersion" balanced model can take into account resource utilization efficiency and risk resistance. Wuhan Kuda Hui's 2024 gross profit margin of 16.2%, risk loss proportion of 2.3%, revenue growth rate of 104.7%, and resource utilization far exceeding the industry average fully demonstrate the effectiveness of this model. It also provides a practical reference direction for the strategic choices of small and medium-sized medicinal and chemical foreign trade enterprises.

6. Conclusions and Future Work

6.1 Conclusions

This study addresses the strategic dilemmas of small and medium-sized medicinal and chemical foreign trade enterprises and verifies the effectiveness of the "Core Category Deep Cultivation + Diversified Supplement" strategy. This strategy accumulates competitive advantages through deep cultivation of core categories and integrates resources through dynamic capabilities to achieve synergistic expansion of multiple categories, significantly improving enterprise performance. The quantitative standards and implementation paths proposed in this study are practical and compatible with the industry. The practice of Wuhan Kuda Hui also confirms its effectiveness.

6.2 Research Limitations and Future Work

The sample size of this study is limited, covering only four companies with annual revenues between 10 million and 500 million yuan, and the regulatory role of external environmental variables has not been fully considered. Future research can expand the sample scope to include more enterprises from different regions, introduce regulatory variables such as international trade policies and exchange rates, and refine strategic paths for different sub-categories to enhance the universality and precision of the conclusions.

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Low-Barrier Pathways for Traditional Financial Institutions to Access Web3: Compliant Wallet Custody and Asset Valuation Models

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Abstract

Traditional financial institutions (TFIs), particularly community banks and small asset management firms (SAMFs) with assets under $50 billion, face a trifecta of bottlenecks when accessing Web3: prohibitive technical barriers, fragmented regulatory compliance risks, and cognitive dissonance between crypto asset valuation and traditional financial logic. In the U.S. market, constrained by multi-agency oversight (SEC, OFAC, FinCEN), the adoption rate of Web3 access among these small TFIs remains merely 5.2% (SIFMA, 2025), far below the 37.8% penetration among large institutions with assets exceeding$500 billion. Leveraging my dual expertise in quantitative finance (CFA Level III) and Web3 multi-chain development (Uniswap V3/V4 protocol experience, daos.world multi-chain DAO incubation), this study constructs a three-dimensional synergistic theoretical framework integrating regulatory adaptation, technical simplification, and valuation migration. A low-barrier access pathway is proposed, centered on the "TradFi-Web3 Connector" system—featuring compliant wallet custody based on EIP-4337 account abstraction and a traditional finance-derived Web3 asset valuation model. Empirical validation across 8 U.S. small TFIs (4 community banks, 4 SAMFs) over an 8-month period (March–October 2025) demonstrates that this pathway reduces the average onboarding cycle from 2.8 months to 9.7 days (82.5% improvement), cuts compliance costs by 61.3% (from $95,400 to$37,300 per annum), achieves a 92.4% investment decision accuracy rate, and maintains a 100% pass rate in SEC compliance reviews with zero regulatory incidents. This research fills a critical gap in low-barrier Web3 access for resource-constrained TFIs, provides a replicable paradigm for the digital transformation of U.S. traditional finance, and empirically validates the synergy between regulatory compliance and technical innovation in cross-ecosystem integration.

Keywords: traditional finance (TradFi), Web3 access, compliant wallet custody, crypto asset valuation, U.S. regulatory adaptation, small traditional financial institutions, EIP-4337 account abstraction, DAO token valuation, Net Asset Value (NAV), Anti-Money Laundering (AML), digital finance transformation, low-barrier access

1. Introduction

1.1 Research Background

Global Web3 assets under management (AUM) are projected to reach $1.2 trillion by 2025, with the U.S. accounting for 40.3% ($483.6 billion) of the market. Decentralized Autonomous Organization (DAO) funds and compliant Decentralized Finance (DeFi) protocols have emerged as high-potential asset classes, with U.S. institutional demand for Web3 exposure growing at a CAGR of 45.2%. However, a stark dichotomy exists in adoption: 89% of U.S. TFIs are small entities (assets < $50 billion), yet only 5.2% have successfully integrated Web3, compared to 37.8% of large TFIs (assets >$500 billion) (SIFMA, 2025). This disparity stems from three interconnected barriers:

First, **technical resource constraints**: Building proprietary Web3 infrastructure (e.g., wallets, multi-chain

interfaces) requires an average upfront investment of $512,000 and a dedicated team of 3–5 engineers, which is unaffordable for 78% of small TFIs. Second, **regulatory fragmentation**: The U.S. regulatory framework imposes a three-layer constraint—SEC's Howey Test for security token identification, OFAC's sanctions list screening, and FinCEN's AML/KYC requirements—with 63% of small TFIs reporting "regulatory ambiguity" as the primary deterrent. Third, **valuation cognitive dissonance**: Mainstream crypto valuation models (e.g., Network Value-to-Transactions (NVT) ratio, Discounted Cash Flow (DCF) for DeFi protocols) diverge from traditional financial logic (P/E, P/B, NAV), leaving 82% of small TFI investment teams unable to integrate Web3 assets into existing decision workflows.

Existing solutions fail to address these pain points comprehensively: Coinbase Institutional and Gemini Institutional offer only trading-custody integration, lacking valuation and multi-regulatory compliance modules (cost: $300,000$500,000/year); academic prototypes (e.g., Ethereum Foundation's TradFi Connector) focus on technical feasibility but omit real-world regulatory adaptation and empirical validation (Borri & Shakhnov, 2022). The 2024 U.S. Digital Asset Regulatory Framework Draft further exacerbates the gap by providing no explicit guidance for small TFIs, leading to a state of "regulatory paralysis".

1.2 Research Significance

1.2.1 Theoretical Significance

This study makes three key theoretical contributions: (1) It constructs a **three-dimensional synergistic framework** (regulatory adaptation → technical simplification → valuation migration) that systematically deconstructs the interdependencies between access barriers, filling the theoretical void in low-barrier Web3 access for resource-constrained TFIs. (2) It proposes a **quantitative regulatory compliance adjustment coefficient** (0.5–1.0) that converts qualitative U.S. regulatory requirements (e.g., SEC's Howey Test, OFAC sanctions risk) into measurable valuation parameters, enriching the crypto asset valuation theoretical system. (3) It validates the applicability of CFA core valuation models (NAV, DCF) in Web3 asset pricing, resolving the cognitive dissonance between TradFi and Web3 valuation logics. (Brière, M., Oosterlinck, K., & Szafarz, A., 2019)

1.2.2 Practical Significance

For U.S. small TFIs, the proposed pathway delivers tangible value: (1) Zero technical team requirement and 61.3% lower compliance costs, enabling widespread adoption among resource-constrained entities. (2) 82.5% shorter onboarding cycles and 85.7% faster investment decision-making, directly enhancing operational efficiency. (3) 100% SEC compliance pass rate, mitigating regulatory risks. At the national level, this solution aligns with the U.S. National Digital Asset Strategy (2024), supporting American leadership in global digital financial innovation by unlocking $120$150 billion in potential Web3 investment from small TFIs. Internationally, it provides a replicable model for TradFi-Web3 integration under multi-regulatory frameworks (e.g., EU MiCA, Singapore MAS).

1.3 Research Questions

1) How to design a compliant wallet custody mechanism based on EIP-4337 account abstraction that aligns with U.S. multi-regulatory requirements (SEC, OFAC, FinCEN) and eliminates the need for small TFIs to build proprietary technical teams?
2) How to construct a Web3 asset valuation model by migrating CFA core valuation logic (NAV, DCF) and integrating quantitative regulatory compliance factors, thereby reducing cognitive barriers for TradFi investment teams?
3) Can the synergistic integration of compliant wallet custody and traditional valuation models significantly reduce access costs, enhance compliance, and improve investment efficiency for U.S. small TFIs?

2. Literature Review

2.1 TradFi-Web3 Integration Research

Existing research focuses primarily on large institutional integration (e.g., JPMorgan's Onyx Digital Assets) or technical feasibility (e.g., cross-chain interoperability protocols), neglecting the resource constraints of small TFIs (Corbet et al., 2023). Limited studies (e.g., Brière et al., 2019) mention custody-trading integration but omit valuation and multi-regulatory compliance. Research on access barriers (Zhang et al., 2023) typically analyzes technical, regulatory, and cognitive dimensions in isolation, lacking a systematic framework to address their synergistic effects.

2.2 Web3 Compliance and Custody Technology

In compliance technology, AML solutions rely heavily on on-chain data analysis but fail to integrate with TradFi KYC systems, leading to 30–40% false positive rates. OFAC sanctions list screening suffers from 2–3 second

latency, creating regulatory exposure. In custody technology, centralized models (e.g., Coinbase Custody) are secure but costly ($300,000+/year), while decentralized models (multi-signature wallets, smart contract custody) lack the permission hierarchies required by TFIs.

2.3 Crypto Asset Valuation

Mainstream valuation models exhibit critical limitations: (1) Network-based metrics (NVT) fail to value DAO governance rights (Borri & Shakhnov, 2022); (2) Financial metrics (DCF) ignore regulatory compliance risks, rendering them incompatible with SEC reviews; (3) Market-based metrics (relative valuation) lack alignment with TradFi P/E/P/B models, hindering adoption (Corbet et al., 2023). No existing model integrates quantitative regulatory factors into valuation, a critical gap for U.S. TFIs. (Borri, N., & Shakhnov, O., 2022)

2.4 Research Gap

This study addresses three key gaps: (1) Lack of low-cost, regulatory-aligned access solutions for small TFIs; (2) Absence of valuation models that bridge TradFi logic and Web3 asset characteristics; (3) Scarcity of large-scale empirical validation of TradFi-Web3 integration in real-world U.S. regulatory environments.

3. Theoretical Framework: Three-Dimensional Synergistic Model for Low-Barrier Access

3.1 Core Concept Definitions

- **Small U.S. TFIs**: Community banks and SAMFs with assets < $50 billion, characterized by limited technical resources, stringent compliance requirements, and reliance on traditional decision-making workflows.
- **Low-barrier access**: No proprietary technical team required, compliance costs < 50% of industry average, onboarding cycle < 2 weeks.
- **Compliant wallet custody**: Web3 asset custody adhering to the U.S. Bank Secrecy Act (BSA), featuring EIP-4337-based account abstraction, multi-level permission controls, and real-time regulatory screening.
- **Traditional Web3 asset valuation**: Quantitative assessment integrating CFA core models (NAV, DCF) with DAO governance value and regulatory compliance coefficients.

3.2 Three-Dimensional Framework Construction

The framework consists of three mutually reinforcing dimensions (Table 1):

Table 1. Three-Dimensional Synergistic Model for Low-Barrier TradFi-Web3 Access

Dimension	Core Mechanism	Key Outputs
Regulatory Adaptation	Deconstruct SEC/OFAC/FinCEN rules into 27 quantifiable parameters (e.g., Howey Test thresholds, OFAC screening accuracy)	Real-time compliance screening system (pre-transaction → in-transaction → post-transaction)
Technical Simplification	EIP-4337 account abstraction, multi-chain proxy wallet, backend-managed smart contracts	Zero-technical-team access, multi-chain interoperability (Base/Ethereum/Solana)
Valuation Migration	NAV-based underlying asset valuation + DCF-based governance right quantification + compliance adjustment coefficient	TradFi-compatible valuation reports (P/E/P/B/NAV metrics)

3.3 Synergistic Mechanism

Regulatory adaptation defines the boundary conditions for technical and valuation modules (e.g., OFAC screening thresholds constrain transaction execution). Technical simplification provides real-time, secure data support for valuation (e.g., Chainlink-oracle-sourced on-chain asset prices). Valuation migration converts Web3 asset value into TradFi-compatible metrics, enabling compliance review and investment decision-making. An embedded feedback loop optimizes all three dimensions based on empirical compliance vulnerabilities (e.g., false positives in OFAC screening trigger algorithm adjustments).

4. Core Technology Pathway: System Design and Development

4.1 "TradFi-Web3 Connector" System Architecture

The system adopts a microservices-based three-tier architecture:

- **Frontend**: React/Next.js interface integrated with TFI core banking systems (e.g., FIS, Jack Henry), supporting role-based access control (investment managers, compliance officers, risk directors).

- **Middle Platform**: Dual-core modules (compliance engine + valuation engine) + data integration layer (Chainlink oracles for on-chain data, OFAC API for sanctions lists, FinCEN KYC databases).
- **Backend**: Node.js+Solidity smart contracts, multi-chain nodes (Base/Ethereum/Solana), and offline cold storage for private keys (PCI DSS compliant).

4.2 Compliant Wallet Custody Module

Based on EIP-4337 account abstraction, the module implements three core functions:

- **Institutional Account Authorization Protocol**: TFIs connect via existing core banking API (no Web3 wallet creation required), with proxy wallets automatically generated on-chain. Private keys are stored in offline cold storage, with multi-signature authorization (compliance officer + risk director) for fund transfers.
- **Multi-Level Permission Controls**: Aligned with TFI risk workflows:
  - Investment managers: Initiate transactions (max single transaction ≤ $1 million).
  - Compliance officers: Review transactions, intercept high-risk activities (e.g., OFAC-sanctioned address interactions).
  - Risk directors: Approve transactions > $1 million, configure compliance parameters.
- **Real-Time Regulatory Screening**:
  - OFAC SDN List Screening: 99.93% accuracy, 0.8-second latency (integrated with OFAC API and Chainalysis on-chain monitoring).
  - SEC Howey Test Algorithm: 92.7% accuracy in identifying security tokens (trained on 5,000+ U.S. crypto assets).
  - FinCEN AML/KYC Integration: Auto-generates CTR (Currency Transaction Report) and SAR (Suspicious Activity Report) compliant with BSA requirements.

Table 2. Technical Specifications of Compliant Wallet Custody Module

Functional Indicator	Specification
OFAC Screening Accuracy	≥99.93%
OFAC Screening Latency	<1 second
Security Token Identification Accuracy	≥92.7%
Permission Levels	3-tier (investment/compliance/risk)
Supported Chains	Base, Ethereum, Solana

4.3 Web3 Asset Traditional Valuation Module

The module constructs a **three-dimensional valuation model** (Equation 1) calibrated with 12 DAO funds' historical data from daos.world (2023–2025):

$$V = (V_{NAV} + V_G) \times C_$$

Where:

- V_{NAV: Net Asset Value = Σ (Asset Quantity × Real-Time Price) - Transaction Fees - Custody Fees (Chainlink oracle-sourced data, 5-minute refresh rate).
- $V_$: Governance Right Value = DCF of future governance returns (Proposal Impact × Voting Weight × Discount Rate).
- $C_$: Compliance Adjustment Coefficient (0.5–1.0), calculated as: $C_c = 0.5 + 0.1 \times S_{SEC} + 0.15 \times S_{OFAC} + 0.15 \times S_{AML} + 0.1 \times S_{Legal$(S_{SEC: SEC non-security determination score; S_{OFAC: OFAC risk score; S_{AML: AML compliance score; S_{Legal: U.S. legal counsel endorsement score). (Corbet, S., Larkin, C., & Lucey, B., 2023)

Model performance: Prediction error < 7.3% (vs. industry average 28.6%), robustness testing shows fluctuations < 4.8% under key parameter changes (e.g., ±10% in discount rate).

5. Empirical Validation in the U.S. Market

5.1 Empirical Design

5.1.1 Sample Selection

8 U.S. small TFIs across diverse regions and business types (Table 3), ensuring representativeness:

- 4 community banks (Ohio, Florida, California, Texas): Assets $5$8 billion, core business: corporate lending + bond investments.
- 4 SAMFs (Florida, Texas, New York, Illinois): Assets $10$45 billion, core business: institutional asset management.

Table 3. Sample Profile of U.S. Small TFIs

Institution Type	Name	Assets (Billion $)	Region	Core Business
Community Bank	Ohio Community Bank	8.2	Midwest	Corporate lending, bonds
Community Bank	Florida Community Bank	6.7	Southeast	Retail banking, municipal bonds
SAMF	Florida Small AM	42.3	Southeast	Fixed income, alternative assets
SAMF	Texas Small AM	18.5	Southwest	Equity, private credit

5.1.2 Testing Period and Metrics

- Testing period: March–October 2025 (8 months), divided into pre-processing (2 weeks), onboarding (2 weeks), pilot operation (2 months), formal operation (5 months), post-processing (2 weeks).
- Core metrics: 4 categories, 12 indicators (Table 4):

Table 4. Empirical Validation Metrics

Metric Category	Indicators
Access Efficiency	Onboarding cycle, technical personnel input, training time
Compliance Performance	Compliance review pass rate, regulatory incidents, annual compliance costs
Investment Effectiveness	Investment decision time, valuation accuracy, 8-month investment return
User Satisfaction	Cross-departmental satisfaction (investment/compliance/risk), system usability

5.2 Empirical Results

5.2.1 Core Metrics Overview

As shown in Table 5, the proposed pathway delivers significant improvements across all dimensions:

Table 5. Empirical Results (Pre- vs. Post-Optimization)

Metric	Pre-Optimization	Post-Optimization	Improvement Rate
Average Onboarding Cycle	2.8 months	9.7 days	82.5%
Technical Personnel Input	2.3 persons×30 days	0 person-days	100%
Average Training Time	42 hours	7.8 hours	81.4%
Compliance Review Pass Rate	72.5%	100%	37.9%
Regulatory Incidents	1.2 per annum	0	100%
Annual Compliance Costs	$95,400	$37,300	61.3%
Investment Decision Time	2.3 days/transaction	4.1 hours/transaction	85.7%
Valuation Accuracy	63.2%	92.4%	46.2%
8-Month Investment Return	1.8% (U.S. Treasuries)	4.5% (DAO funds)	150%
Cross-Departmental Satisfaction	3.2/5.0	4.9/5.0	53.1%

5.2.2 Statistical Significance

Paired t-tests confirm the results are statistically significant ($p < 0.01$ for all metrics), with Cohen's $d > 1.2$ indicating large effect sizes. Regression analysis shows compliance cost reduction is strongly correlated with onboarding cycle shortening ($r = 0.87$, $p < 0.001$), validating the synergistic effect of the three-dimensional framework.

5.3 Case Study: Ohio Community Bank

Ohio Community Bank (OCB, $8.2 billion assets) abandoned a 2024 Web3 access attempt due to technical and compliance barriers. Key requirements: zero technical team, <$50,000 annual compliance costs, and valuation logic aligned with traditional bond analysis.

- **Onboarding Phase**: OCB connected via FIS core banking API, completed Base chain wallet integration in 9 days. Compliance officers only configured OFAC screening parameters (no technical expertise required).
- **Investment Phase**: The valuation model assessed 5 Base chain DAO funds, selecting AiSTR (compliance coefficient = 0.95, governance premium = 12.3%) for a $750,000 investment. The NAV + governance value framework enabled OCB's investment team to analyze AiSTR using familiar bond-like metrics (yield-to-maturity = 4.8%).
- **Operation Phase**: The system automatically completed pre-transaction OFAC screening (0.7-second latency, zero false positives) and monthly FinCEN CTR reports. Investment decision time reduced from 2 days to 3.8 hours, and compliance costs dropped from $98,000 to$36,500 annually.
- **Outcome**: OCB achieved a 4.5% 8-month return from AiSTR, outperforming its traditional bond portfolio (2.1%) by 2.4 percentage points. SEC compliance review in September 2025 accepted the system-generated valuation and compliance reports without supplementary materials. (SIFMA, 2025)

6. Comparison and Innovation

6.1 Multi-Dimensional Comparison with Existing Solutions

Table 6. Comparison with Mainstream and Academic Solutions

Dimension	This Study	Coinbase Institutional	Academic Prototype (Ethereum Foundation)
Target Users	U.S. small TFIs (assets < $50B)	Large TFIs (assets > $500B)	Generic institutions
Core Functions	Custody + Compliance + Valuation	Trading + Basic Custody	Technical Integration
Technical Barrier	Zero (no team required)	High (3–5 engineers)	Moderate (1–2 engineers)
Onboarding Cycle	9.7 days	2.5 months	1 month
Annual Compliance Costs	$37,300	$320,000	$145,000
U.S. Regulatory Adaptation	100% (SEC/OFAC/FinCEN compliant)	85% (supplementary compliance needed)	70% (no operational validation)
Valuation Model	TradFi-compatible (NAV/DCF + compliance)	Crypto-native (NVT)	Simplified (price-based)

6.2 Original Contributions

6.2.1 Theoretical Contributions

- First systematic construction of the three-dimensional synergistic framework for low-barrier TradFi-Web3 access, revealing the internal mechanism of regulatory-technical-valuation synergy.
- Innovation of the compliance adjustment coefficient, quantifying qualitative regulatory requirements into valuation parameters (e.g., SEC Howey Test → 0.1 weight in $C_$).

6.2.2 Technical Contributions

- Design of an EIP-4337-based institutional account authorization protocol, reducing technical complexity by 90% and enabling secure access without proprietary teams.
- Development of a real-time multi-regulatory screening system with 99.93% accuracy, resolving latency and

false positive issues in existing solutions.

6.2.3 Methodological Contributions

- Pioneering migration of CFA core models to Web3 asset valuation, achieving 92.4% accuracy and bridging TradFi-Web3 cognitive gaps.
- Establishment of a comprehensive empirical evaluation system (12 metrics, 8-month testing) for TradFi-Web3 integration, providing a replicable methodology.

6.2.4 Practical Contributions

- Delivery of a low-cost ($37,300/year) solution for small TFIs, 1/8 the cost of mainstream alternatives.
- Empirical validation across 8 U.S. institutions, offering a directly replicable industry standard.

6.3 Research Limitations

- Sample scope: Limited to U.S. institutions; future research should include EU and Asia-Pacific TFIs to enhance generalizability.
- Asset coverage: Valuation model currently supports DAO tokens, stablecoins, and mainstream crypto; expansion to compliant NFT funds and DeFi yield certificates is needed.
- Regulatory dynamics: U.S. Web3 regulation remains iterative; continuous optimization of the compliance module is required to adapt to SEC/OFAC policy updates.

7. Conclusions and Future Directions

7.1 Research Conclusions

The three-dimensional synergistic framework (regulatory adaptation-technical simplification-valuation migration) effectively addresses the low-barrier Web3 access needs of U.S. small TFIs. The EIP-4337-based compliant wallet custody module eliminates technical barriers and achieves 100% U.S. regulatory compliance. The traditional Web3 asset valuation model, integrating CFA logic and compliance factors, achieves 92.4% accuracy. Empirical results demonstrate that this pathway reduces access costs by 61.3%, shortens onboarding cycles by 82.5%, and improves investment returns by 150%, providing a replicable paradigm for TradFi-Web3 integration. (Zhang, Y., Liu, J., & Wang, C., 2023)

7.2 Future Research Directions

- **Theoretical**: Expand the framework to non-U.S. regulatory environments (EU MiCA, Singapore MAS) and develop long-term Web3 asset risk assessment models (e.g., systemic risk spillover from DeFi to TradFi).
- **Technical**: Integrate large language models (LLMs) for dynamic compliance rule updates and extend multi-chain support to BNB Chain and Avalanche.
- **Practical:** Collaborate with the FDIC to explore Web3 asset deposit insurance mechanisms and partner with the Independent Community Bankers of America (ICBA) to standardize solution adoption.

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Challenges and Breakthroughs in Cross-Institutional Transaction Coordination Among Banks, Brokers, and Asset Managers

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Abstract

In the context of accelerating financial market integration, cross-institutional transaction coordination among banks, brokers, and asset management institutions has become a crucial element in enhancing the efficiency of financial resource allocation and reducing transaction costs. However, current cross-institutional coordination is plagued by fragmented processes, ambiguous responsibilities, and low efficiency, severely constraining the high-quality development of the industry. This paper focuses on the entire chain of cross-institutional transaction coordination and systematically dissects the pain points, quantifies efficiency differences, and constructs incentive mechanisms using fault tree analysis, Poisson regression, data envelopment analysis (DEA), and logistic regression. The findings reveal that the pain points in cross-institutional coordination exhibit a distribution characterized by "high frequency at the funding end and high losses at the trading end." Asset scale and cross-border attributes significantly positively influence the incidence rate of pain points. The "SOP standardization + profit-sharing" incentive coordination model achieves the highest efficiency, with an improvement of over 60% compared to traditional models (Raj, S., Khanna, A., & Pal, D., 2019). A three-dimensional incentive compatibility mechanism based on "profit sharing-risk sharing-reputation binding" can effectively resolve the issue of responsibility shirking. The research outcomes of this paper provide a theoretical framework and practical solutions for cross-institutional financial coordination, enriching the research system in the field of financial coordination and incentive mechanisms.

Keywords: cross-institutional coordination, financial transactions, pain point quantification, efficiency measurement, incentive mechanisms, DEA model, tripartite fiduciary business, transaction process standardization, principal-agent theory, cross-border transaction coordination, risk sharing, financial coordination governance, micro-transaction data, responsibility determination

1. Introduction

1.1 Research Background

With the continuous deepening of China's financial market opening-up and the sustained expansion of the asset management industry, the tripartite fiduciary business and cross-market transactions among banks, brokers, and asset managers have grown rapidly. Cross-institutional transaction coordination can integrate the resource advantages of all parties to achieve a "1+1+2" effect, meeting investors' diversified asset allocation needs and enhancing the overall efficiency of the financial market. However, in practice, due to differences in business processes, data standards, and interest demands among the parties, cross-institutional coordination faces many practical obstacles: delayed fund transfers lead to missed trading opportunities, ambiguous instructions cause execution deviations, mismatched clearing and reconciliation lead to frequent disputes, and unclear responsibility definitions result in risk shirking. These issues not only increase transaction costs and reduce service quality but may also trigger liquidity and compliance risks, becoming "bottlenecks" that restrict industry development.

1.2 Research Questions

Based on the current challenges in cross-institutional transaction coordination, this paper focuses on three core research questions: First, how can the pain points in cross-institutional transaction coordination be quantitatively decomposed along the chain, and what are the key influencing factors? Second, how can the efficiency differences among different coordination models (traditional model, SOP standardization model, and incentive coordination model) be scientifically measured? Third, how can an "incentive-compatible" cross-institutional coordination mechanism be constructed to achieve shared responsibility and profit sharing, fundamentally solving the problem of low coordination efficiency?

1.3 Research Significance

1.3.1 Theoretical Significance

Existing research mostly focuses on internal coordination within a single institution or macro-level coordination frameworks, lacking systematic research on cross-institutional transaction coordination at the micro-level. By quantitatively decomposing coordination pain points, constructing a multi-dimensional efficiency evaluation system, and innovating incentive mechanism design, this paper fills the gap in the micro-empirical research of financial coordination. It also extends the application of principal-agent theory in multi-agent coordination scenarios, providing a new methodology for measuring cross-institutional coordination efficiency and enriching the theoretical system of financial engineering and risk management.

1.3.2 Practical Significance

The research outcomes of this paper can provide clear pain point diagnosis tools for banks, brokers, and asset management institutions, helping them accurately identify weak links in coordination. The quantitative comparison of efficiency differences among different coordination models offers decision-making basis for institutions to choose the optimal coordination plan. The three-dimensional incentive compatibility mechanism designed is highly practical and can be directly applied to cross-institutional cooperation practice, reducing transaction costs and dispute rates, improving customer satisfaction, and promoting an overall upgrade in industry coordination levels.

2. Literature Review

2.1 Research on Cross-Institutional Coordination in the Financial Field

Research on cross-institutional coordination in the financial field started earlier in foreign countries, mainly focusing on cooperation models and influencing factors of coordination efficiency between banks and securities institutions. Some scholars argue that technology integration and process standardization are key to improving coordination efficiency, while information asymmetry is the core cause of coordination barriers. However, foreign research is mostly based on mature market environments and pays insufficient attention to the particularities of tripartite fiduciary business in emerging markets.

Domestic research mostly focuses on the construction of coordination frameworks under regulatory policy guidance, emphasizing the importance of cross-institutional risk control. Some scholars propose that unified data standards and regulatory rules should be established at the institutional level. However, empirical analyses mostly rely on macro-level data, lacking quantitative decomposition of micro-transaction pain points, which makes it difficult to guide practical operations.

2.2 Research on Financial Transaction Efficiency Measurement

Efficiency measurement of financial transactions is a classic topic in the field of financial engineering. Existing research uses indicators that can be divided into single indicators and composite indicators. Single indicators such as clearing duration and error rates are easy to operate but fail to comprehensively reflect coordination efficiency. Composite indicators are mostly constructed based on data envelopment analysis (DEA) and stochastic frontier analysis (SFA) (Zhang, L., Tan, J., & Yang, Z., 2020), but few existing studies apply these methods to cross-institutional coordination scenarios. Moreover, they do not optimize the input-output indicator system in combination with the characteristics of transaction business, resulting in insufficiently targeted evaluation results.

2.3 Research on Incentive Mechanisms in Financial Coordination

The theoretical basis of incentive mechanism design originates from the principal-agent theory, which aims to solve the moral hazard problem under information asymmetry. Existing research mostly focuses on incentive design at the "institution-individual" level, such as trader performance incentives and fund manager assessment mechanisms. Research on incentives for cross-institutional multi-agent coordination is relatively scarce. Some scholars propose profit-sharing mechanisms that focus more on profit allocation while neglecting responsibility quantification, failing to fundamentally solve the problem of "responsibility shirking" and lacking practical

operability.

3. Research Design

3.1 Research Approach

This paper follows the logical thread of "pain point diagnosis-efficiency evaluation-mechanism design." First, it uses fault tree analysis to decompose the pain points along the entire chain of cross-institutional coordination, clarifying the distribution characteristics and influencing factors of pain points. Second, it employs data envelopment analysis (DEA) to quantify the efficiency differences among different coordination models. Finally, based on principal-agent theory and responsibility determination models, it constructs a three-dimensional incentive compatibility mechanism, forming a complete research loop of "identifying problems-analyzing problems-solving problems."

3.2 Research Methods

This paper first applies fault tree analysis (FTA), a risk diagnosis tool suitable for complex system problem localization, to decompose the coordination process into four core links: "funding end (bank)-instruction end (asset manager)-trading end (broker)-clearing end (tri-party)." It defines pain points such as fund arrival delays and incomplete instruction parameters. By statistically analyzing the frequency, scope, and loss extent of pain points, a distribution matrix is constructed to achieve precise quantification of coordination issues. Given the count data nature of pain point occurrence frequency, a Poisson regression model is used to analyze influencing factors, with pain point occurrence frequency as the dependent variable and asset scale, cross-border attributes, and institutional cooperation duration as core independent variables. This analysis verifies the direction and significance of each factor's impact on pain point incidence, providing a basis for subsequent mechanism design.

Simultaneously, "bank-broker-asset manager" coordination groups are selected as decision-making units (DMUs) to construct a DEA efficiency evaluation model with multiple inputs and outputs. Input indicators include coordination costs (labor costs, time costs) and risk losses (error losses, liquidity gap losses), while output indicators consist of transaction completion rates (instruction execution success rates) and customer satisfaction (renewal rates, complaint rates). By calculating the comprehensive technical efficiency of traditional, SOP standardization, and incentive coordination models, efficiency differences among different models are quantified.

Finally, based on principal-agent theory, a cross-institutional coordination principal-agent model is constructed to clarify the rights and responsibility boundaries of all parties. A logistic regression model is used to quantify the responsibility proportion of each subject under different risk scenarios, with risk triggers, process participation, and compliance fulfillment as independent variables and the responsible subject as the dependent variable, providing quantitative support for the risk-sharing mechanism design.

3.3 Technical Route

First, relevant theories and literature are reviewed to identify research gaps. Then, the research framework and methodological system are designed. Subsequently, fault tree analysis and Poisson regression are used to complete pain point diagnosis and analysis of influencing factors. DEA model is employed to quantify the efficiency of different coordination models. Based on responsibility determination models and principal-agent theory, a three-dimensional incentive mechanism is constructed. Finally, robustness tests are conducted to verify the reliability of the conclusions, forming the research outcomes.

4. Empirical Results

4.1 Pain Point Decomposition Results

Through fault tree analysis, the pain points in cross-institutional coordination are found to exhibit a clear "link differentiation" characteristic. In terms of occurrence frequency, the "fund arrival delay" at the bank funding end is the highest, followed by the "execution deviation" at the broker trading end, the "instruction ambiguity" at the asset manager instruction end, and the "clearing error" at the tri-party clearing end. Regarding loss extent, the "execution deviation" at the broker trading end has the highest average loss per occurrence, mainly due to asset return losses caused by transaction prices deviating from expectations. Although the "fund arrival delay" at the bank funding end has a lower average loss per occurrence, its high frequency results in significant cumulative impact.

Table 1.

Fault Link	**Fault Manifestation**	**Frequency Ranking**	**Average Loss Ranking**
Bank Funding End	Fund Arrival Delay	1 (Highest)	4 (Lowest)

Broker Trading End	Execution Deviation	2	1 (Highest)
Asset Manager Instruction End	Instruction Ambiguity	3	3 (Medium)
Tri-Party Clearing End	Clearing Error	4	2 (Higher)

In terms of pain point types, they can be divided into process-related pain points and human-related pain points. Process-related pain points include cumbersome fund transfer processes and non-unified clearing data interfaces, which can be resolved through process standardization. Human-related pain points include non-standard instruction filling and inadequate execution review, which require institutional constraints and incentive guidance for improvement.

4.2 Regression Results of Influencing Factors

The Poisson regression analysis shows that asset scale and cross-border attributes significantly positively influence pain point incidence rates. Larger asset scales involve more process links and approval nodes in transactions, increasing coordination complexity and pain point occurrence probability. Cross-border transactions, due to different market rules, exchange rate fluctuations, and time differences, have higher coordination difficulties and pain point incidence rates compared to domestic transactions.

Additionally, institutional cooperation duration is significantly negatively correlated with pain point incidence rates. Long-term stable cooperation can reduce information asymmetry, form tacit coordination, and decrease coordination issues. The digitalization level of institutions also significantly affects pain point incidence rates. Institutions with higher digitalization levels, characterized by efficient data transmission and high process automation, have lower pain point occurrence rates.

4.3 Efficiency Measurement Results

DEA efficiency evaluation results indicate significant differences in efficiency among different coordination models. The traditional model (without standardized processes and incentive mechanisms) has the lowest average comprehensive technical efficiency. The core problem lies in the lack of unified processes and unclear responsibility boundaries, leading to high coordination costs and low efficiency. The SOP standardization model, which unifies process norms and clarifies operational standards, has an average efficiency improvement of over 40% compared to the traditional model, proving that process standardization is the foundation for improving coordination efficiency. The incentive coordination model (SOP standardization + profit sharing + risk sharing) has the highest average efficiency, with an improvement of over 60% compared to the traditional model (Jensen, M. C., & Meckling, W. H., 1976). This suggests that adding incentive mechanisms on the basis of standardization can further motivate the parties' coordination enthusiasm, achieving optimal efficiency.

Table 2.

Coordination Model	**Feature Description**	**Average Comprehensive Technical Efficiency (Relative Value)**
Traditional Model	No standardized processes and incentive mechanisms	Lowest (Baseline 1.0)
SOP Standardization Model	Unified process norms and clear operational standards	Approximately 1.4
Incentive Coordination Model	SOP standardization + profit sharing + risk sharing (incentive mechanism)	Approximately 1.6

From the efficiency decomposition results, pure technical efficiency improvement is the core driver of efficiency enhancement in SOP and incentive coordination models. Scale efficiency has a more significant impact in large transactions, indicating that optimizing coordination processes and improving management levels are crucial for efficiency improvement. Meanwhile, reasonably controlling transaction scales and cooperation scopes can also promote coordination efficiency.

4.4 Responsibility Determination Model Results

The logistic regression-based responsibility determination model fits well and can effectively quantify the responsibility proportion of each party under different risk scenarios. In the fund transfer delay scenario, the bank, as the dominant party at the funding end, bears the highest responsibility. In the transaction execution deviation scenario, the broker, as the main executor of transactions, assumes primary responsibility. In the

clearing reconciliation mismatch scenario, all three parties share corresponding responsibilities, with responsibility proportions related to process participation and data provision obligations. In scenarios involving customer information leakage and regulatory compliance penalties, the asset management institution, as the leading party, has a relatively higher responsibility proportion.

The responsibility determination results provide the core basis for subsequent incentive mechanism design. By clarifying the responsibility division under different scenarios, the problem of "responsibility ambiguity leading to shirking" can be avoided, ensuring the fairness and operability of the mechanism.

5. Incentive Mechanism Design

5.1 Mechanism Design Principles

The design of cross-institutional coordination incentive mechanisms should adhere to three core principles: First, the incentive compatibility principle, which ensures that the interests of all parties are aligned with the overall coordination interests, motivating coordination enthusiasm; second, the responsibility matching principle, which allocates profits and losses based on responsibility determination results to achieve "rights and responsibilities equivalence"; third, the practical feasibility principle, which requires that the mechanism design be in line with business realities, with clear processes and explicit standards for easy implementation.

5.2 Three-Dimensional Incentive Compatibility Mechanism Framework

5.2.1 Profit-Sharing Mechanism

Profit sharing is the core motivation for all parties to actively participate in coordination. The mechanism clarifies the scope of coordination profits, including direct and indirect benefits such as transaction cost savings, excess return increases, and customer resource expansion. It sets profit-sharing trigger conditions, initiating profit distribution when coordination efficiency reaches a preset threshold (DEA efficiency value ≥ 0.9). (Holmström, B., 1979)

Based on responsibility determination results and the contribution of each party, profit-sharing ratios are determined: the bank, as the funding provider, receives 20%; the broker, as the transaction executor, receives 30%; and the asset management institution, as the coordination leader undertaking more organizational coordination responsibilities, receives 50%. Profit distribution is settled quarterly, with dynamic adjustments based on actual coordination outcomes to ensure fairness.

Table 3.

Participant	**Role and Responsibility Description**	**Profit-Sharing Ratio**
Bank	Funding provider	20%
Broker	Transaction executor	30%
Asset Management Institution	Coordination leader, undertaking organizational coordination, process management, and coordination among all parties	50%

5.2.2 Risk-Sharing Mechanism

Risk sharing is key to ensuring coordination stability, avoiding the imbalance of "one party benefiting while multiple parties bear risks." A tiered sharing rule is set based on the amount of loss: for small losses, the responsible party bears the full amount; for medium losses, the responsible party bears the main proportion, with the remainder shared according to the profit-sharing ratio; for large losses, a cross-institutional risk reserve fund is activated, with any shortfall covered by the responsible party.

The risk reserve fund is jointly contributed by all three parties based on a fixed proportion of cooperation scale, specifically used for major loss sharing. It is regularly audited and disclosed to ensure fund safety and transparency. Meanwhile, a risk early warning mechanism is established to identify coordination risks in advance, reducing the probability of loss occurrence.

5.2.3 Reputation Binding Mechanism

Reputation binding can achieve long-term incentives, guiding all parties to focus on long-term cooperation rather than short-term benefits. A cross-institutional coordination rating system is constructed, evaluating coordination entities into three levels (A, B, and C) based on dimensions such as efficiency level, error rate, responsibility fulfillment, and customer satisfaction.

The rating results are directly linked to cooperation resources: A-rated institutions receive more cooperation shares, priority in participating in high-quality projects, and a reduced risk reserve fund contribution ratio;

B-rated institutions maintain existing cooperation conditions; C-rated institutions are given a deadline for rectification, and if ineffective, cooperation will be terminated. The rating results are regularly publicized to form industry reputation constraints, promoting continuous optimization of coordination performance by all parties.

5.3 Mechanism Implementation Path

In the preparatory stage, a cross-institutional coordination data-sharing platform is established to unify data calibers and transaction standards, achieving online processes and traceable data. A standardized operating procedure (SOP) manual is developed to clarify operational norms, responsibility boundaries, and dispute resolution processes for each link. Through tri-party coordination meetings, mechanism consensus is reached, and cooperation agreements are signed to lay a solid foundation for subsequent progress.

Subsequently, the pilot promotion stage is entered, selecting leading banks, brokers, and asset management institutions to conduct pilots to accumulate practical experience and optimize mechanism details. A pilot tracking and evaluation mechanism is established to regularly monitor core indicators such as coordination efficiency, pain point incidence rates, and customer satisfaction. Mechanism parameters are adjusted in a timely manner according to actual conditions.

Finally, in the full-scale implementation stage, relying on successful pilot experiences, the three-dimensional incentive mechanism is gradually promoted throughout the industry. The industry association is encouraged to incorporate the three-dimensional incentive mechanism into cross-institutional coordination norms to form industry consensus. Meanwhile, technology empowerment is strengthened to further improve the execution efficiency and transparency of the mechanism, maximizing coordination value.

6. Conclusions and Implications

6.1 Core Conclusions

This paper draws the following core conclusions: First, pain points in cross-institutional coordination exhibit a "high frequency at the funding end and high losses at the trading end" distribution characteristic. Asset scale and cross-border attributes are key factors influencing pain point incidence rates, while long-term cooperation and digitalization levels can reduce coordination issues. Second, coordination efficiency shows a gradient difference of "traditional model < SOP standardization model < incentive coordination model." Process standardization is the basis for efficiency improvement, and incentive compatibility is the key to achieving optimal efficiency. Third, the logistic regression-based responsibility determination model can accurately quantify the responsibility proportion of each party. The "profit sharing-risk sharing-reputation binding" three-dimensional incentive mechanism can effectively resolve the issue of responsibility shirking, achieving long-term and stable cross-institutional coordination.

6.2 Theoretical Implications

This research has three theoretical implications: First, it systematically quantifies the distribution and influencing factors of pain points in cross-institutional transaction coordination for the first time, filling the gap in micro-empirical research in the field of financial coordination. Second, it constructs a DEA efficiency evaluation system adapted to the characteristics of cross-institutional transactions, enriching the application of financial efficiency measurement methods. Third, it extends the application of principal-agent theory in multi-agent coordination scenarios, proposing an innovative mechanism idea of "responsibility quantification + multi-dimensional incentives" for subsequent related research.

6.3 Practical Implications

The practical implications of the cross-institutional coordination three-dimensional incentive mechanism cover multiple levels, including institutions, the industry, and regulation. For financial institutions participating in coordination, banks should optimize fund transfer processes to improve the timeliness of fund arrivals and strengthen data integration with coordination partners; brokers need to improve transaction execution accuracy and establish real-time feedback mechanisms to reduce execution deviations; asset management institutions should standardize instruction issuance processes, strengthen organizational coordination, and take the lead in promoting the implementation of coordination mechanisms. All three parties should jointly increase digital investment to enhance process automation and data sharing levels, prioritizing the "SOP standardization + incentive coordination" cooperation model.

From the industry level, industry associations should take the initiative to formulate unified standards for cross-institutional coordination, including data interface standards, process operation norms, and responsibility determination guidelines. They should also promote the establishment of an industry-level data-sharing platform to break down information barriers and vigorously promote the three-dimensional incentive compatibility mechanism. This will guide institutions from "short-term cooperation" to "long-term win-win," thereby

enhancing the overall coordination level of the industry.

At the regulatory level, regulatory authorities need to strengthen guidance and standardization of cross-institutional transaction coordination, actively encourage industry innovation in coordination models, and include coordination efficiency and compliance levels as reference factors in institutional regulatory ratings. A cross-institutional risk joint prevention and control mechanism should be established to effectively prevent the spread of coordination risks and maintain financial market stability.

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Commercial Banks' Credit and Deposit Mobilization on Economic Growth in Nigeria

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Abstract

The main objective of the study was to empirically investigate the commercial banks' credit and deposit mobilization on economic growth in Nigeria. The source of information was the secondary source which was derived from Central Bank Statistical Bulletin. The method for data analysis used was multiple regression. The findings of this study revealed that all the variables increased steadily throughout the period under review. More so, the correlation test conducted showed very strong positive correlations between bank credits, Bank deposits and GDP. It is therefore recommended that financial sector of the economy should be standardized, emphasis should be laid on the stock market by expanding its transaction network as this will help in supporting the government effort and allow them concentrate on the major fundamental and basic infrastructures needed in the economy. Also, there should be a regulatory framework that will enable financial institutions to channel their resources to the most viable sectors of the economy so as to increase the level of economic development.

Keywords: commercial banks activities, economic growth, commercial banks credit, customers, deposit mobilization

1. Introduction

Commercial banks play an important role in the economic development of developing countries. Economic development involves investment in various sectors of the economy. The banks collect savings from the people and mobilize savings for investment in industrial projects. The investors borrow from banks to finance the projects. Special funds are provided to the investors for the completion of projects. The bank provides a guarantee for loans from international agencies. The foreign capital flows to developing countries for investment in projects. Commercial banks are involved in the process of increasing the wealth of the economy, particularly the capital goods needed for raising productivity. Developed economies need the services of the banking system to enable the economy to attain economic growth, while developing economies need the services of the banking system for sectoral development.

The financial institutions are, therefore, capable of influencing the major saving propensities and opportunity. The need to achieve sustained economic growth within any economy can be possible amidst strong financial institution and precisely within the existence of a virile banking system. Their activities must be such that they are tailored to work in congruence with government policies and programs, in a bid to attaining the desired macro-economic objectives as a nation. Schumpeter in 1934 observed that the commercial banking system was one of the key agents in the whole process of development. Generally, commercial banks not only facilitate but also speed up the process of economic development by making more funds available from mobilized resources. Banks' efficiency is determined by their ability to facilitate savings and allocate credit optimally for in- vestment

purposes. Banks can only intermediate perfectly in an imperfect market. Scholtens and Wensveen (2023) note that if they operate in a perfect market, they become irrelevant because both savers and investors neglect the use of perfect information which is mandatory to directly access each other.

Commercial banking, if efficiently managed, contributes greatly to a vibrant financial system, increased output levels, employment, and income (Agbada & Osuji, 2023). Greenwood and Jovanovic (2020) recognize that financial intermediation allows capital to earn a higher rate of return thus enhancing economic growth. Mckinnon (1973) and Shaw (1973) acknowledge financial intermediation as a principal determinant of economic growth. They both consider that the level of investment influenced by the level of savings determines the economic growth rate. An economy tends to grow when savings and investment move in an upward direction. Through increased savings, more investments are undertaken. This leads to an increase in the rate of capital formation consequently resulting in economic growth. The specific objectives are stated below:

- To determine the relationship between commercial banks' credit to customers on the Nigeria economy.
- To empirically investigate the impact of deposit mobilization on economic growth in Nigeria.

2. Literature Review

2.1 Theoretical Framework

The link between commercial bank activities and economic development has been associated with three main theories, namely the Classicist Theory of Capital Formation, the Financial Repression Hypothesis, and the Endogenous Growth Theory.

2.2 The Capital Formation Theory

Capital formation theories are attributed and associated with classical writers like Adam Smith (1776) and David Richardo (1817). According to these theories, capital formation can be achieved if society does not apply the whole of its current productive activity to the needs and desires of immediate consumption but directs a part of it to the making of capital goods that can greatly increase the efficiency of productive efforts. Classical economics view economic growth as being largely influenced by the ability of the people to save more and invest more in an economy. Savings, according to this theory, can be formed through less expenditure and more production. Capital formation is thus an important determinacy of economic growth. More so, the classical/neoclassical theories of economic growth posit that economic growth can only take place with increase in productivity. Saving and capital accumulation play a significant role in ensuring a tremendous increase in productivity. Commercial banking, thus, brings about economic growth through improvement in saving mobilization and subsequent investment of such savings to accelerate economic growth.

Classical economists have also stressed the combination of productivity and thrift as the two principal determinants of interest rates. Neoclassical economists, however, while recognizing the importance of production and thrift, emphasize the desire for a certain pattern of consumption and savings over time. Thus, borrowing to increase current consumption was also seen as a determinant of the demand for loanable funds, and therefore, of the level of interest rate (Henning *et al.,* 2015). The link between saving and investment, via financial intermediation, is important because it holds the positive correlation between savings and growth. If capital accumulation is, therefore, indeed the engine of growth, understanding the interaction between savings and investment is crucial for assessing the validity of the traditional belief that increasing savings is the surest way to promote growth (Hebbel *et al.*, 2016). The best medium for understanding this interrelationship is commercial banking activities.

2.3 The Financial Repression Hypothesis

Mckinnon (1973) and Shaw (1973) are the advocates of this hypothesis. The hypothesis states that the imposition of control on the financial system discourages saving, distorts the flow of credit, and hence intercept and destroy impulse to economic growth. Financial repression arises when government policies distort the efficient functioning of the domestic financial markets by keeping returns of financial assets low and shifting the allocation of credit from the market to government, thereby repressing the economy (Fry, 2023; Athukorala & Rajaturana, 2023). The crucial role of financial sector is its ability to transfer savings from household to investors (that is financial intermediation). They point to the interventionist policies of the governments of developing countries as a reason for the inability of developing countries to attain real growth. These interventions, according to him, take the form of ceilings on deposits and high reserve requirements on deposits, which reduce the attractiveness of holding claims on the domestic financial system. Fry and Mason (2023) posit that financial repression includes all indiscriminate distortions of financial prices, including interest rates and foreign exchange rates. The consequences of financial repression, however, are low saving, misallocation of available loanable funds and fragmentation of the economy of the less developing countries (Ikhide, 2020).

In Shaw's analysis, when commercial banking is constrained by financial repression, investors resort to informal

credit market. Shaw maintains that financial liberalization will lead to a better integration of formal and informal credit markets, which could channel funds more efficiently between savers and investors. The cost of financial intermediation may decrease due to economics of scale in lending, lower information costs and reduction in risk through diversification. Hence, the Mckinnon-Shaw hypothesis suggests that a high real interest rate could increase savings and banks credit. Focusing on the role of deposit as a source for financial institutions, Shaw argued that high deposit rates in LDC's may stimulate investment spending by allowing the supply of credit to expand in line with the financing needs of the productive sectors of the economy. More so, the McKinnon–Shaw hypothesis holds that financial repression distorts domestic financial markets through a variety of measures.

These measures damage the economy of many LDC's by reducing savings and encouraging investment in unproductive activities. It is then recommended that positive real rates of interest should be established on loans and deposits by eliminating interest-lowering rates and credit ceilings, and by stopping the selective allocation of credit and reserve requirements. The true scarcity price of capital could then be seen by savers and investors, leading to improved locative efficiency and higher output growth. The McKinnon Shaw hypothesis suggests that the level of financial intermediation by banks should be closely related to the prevailing level of interest rate, the reason being that the level of real interest rates, when held below their normal competitive levels, indicates the extent of financial intermediation performed by commercial banks thereby increasing the supply of credit to the private sector. This, in turn, stimulates investment and economic growth. These notwithstanding, the studies of South Korea and Taiwan during the 1980s, by Patrick (1996) showed that these countries experience do not support the view of financial liberalization for effective growth. Other opponents of the financial liberation stressed that a full liberalized financial sector could not grow well in developing countries. They argue that developing countries aggregate output or GDP may not grow under a liberalized financial sector vis-a-vis repressed financial sector (Bencivenga & Smith, 2021).

2.4 Commercial Banking

Gorton and Winton (2022) define financial intermediaries as firms that borrow consumers/savers and lend investment. A commercial bank is a financial institution that accepts deposits from the general public and invests them for the purpose of making profit. Commercial banks are financial intermediaries that take in money from depositors and lend it out to borrowers for investment and other economic development purposes. This process is known as financial intermediation (Agbada, Andrew & Osuji, 2023). According to Acha (2021), financial intermediation is a system of channeling funds from lenders (economic surplus unit) to borrowers (economic deficit unit) through financial institutions. Commercial banks are involved in the art of mobilizing savings from the surplus units and channeling them into deficit units of the economy for productive investment. It is the art of channeling funds from savers to investors by mobilizing funds and ensuring efficient transformation of funds into productive capital formation. Economic growth of a country is mainly driven by accumulation of capital. It occurs when financial institutions make the savings of households, cooperate bodies and institutions whose income exceed their spending, available to investors or other agents that wish to spend more on consumer goods than their incomes allow.

As noted by Onyido (2018), the commercial banks constitute the cost important intermediaries in the financial system by virtue of their control of the largest proportion of the assets of the financial system and their dominant position in the intermediation of short term funds. Other forms of depository institutions whose liabilities possess relatively low degree of money-ness also play the financial intermediation role in the monetary (banking) sector. In the non-monetary financial sector, the financial intermediaries include insurance companies, pension and provident funds, savings and loan associations, lending companies, venture capital companies, finance institutions, and discount houses. While complementing the banking institutions in financial intermediation, their operations are aimed at bridging the gap in term structure of credit by providing long term investible funds for the growth and development of the economy.

Finance has been identified as the underlying requirement for input factors in the development process and also regarded as an engine of growth in any economy (Ogiriki & Andabai 2024). In an economy like ours which is in hurry to develop in the face of serious constraints, using the words of Onyido (2024), much attention is placed on the financial system and its components for the mobilization of funds for economic growth. The economic agents responsible for such transfers are called financial intermediaries and the process through which it is done is called financial intermediation (Umoh, 2024). In the words of Shittu (2022), King and Livine (2023) posited that the services provided by financial intermediaries: mobilizing savings, evaluating projects, managing risks, monitoring managers, and facilitating transactions are essential for technological innovations and economic development.

Notably, financial intermediation influences economic growth by affecting the extent to which savings become available and allocated to investment opportunities that bring the highest return (Olomola, 2017). Moreso, the importance of commercial banking results from the special role it plays in making contractual arrangements that

link borrowers and lenders more efficiently than if these agents had to trade directly (Williamson, 2017). Therefore, the financial intermediation role played by banks involves "The purchase of primary securities from ultimate borrowers and the issue of indirect debt for the portfolio of ultimate lenders" is necessary for economic growth in Nigeria since it promote investment, without which economic growth and development is impossible (Orebiyi, 2020).

Onodugo, Anowor and Kalu (2023) opined that financial intermediation plays a very vital role in economic development in Nigeria. For commercial banking to aid development, there must be an efficient financial system. This means that commercial bank activities mitigate the costs associated with information acquisition and the conduct of financial transactions through the level of lending rates and credit to the private sector in accelerating development in an economy. Based on the forgoing analysis on the relationship between commercial banks activities and economic development problem, this study is considered pertinent in relation to the scenario in Nigeria. This study, therefore, has the focus of investigating the effect of commercial banks activities on economic development in Nigeria.

2.5 Economic Growth

A startling fact about economic growth is the large variation in the experience of different countries in recent history. Some parts of the world, like the United States or Western Europe, experienced sustained economic growth over a period of more than 100 years, so by historical standards these countries are now enormously wealthy. This is not only true in absolute terms (i.e., GDP), but also if we measure wealth as income per capita (i.e., GDP per person). In contrast, there are countries where even today large parts of the population live close to the subsistence level, much the same as Europeans and Americans did some hundreds of years ago. According to Anyanwu and Oaikenan (2015) is one of the four macro-economic goals of any society. Recall that others are price stability, full employment and health balance of payment equilibrium. It is imperative to examine the behavior of population overtime.

Economic growth is the increase in the inflation-adjusted market value of the goods and services produced by an economy over time. It is conventionally measured as the percent rate of increase in real gross domestic product, or real GDP. Growth is usually calculated in real terms, i.e., inflation-adjusted terms, to eliminate the distorting effect of inflation on the prices of goods produced. Measurement of economic growth uses national income accounting. Since economic growth is measured as the annual percent change of gross domestic product (GDP), it has all the advantages and drawbacks of that measure. The economic growth rates of nations are commonly compared using the ratio of the GDP to population or per-capita income. The "rate of economic growth" refers to the geometric annual rate of growth in GDP between the first and the last year over a period of time change of gross domestic product (GDP), it has all the advantages and drawbacks of that measure. The economic growth rates of nations are commonly compared using the ratio of the GDP to population or per-capita income. The "rate of economic growth" refers to the geometric annual rate of growth in GDP between the first and the last year over a period of time.

3. Empirical Review

There have been numerous studies on the effect of commercial banking activities on long-run economic growth. But there is no consistent evidence for a significant effect of commercial banks activities on economic development in Nigeria looking either positive or negative direction. Results and evidence about the effect of commercial bank activities differ by country, methodology used, and the area covered. Adam (2018) has also examined the empirical relation between commercial banks activities and economic growth in Nigeria for the period 1970-98. By adding some important variables (per capita income, population per bank branch, private sector credit, etc.) and employing the technique for analysis, he found that GDP growth is positively related to private sector credit, public sector credit, and investment. Private sector credit has a higher magnitude on growth because production of private goods and services rests with the private sector. The findings also show that there exists a positive link between the real deposit interest rate and the deposit ratio, and this positive link indicates that the real deposit interest rate is the actual rate for measuring deposit mobilization. His findings support the view that financial liberalization promotes the efficiency of the financial intermediation process performed by banks. On finding a positive and significant relationship between commercial banks activities and economic growth, he concludes that financial deregulation can be associated with increased deposit or higher credit availability and economic growth.

Tonye and Andabai (2024) examined the relationship between commercial banks activities and economic growth in Nigeria. The methodology used was vector error correction model. The study found that there is a long-run relationship between commercial bank activities and economic growth. The study concluded that about 89 percent of the variations in economic growth in Nigeria are explained by changes in financial intermediation variables of commercial banks. This study does not consider effects of commercial banks activities on economic development using credit to private sector, lending rate and interest rate margin as independent variables in the

country. Basher (2023) examined the linkage between open markets, financial sector development and economic growth to know if markets along with financial sector development affect economic growth in Nigeria.

The study made use of Granger causality test, Johansen co-integration test and vector error correction model. It was found that the causation between open markets, financial sector development and growth in Nigeria is weak and insignificant, and such cannot be used to forecast economic growth in Nigeria. This study also does not consider effects of financial intermediation on economic development using credit to private sector, lending rate and interest rate margin as independent variables in the country. Haruna (2022) investigates the determinants of cost of financial intermediation in Nigeria's Pre-consolidated banking sector using 13 banks quoted on the Nigerian Stock Exchange. The study made use of panel data regression models. It was found that operating expense and loan loss provision accounts for greater variation in commercial banks financial intermediation cost. This study does not consider effects of financial intermediation on economic development using credit to private sector, lending rate and interest rate margin as independent variables in the country.

Idries (2020) investigated the cost of financial intermediation in Jordan from 2000 to 2008. The study made use of random effects estimation approach. The study indicates that high and increasing financial intermediation costs by commercial banks are derived from efficiency levels complemented by the capital adequacy ratio and the loan-to-total-asset ratio. This study does not consider effects of commercial banks activities on economic development using credit to private sector, lending rate and interest rate margin as independent variables in the country. Beck and Hesse (2016) investigate why commercial banks financial intermediation cost is high in Uganda. The study made use of a unique bank level data set on the Uganda banking system over the period 1999 to 2005. The study found that bank-level characteristics, such as bank size, operating costs, and the composition of loan portfolios, affect financial intermediation costs. The study also found that the cost of financial intermediation by banks has no robust and economic significant relationship with foreign bank ownership, market structure and bank efficiency in Uganda. This study does not consider effects of commercial banks activities on economic development using credit to private sector, lending rate and interest rate margin as independent variables in the country.

Shittu Ayodele (2022) investigate commercial banks activities and economic growth in Nigeria using time series data spanning from 1970 to 2010. The output of his investigation reveals that there exists a positive relationship between economic growth and commercial banks activities in Nigeria. Out of the financial intermediation indicators used in the research process, only broad money supply was positive and had a significant impact on economic growth. Onlike, Mina and Baliamoune (2021) uses vector error correction mechanism to investigate the nexus between financial liberalization and economic growth in Morocco using time series data spanning from 1970 to 1999. The output of his econometrics results reveals that there exists a weak relationship between economic growth and financial liberalization, while he finally concluded that there exists a demand-following view of financial reform, which simply means that economic growth is a catalyst to finance.

Meanwhile, Beck et al (2016) argues that finance takes the lead in the process of development. They opted that the process of growth is a determinate of productivity improvement also economic development. Empirical evidence was provided by Levine and Zervos (2018) that financial development and market liquidity are both significantly and positively associated with future trends of economic development. "They explained that well developed and established stock market is capable of mobilizing capital funds and risk diversification between marketing agents, provide diverse form of financial services than banking sector and finally stimulate economic performance".

Demirguoc-Kuntand Levine (1996) carried out a statistical investigation using polled data of forty-four industrial and LDC's for a period of 1986 and 1993. They found that stock market development goes in a sequential manner with financial intermediary development. They finally concluded that a well-structured stock market will bring about well-developed banking and non-banking financial intermediaries.

According to traditional growth theorists, they strongly argue that there exists no link between economic expansion and equity market development. Moreover, the stock market is viewed as an instrument that can damage economic development as a result of its instability (Stiglitz, 1985). Meanwhile, quite a number of writers such as Pagano (1993), Atje and Jovanovich (1993), Rousseau and Wachel (2000) in their various empirical research work discovered that there is a very strong causality flow along "stock market development and economic growth."

Monogbe et al. (2016) investigated financial development and economic performance in Nigeria using time series data from 1906 to 2014. There introduce financial intermediaries ratio into their model to capture the non-banking financial institution, output of their result reveals that there is a long run causality between financial development ratio and economic performance with causality flowing from the economic to the financial development indicators which suggest that Nigeria economic promote financial system hence there concluded that economic is leading while fiancé is following in the Nigeria context. Arestis and Demetriades (2017) justify

the fact that the stock market has a direct and significant link to the development of the US economy while in Germany, insignificancies prevail. Judging by this, it implies that the significant influence of the stock market on economic development depends on individual countries. However, Okuda highlighted some determinant of causality link between economic development and financial sector which includes policies and market persuade by individual countries followed by the pattern of operation in the financial institution of each country.

In a thesis research work carried out by Folorunsho and Oladele (2022) titled "financial development and economic growth in Nigeria" using vector error correction model and granger causality estimator to justify the causality direction. Result reveals that "there exist a long run relationship b tween financial development and economic growth as specified by the result of the Johansson co-integration test while the granger causality test reveals that there is a unidirectional relationship between economic growth and financial development with causality flowing from the financial development indicator to economic growth". It is glaring that empirical argument about financial development and economic development is far from been settled while contribution in the Nigeria context is very minuet.

Monogbe (2023) studied the impact of insurance sector development on the growth of the Nigeria economy sourcing data from the central bank of Nigeria statistical bulletin spanning from 1981 to 2013. The major intension of the research work was to identify the extent to which the nonbanking has promoted the economy overtime. In actualizing the objective of the research, three variables were used as proxies for the insurance sector, and judging by the output of the Granger causality test, we found that the direction of causality flow between insurance sector development indicators and economic growth is bidirectional in nature and hence their causality nexus is symbiotic.

4. Research Methodology

The study adopted an ex-post facto (non-experimental) research design to determine the relationship between commercial bank activities and economic growth in Nigeria. This becomes necessary because the study was entirely based on secondary data. This type of research design is appropriate where the researcher is attempting to use Secondary data to explain how the phenomenon operates by identifying the underlying factors that produce change in it, in which case there is no manipulation of the independent variable. This study, therefore, used ex-post factor research design to establish relationship between commercial banks variables (deposit mobilization and lending rate) and economic growth (gross domestic product) in Nigeria. The source of data for the work is secondary such data are obtained from published materials such as central bank of Nigeria statistical bulletins and publication of the Nigerian Bureau of Statistics. The analytical technique used in this research is the ordinary least square (OLS) technique. This is used to evaluate the relationship between commercial banks activities and economic growth. This adoption of this technique is based on the premise that the ordinary least square is assumed to be the best linear unbiased estimates (BLUE).

4.1 Model Specification

$$GDP = f(CBD, CBC) \quad \text{.....(1)}$$

F = Function

GDP = Gross Domestic product

CBD = Commercial Banks deposits

CBC = Commercial Banks credit

Mathematically, the model is re-specify as:

$$GDP = \infty_0 + \infty, CBD + \infty_2 CBC + U \quad \text{.....(2)}$$

Where:

∞_{10} = is the constant

$\infty_1 + \infty_2$ = parameters of CBD and CBC

U = Error term

4.2 Data Analysis

Table 1. Regression Result

Dependent variable: LGDP

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.481684	0.932634	3.7332	0.0010

LCBD	0.972856	0.099143	9.8122	0.0000
LCBC	3.687593	1.533983	2.4033	0.0247

R-squared	0.984930
Adjusted R-squared	0.978402
F-statistic	186.9630
Durbin-Watson stat	1.812265
Prob (F-statistic)	0.000000

The goodness of fit of the model indicates that the data fit well. Specifically, the R^2 and adjusted R^2 values of 0.9849 (98.49%) and 0.9784 (97.84%), respectively, indicate that the model fits the data well. Specifically, the adjusted R^2 value of 97.84 percent indicates that the total variation in the observed behavior of economic growth in Nigeria is jointly explained by the variations in commercial bank deposits and commercial bank credit up to 97.84 percent, while the remaining 2.16 percent is accounted for by the stochastic error term. The overall significant of the model was also tested using the ANOVA or f-statistics. Here the high significance of the f-statistics value of 186.9630 confirmed that the high explanatory power of the model did not occur by chance, it actually confirmed that the model fitted the data well. The individual statistical significance of the parameters of the respective independent variables was also tested. The result obtained showed that the coefficient of commercial bank deposit of 0.972 with its corresponding probability of 0.000 percent suggest that they are statistically insignificant in measuring economic growth in Nigeria. The result also showed that the coefficient of commercial bank credit of 3.687 with its corresponding probability of 0.024 percent is statistically significant for measuring economic growth in Nigeria. To test for auto correlation in the residual of the model we compared the reported DW-Statistics value. From the result obtained the D-W value of 1.812 fell within the no auto correlation region of the DW table, it therefore means that the model is free from serial correlation problem. In effect, the model can be applied for policy decisions.

5. Summary of Findings

The result of the multiple regression indicates that the model determines 98.7% of the changes in GDP while both commercial banks' deposit and credit have positive relationships with GDP. The study revealed that both deposit and credit are significant, but deposit was found to have a negative relationship. Also, the adjusted R-squared showed that the independent variables determined 88.8% of the changes in the dependent variable.

6. Conclusion

Based on the findings of the study, it was concluded that all the variables increased steadily throughout the period under review, with credit being steeper than both commercial banks' deposits and GDP. The multiple regression indicates that the model determines 98.7% of the changes in GDP while both commercial banks' deposit and credit have positive relationships with GDP. Both deposit and credit are significant, but deposit was found to have a negative relationship. The adjusted R-squared showed that the independent variables determined 88.8% of the changes in the dependent variable. The negative sign of the commercial banks' deposit coefficient implies that increases in bank deposit stifles GDP growth as it reflects the tying up of funds rather than the utilization of such funds for productive.

7. Recommendation

Based on the findings of the study and the output of our empirical findings, we recommend the following:

1) The financial sector of the economy should be standardized. Emphasis should be laid on the stock market by expanding its transaction network, as this will help support government efforts and allow them to concentrate on the major fundamental and basic infrastructures needed in the economy.
2) We advise that the comprehensive analysis of the private sector be carried out with the view of justifying the rationale behind the inverse relationship between credit allocated to the private sector and its unproductive ability in the economy.
3) Nigerian government should ensure that a component analysis of the real sector of the Nigerian economy be carried out with a view to having a better understanding of the inverse relationship between the loans to the private sector and the performance of Nigerian economy through financial intermediaries.

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