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THE IMPACT OF EVALUATION-BASED PERFORMANCE APPRAISAL ON THE PROFESSIONAL DEVIANT BEHAVIORS OF MEDICAL STAFF

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Abstract: Performance appraisal is divided into two types: developmental and evaluative. To enhance medical quality and efficiency, the healthcare service system widely adopts evaluative performance appraisal as a key management tool, primarily focusing on short-term goal achievement and closely linking compensation, promotions, and task indicators. On one hand, the "reward diligence and penalize laziness" mechanism can effectively motivate employees to improve performance output. On the other hand, if the appraisal system excessively pursues instrumentalism, this overemphasis on results and competition can translate into psychological pressure for employees, triggering work-related anxiety and even leading some to engage in professional misconduct to achieve targets. This phenomenon is particularly pronounced in high-pressure environments like healthcare work. Currently, research on evaluative performance appraisal predominantly examines its direct relationship with job performance, while lacking in-depth exploration of the psychological transmission mechanisms behind professional misconduct and the moderating role of individual stress resilience. Based on this, this study selects the Conservation of Resources Theory as its theoretical foundation. From a stress-coping perspective, it treats workplace anxiety as a mediating variable and employee resilience as a moderating variable, systematically analyzing the impact pathway of evaluative performance appraisal on healthcare workers' professional misconduct. By leveraging workplace anxiety, the study reveals the intrinsic connection between evaluative performance appraisal and professional misconduct, while introducing employee resilience to explore how it moderates the relationships among evaluative performance appraisal, work-related anxiety, and professional misconduct.
Keywords: Evaluation performance assessment; Professional misconduct; Workplace anxiety; Medical staff

1 INTRODUCTION

1.1 Research Background and Problem Statement

Performance evaluation is divided into developmental and assessment types: Developmental performance evaluation is a model focused on the long-term growth of employees, emphasizing skill enhancement, career advancement, and the exploration of personal potential. During implementation, organizations provide employees with abundant training resources to help them acquire new knowledge and master new skills, thereby adapting to evolving job demands. Assessment-based performance evaluation primarily revolves around the achievement of short-term goals, closely linking employees' key interests—such as salary adjustments and promotions—to specific task metrics. This evaluation method has clear objectives and can quickly motivate employees to concentrate on completing designated tasks in the short term. However, when it excessively emphasizes outcomes and competition, employees facing excessive performance pressure may resort to inappropriate measures to meet targets, such as simplifying necessary procedures or falsifying records[1].

From a positive perspective, setting certain performance indicators can serve as a motivational tool, encouraging employees to strive for excellence, continuously improve their skills, and thereby enhance their work capabilities and professional competence. Conversely, high-performance targets imposed by organizations on team members also imply higher demands, which may significantly lead to a decline in work quality, increased mental stress, and consequently workplace anxiety, triggering a series of uncivilized behaviors—referred to as professional misconduct—to evade intense work expectations. Specifically, professional misconduct includes actions that violate work norms [2](e.g., lack of effort, tardiness, absenteeism), breach professional ethics (e.g., corruption, bribery, fraud), and transgress organizational policies and social norms (e.g., sabotaging colleagues, engaging in unfair competition).

For the professional motivation of medical workers, the effectiveness of performance appraisal and its negative impact have a significant relationship, necessitating precautions against such adverse effects. When organizational performance appraisal goals rely excessively on quantitative metrics, it can easily induce counterproductive and unethical behavioral choices among employees . Particularly in the healthcare industry, if the performance appraisal system is poorly designed (e.g., emphasizing outcomes over processes, rigid performance indicators), it may lead to a series of hidden consequences: overemphasizing performance appraisal can shift employees' focus from "work tasks" to "work performance," fostering a cognitive bias of "working for appraisal" and diminishing their sense of professional mission. On the other hand, prolonged excessive performance pressure can trigger psychological anxiety, leading to professional misconduct in the workplace[3].

In recent years, research on the influencing factors of occupational misconduct has gradually become a shared focus in both domestic and international academic and practical circles. Occupational misconduct is a multidimensional and comprehensive issue that requires multifaceted investigation and discussion. Although some studies have explored the definition, classification, influencing factors, and countermeasures of occupational misconduct, no consensus has yet been reached based on the findings. The mechanisms underlying the causes and consequences of occupational misconduct also remain under exploration. While existing research suggests that performance appraisal may influence the occurrence of employee occupational misconduct, the empirical relationship between the two remains unclear. Moreover, the causal mechanisms—how performance appraisal promotes occupational misconduct—as well as the boundary conditions between them, are still not well understood. Current literature has confirmed that evaluative performance appraisal affects employee behavior, yet the mechanisms of its influence remain limited to the direct effects on employees, with an overemphasis on the goal-oriented function of performance targets in goal-setting . The impact of evaluative performance appraisal on employee negative behavior has not reached a consensus in previous research findings.

Therefore, to further investigate and address the aforementioned questions, this study adopts the Conservation of Resources Theory as its theoretical foundation. From the perspective of stress coping, it examines the impact of evaluative performance appraisal on healthcare workers' occupational deviance behaviors and the underlying mechanisms involved[4]. The high stress induced by evaluative performance appraisal may also reduce employees' psychological resilience and trigger psychological tension (anxiety). However, how anxiety functions to evolve into employees' occupational deviance behaviors still requires empirical validation. Additionally, employee resilience is introduced as a boundary-moderating variable, which theoretically enriches and supplements research on the influence of resilience factors on employee behavior, thereby contributing to the refinement of this theoretical framework.

1.2 Research Ideas

This study based on the perspective of Conservation of Resources Theory, aims to explore the influencing factors of occupational misconduct among healthcare professionals, clarifying the entry point and key focus of the research. Utilizing the questionnaire survey method, the study meticulously designs the questionnaire content to ensure coverage of various dimensions closely related to the research hypotheses. Meanwhile, through scientifically sound sampling methods, a broadly representative group of healthcare professionals is selected as survey subjects to guarantee the validity and reliability of the data. A series of targeted and verifiable research hypotheses are proposed, followed by result analysis, which elaborates in detail the intrinsic relationships among performance appraisal, workplace anxiety, employee resilience, and occupational misconduct among healthcare professionals[5]. This study plays a crucial role in enhancing organizational management practices, scientifically adjusting appraisal objectives and methods, balancing organizational efficiency with employee development needs, reducing the risk of occupational misconduct caused by improper appraisal at its source, and promoting the healthy professional development of healthcare professionals.

2 Literature review

2.1 Performance Assessment

Performance management originated in enterprises, where it was used to accurately and clearly allocate and assess organizational development strategies and objectives. It later became a robust supervision mechanism for public organizations, particularly public hospitals. In the 20th century, many countries such as the United States, the United Kingdom, Australia, and the Netherlands explored hospital performance evaluation methods based on corporate performance management, aiming to control healthcare costs and improve medical quality through hospital performance assessments[6]. Internationally, research on hospital performance evaluation encompasses three levels: overall hospital performance, management capabilities of middle-level managers, and employee performance evaluation .The PAJ model is used to evaluate the rationality of hospital performance indicators; the comprehensiveness of quality management is leveraged to improve hospital performance evaluation systems; indicators for assessing the comprehensive capabilities of middle-level managers are explored; and current evaluations primarily focus on peer employee assessments. Overall, individual evaluations mainly target the physician group, which is relatively narrow and does not fully consider the conditions of multiple members within the hospital.

Due to differences in national conditions, the scale, nature, operational mechanisms, and funding budgets of hospital evaluation agencies vary. However, in general, the evaluation of public hospitals is primarily conducted by third-party social organizations or government departments. Third-party social organizations authorized by the government possess both the executive power of the government and the neutrality of social organizations[7].

2.2 Workplace Anxiety

Anxiety is often defined as a mild tendency toward fear triggered by future and realistic threats (Chambliss, Chen, and Easterly, 2017). Work anxiety is a state of fear induced by threatening events in the work environment and represents a negative emotional experience . Research indicates that although individuals exhibit varying degrees of work anxiety tendencies, the level of anxiety in the workplace is steadily increasing.

In workplace scenarios, individuals frequently experience anxiety when facing pressure or tackling specific tasks, which is termed workplace anxiety. Workplace anxiety is a form of performance anxiety, where performance anxiety refers to the anxiety experienced when engaging in certain tasks, such as job interviews, selective tests, artistic presentations, and sports competitions. Although substantial background research exists on performance anxiety, studies on workplace anxiety remain relatively limited and require further investigation. Compared to other forms of anxiety, workplace anxiety shares conceptual and impact-related similarities but also exhibits distinct differences. Unlike state anxiety, workplace anxiety is not momentary but rather a persistent, generalized sense of anxiety related to the work environment over an extended period. It also differs from trait anxiety, as workplace anxiety leans more toward evaluative anxiety and is specific to the work setting[8].

As one of the early scholars to propose work anxiety, McCaffrey developed an eight-item workplace anxiety scale (e.g., "The thought of work not going smoothly leaves me at a loss") based on an earlier five-factor scale. This scale demonstrates high reliability ($\alpha = 0.94$) and has been widely adopted by numerous scholars.

2.3 Employee Resilience

Employee resilience is a crucial factor in an organization's and its members' ability to adapt to change and withstand risks. As Linnenluecke pointed out in her 2017 study, employee resilience can directly foster the formation of positive attitudes and cognitions in individuals, as demonstrated by Luthans et al.'s research findings in 2007. Moreover, it enhances employees' commitment to the organization. Moon and Lee's 2021 study found that teams with high employee resilience exhibit greater loyalty to the organization; Santoro et al.'s 2021 research indicated that employee resilience contributes to improved well-being levels among employees; Cort's 2021 study revealed a positive correlation between employee resilience and job satisfaction; Malik and Garg's 2020 research highlighted that employee resilience strengthens employee engagement. Additionally, employee resilience aids in enhancing a team's problem-solving capabilities. Through case analysis, Barton and Kahn's 2019 study demonstrated that high-resilience teams can identify solutions more efficiently when confronting complex challenges[9] . From an organizational perspective, employee resilience benefits work performance and fosters innovative behaviors, as elaborated in detail by Cui Yuwen and Guo Lifang's 2022 research.

2.4 Professional Misconduct

"Professional misconduct" (faculty misconduct), also known as deviant behavior or deviance, refers to actions that violate the common standards generally followed by members of society . According to foreign scholars Robinson et al. in 1995, professional misconduct is defined as the conscious implementation and adoption of behaviors that harm organizational members, the organization's survival, and its institutions in various contexts[10]. This behavior ranges from minor infractions such as being late, leaving early, procrastinating, and rudeness, to more serious harmful acts like falsifying accounts, leaking secrets, and stealing public property.

3 RESEARCH HYPOTHESES

3.1 The Relationship Between Evaluation Performance Appraisal and Occupational Misconduct

Evaluative performance appraisal is a process of assessing the effectiveness of work tasks completed by a unit or individual employee over a certain period. A relatively reasonable performance appraisal standard should clearly define the specific task objectives and qualification criteria for the evaluated subjects, enabling employees to understand their work tasks and expected behavioral performance. This helps employees regulate their behavior according to organizational requirements, achieve what the organization expects, and reduce occupational misconduct caused by unclear objectives. In enterprise management, the results of employee performance appraisals are often linked to incentive mechanisms such as employee compensation, promotions, and rewards[11]. Employees who exhibit standardized, lawful, and ethically compliant work behaviors to achieve good performance and receive corresponding rewards in appraisals will further reinforce such behaviors, promoting adherence to professional norms and preventing occupational misconduct.

However, overly complex performance appraisal standards or excessive appraisal pressure beyond employees' actual capabilities may lead them to resort to unethical means to avoid penalties for failing to meet targets, such as reduced bonuses or demotions. This can result in occupational misconduct. For example, sales personnel may resort to exaggerated promotions or bribing clients to meet excessively high performance targets. Some performance appraisals emphasize results while neglecting the process and methods of behavior, leading employees to focus solely on performance data outcomes rather than the means to achieve them. In pursuit of short-term performance improvements, employees may engage in short-sighted or non-compliant activities, increasing the likelihood of occupational misconduct.

H1:There is a positive correlation between evaluative performance appraisal and occupational deviance behavior.

3.2 The Mediating Role of Workplace Anxiety

Workplace anxiety refers to an individual's experience of negative emotions such as unease, stress, and fear in a professional environment. The medical industry is characterized by high work pressure, where healthcare professionals face intense workloads and demanding technical skills while also navigating complex doctor-patient relationships and interpersonal dynamics, making them particularly susceptible to workplace anxiety. This anxiety may lead to feelings of insecurity and tension when confronting job pressures, responsibilities, and risks. Anxious emotions can increase impulsivity and reduce consideration of behavioral consequences, thereby affecting work performance and professional conduct.

Workplace anxiety can distract healthcare workers, making it difficult for them to think comprehensively and rationally, which in turn diminishes their moral judgment[12]. In such a state, employees may be more prone to overlook professional norms and ethical standards, leading to deviant behavior. High levels of workplace anxiety may create a psychological urge to escape pressure, increasing the likelihood of resorting to shortcuts or unethical methods to resolve work-related issues. Prolonged psychological stress and anxiety can result in behavioral deviations among medical staff, contributing to professional misconduct.

When employees recognize that their misconduct conflicts with their personal values and professional ethics, they may experience internal conflict and self-reproach. This cognitive dissonance can intensify their anxiety. Once professional misconduct is discovered, it often negatively impacts career development, leaving employees uncertain and worried about the future and further exacerbating workplace anxiety. Thus, a vicious cycle forms between workplace anxiety and professional misconduct.

H2:Workplace anxiety mediates the relationship between evaluation-based performance appraisal and occupational deviance.

3.3 The Moderating Effect of Employee Resilience

Employee resilience refers to an individual's objective ability to maintain a positive mindset, adaptability, effective coping, rapid recovery, and growth when facing work pressures, challenges, and difficulties. It encompasses multiple factors such as psychological resilience, adaptability to change, emotional regulation, and problem-solving capabilities. Employee resilience is a concrete manifestation of psychological capital. Individuals with higher psychological capital tend to adopt more proactive coping strategies when confronted with challenges and adversities[13]. In the context of performance evaluations and the challenges posed by assessment orientations, highly resilient employees perceive these situations as opportunities for growth and self-improvement. They employ positive cognitive reframing to accept stressors, thereby reducing their anxiety. Conversely, employees with low resilience are more likely to interpret high-performance goals as unattainable, leading to heightened anxiety[14].

H3: Employee resilience has a negative moderating effect on the mediating process between evaluative performance appraisal and workplace anxiety.

4 RESEARCH SUBJECTS ,METHODS AND FRUIT

According to the principle of convenience sampling, medical staff working in five hospitals in Xinxiang City were selected for the survey, and their basic information was collected through questionnaire methods. A total of 512 questionnaires were gathered via both online platforms like Wenjuanxing and offline direct distribution.

In this survey, 28 invalid questionnaires (due to unanswered questions, inconsistent responses to reverse-scored items, or identical answers throughout, etc.) were excluded, resulting in a final collection of 484 valid questionnaires.

The questionnaire consists of four parts: performance appraisal scale, workplace anxiety scale, employee resilience scale, and occupational deviance behavior scale. This study employs established mature scales from domestic and international sources as measurement tools. Except for basic demographic items such as gender, education level, professional title, and employment type, all other scales adopt the Likert 5-point scoring method for measurement. The specific contents are as follows:

(1) The evaluative performance appraisal orientation scale adopts the performance appraisal scale developed by Murphy, Williams, et al. consisting of a total of 4 items. Extensive domestic research has confirmed that this scale exhibits good reliability and validity. A five-point Likert scale is used for scoring, where "1" indicates "completely inconsistent," and "5" indicates "completely consistent." Higher scores indicate a greater degree of alignment, meaning the team's tendency toward performance appraisal objectives is more pronounced.In this study, the Cronbach's α value of the scale reached 0.94, and through confirmatory factor analysis, all the fit indexes met the standards: x^2/df=1.77, CFI=0.98, TLI=0.97, RMSEA=0.04, SRMR=0.04.

(2) The assessment of work-related anxiety is based on the scale designed by McCarthy et al. (2016),The scale adopts a five-point rating system, with higher scores indicating greater conformity to the described situation, that is, higher levels of workplace anxiety among employees. The first-order confirmatory factor analysis results of the scale show that all fit indices meet the standard measurement criteria: x^2/df=2.73, CFI=0.93, TLI=0.94, RMSEA=0.05, SRMR=0.04. The Cronbach's alpha value for this scale is 0.90.

(3) Naswall Employee resilience questionnaire designed by Naswall and Kuntz,The Likert5 scale was used to score the employee resilience questionnaire, with higher frequency of occurrence leading to higher scores for employee resilience [56]. The first-order confirmatory factor analysis results show that all fit indices meet the standards: x^2/df = 1.96, CFI = 0.92, TLI = 0.93, RMSEA = 0.06, SRMR=0. The Cronbach's α coefficient value is 0.87.

(4) The measurement section of occupational misconduct includes nine questions, which indirectly assess the likelihood of occupational misconduct by measuring healthcare professionals 'perceptions of such behavior. Due to individual self-protection mechanisms and the prevailing moral standards in society, it is difficult to directly measure occupational misconduct through scales. Therefore, this study measures healthcare workers' level of agreement with occupational misconduct to indirectly predict their likelihood of engaging in such behavior. The scale uses a five-point rating system, from "strongly disagree" to "strongly agree," scoring 1-5 points respectively. Higher scores indicate greater agreement with occupational misconduct, suggesting a higher likelihood of engaging in such behavior; conversely, lower scores indicate less agreement, suggesting a lower likelihood of engaging in such behavior.The results of the first-order confirmatory factor analysis showed that all the fit indexes were within the standard range: $x^2/df=2.59$, CFI=0.95, TLI=0.96, RMSEA=0.05, SRMR=0.03. The Cronbach's value of the scale was 0.93.
Since this questionnaire collection primarily involved medical staff from hospitals, there exists a certain degree of common method bias. To examine this issue, first, Harman's single-factor test was conducted using SPSS 22.0. Principal component analysis was performed on all data, ultimately extracting four factors that collectively explained 66.32% of the variance. The first factor accounted for only 26.82% of the variance, which is below the empirical threshold of 40%, indicating that common method bias is not severe.
Second, discriminant validity was tested by constructing different factor models for confirmatory factor analysis. The results showed that compared to other models, the four-factor model exhibited the best fit indices, all within acceptable ranges (see Table 1). This indicates good discriminant validity among the four research variables, and the issue of common method bias was effectively controlled.

Table1 Results of Confirmatory Factor Analysis

model	$\chi 2$	df	$\chi 2$/df	RMSEA	CFI	TLI	SRMR
Four-factor model	1032.08	388	2.66	0.07	0.93	0.95	0.05
Three factor model	1642.23	391	4.20	0.09	0.90	0.92	0.08
Two-factor model	2137.91	393	5.44	0.10	0.86	0.89	0.10
Single factor model	2639.82	394	6.70	0.12	0.77	0.75	0.12

Table 2 presents the descriptive statistics and correlation analysis results of the variables. It can be seen that performance evaluation is significantly positively correlated with job anxiety ($r=0.48$, $p<0.01$) and occupational misconduct ($r=0.39$, $p<0.01$), and job anxiety is significantly positively correlated with occupational misconduct ($r=0.52$, $p<0.01$); employee resilience is significantly negatively correlated with job anxiety ($r=-0.31$, $p<0.01$).

Table 2 Correlation Analysis

	M	SD	1	2	3	4
1. Evaluative performance appraisal	4.23	0.75				
2 Workplace anxiety	2.82	0.87	0.48**			
3. Misbehavior	2.15	0.69	0.39**	0.52**		
4. Employee resilience	3.89	0.76	-0.12*	-0.31**	-0.26**	

5 RESEARCH CONCLUSION

(1) There is a significant positive correlation between evaluative performance appraisal and professional misconduct. This indicates that in the actual operation of public hospitals, when an evaluative performance appraisal approach is adopted—primarily focused on short-term goal achievement and closely linking salary and promotion to task indicators —it can to some extent lead to an increase in professional misconduct among medical staff.
(2) Workplace anxiety plays a mediating role between evaluative performance appraisal and professional misconduct. The pressure induced by evaluative performance appraisal causes medical staff to experience workplace anxiety, and this anxious emotion further contributes to the occurrence of professional misconduct. In other words, evaluative performance appraisal does not directly trigger professional misconduct but rather exerts a negative influence on medical staff's professional behavior indirectly through the key mediating variable of workplace anxiety.
(3) Employee resilience exerts a negative moderating effect in the mediating process between evaluative performance appraisal and workplace anxiety. When employees possess higher resilience, they are better able to cope effectively with the pressure brought by evaluative performance appraisal, thereby mitigating the generation of workplace anxiety[15]. Conversely, when employee resilience is low, evaluative performance appraisal is more likely to trigger workplace anxiety.

COMPETING INTERESTS

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

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OPTIMIZING THE DECISION-MAKING OF ENTERPRISES IN THE PRODUCTION PROCESS BASED ON DECISION TREE MODELS

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Abstract: In the enterprise's production activities, the enterprise's production efficiency is the key to whether the enterprise to obtain the maximum benefit, efficient production efficiency is the enterprise to the good development of the top priority, on this basis, due to the enterprise's decision-making directly affects the efficiency of the enterprise's organization and management, whether to make the optimal decision can be a direct impact on the enterprise's production efficiency.Therefore, this paper proposes the basic model of enterprise optimization production process based on decision tree model algorithm. Firstly, the model is established through the establishment of hypothesis testing and the method of cost-profit; secondly, combined with the principle of multi-recursive optimization algorithm and the overall optimal solution of which any step is optimal, it is applied to the construction of the model of decision-making problem in the enterprise's production process, and the basic sampling method is proposed, and the validity is determined through the method of proposing a specific sampling scenario; lastly, some basic conditions are assumed, and using the established Decision Tree Model algorithm to give the corresponding sampling scheme, by comparing the cost required to make the decision, the results can be derived as a result of the optimal solution in a specific scenario can be depicted by Fig. 5; in the specific conditions of the enterprise decision-making results in the optimal decision-making scheme for the inspection of spare parts 1, spare parts 2, spare parts 3, and semifinished products 1 but the semifinished products 1 is not disassembled; for spare parts 4, spare parts 5, Spare part 6 and semi-finished product 2 are tested but semi-finished product 2 is not disassembled; Spare part 7 and spare part 8 are tested and semi-finished product 3 is not tested and disassembled; only finished products are tested and unqualified finished products are not disassembled, and finished products that are returned from customers are not disassembled.The advantage of the decision tree model is that it does not require data preprocessing, it can directly deal with numerical and categorical features, reducing the complexity of data preprocessing and at the same time has a very strong adaptability, able to deal with complex nonlinear relationships, and can to a large extent to capture the complex patterns in the data. Most of the traditional enterprises in the decision-making process there are many problems, this paper will be the decision tree model used in the production of enterprise decision-making, can be more accurate, fast and efficient for the enterprise to make the right decision, can improve the accuracy of the enterprise decision-making, especially in dealing with the small amount of data in the problem. Decision tree is a very intuitive model, extensive in-depth study of the decision tree model can help to improve the efficiency of decision-making and prediction accuracy in the fields of finance, health care, marketing and manufacturing, etc., and at the same time, it can optimize the decision-making algorithms, improve the performance of the algorithms to promote the explanatory and transparency of the algorithms.
Keywords: Decision tree model; Local optimization; Hypothesis testing; Sampling test

1 INTRODUCTION

Since the implementation of the reform and opening-up policy, China has continued to develop and grow amidst competition in the global market, a process that has not only witnessed profound changes in Chinese economic system, but has also reflected Chinese ability to adapt to the international business environment. With the increase in market openness and the expansion of foreign trade, domestic and foreign enterprises are actively exploring diversified strategies to enhance their competitiveness, among which, improving the decision-making efficiency of enterprises has gradually become an important way to improve their competitiveness. As a representative of Chinese high-tech enterprises, Huawei was engaged in the production and sale of communication equipment in the early stage, but with the process of globalization, it faced considerable competitive pressure, in order to alleviate the external competitive pressure, Huawei has made decisions such as globalization strategy and optimization of organizational structure through independent innovation, and through the implementation of the decisions, it has not only taken a dominant position in the domestic market, but has also succeeded in moving towards the global market, which have directly contributed to its standing out in the fierce competition and eventually established a strong corporate competitivenessTherefore, there is an urgent need to optimize and improve the decision-making efficiency of enterprises.

At present, there are many studies on enterprise decision-making model at home and abroad, Zhang et al. proposed that the C4.5 algorithm in decision tree model is one of the decision tree algorithms[1], which has the advantages of easy to understand, high accuracy, etc., and compared with the predecessor ID3 algorithm, the concept of information gain rate is added, and the system takes the decision tree algorithm as the core technology, obtains the scientific, reliable and accurate information of the project management, and realizes the visualization of the data, which can assist enterprises to establish a good management system in the era of big data, Li and others applied the decision tree model based on machine learning to industrialized risk management decisions[2], showing good results, Lee C S and others pointed out that in the business big analytical model[3], the decision tree model is not one of the most important models, but it is really one of the most simple and intuitive models used to analyze data, Bian et al. proposed a novel school-enterprise cooperation mechanism based on decision tree model[4], Lu H et al. applied the research on decision tree modeling to water resources and water quality detection and proposed two novel hybrid decision tree-based machine learning models to obtain more accurate short-term water quality prediction results[4], Masood et al. proposed a novel system centered on CIMOSA Enhanced Integrated Modeling Framework that can be used to facilitate the transfer of driven decision models in manufacturing firms[5], Sishi M et al. stated that a business process is a structured set of activities with understandable sequences and dependencies to produce a desired outcome[6]. Optimization of these processes is critical and Decision Tree (DT) is a tool that supports decision making by mapping the possible outcomes of a set of interrelated choices through a tree-structured modeling approach, Sarker I H developed a scenario-aware predictive model based on decision tree learning[7]. Compared to the above decision models for different situations and approaches, the decision tree model based on the principle that any step of the overall optimal solution is optimal is more stable and accurate in corporate decision making. The principle of optimality means that the decision maker should always choose the best decision at each stage of the decision problem, conditional on the best behavior thereafter, and is the basis of many optimal dynamic decision theories[8]. It is worth mentioning that the number of decisions in a business can often be too large to be listed individually, so there is a need to find a more accurate and simpler way to reduce the overall number of decisions while ensuring their accuracy.

hrough the analysis of the previous research of scholars at home and abroad, this paper establishes a basic model for optimizing enterprise decision-making based on the decision tree model and the principle that any step of the overall optimal solution is optimal. In order to reduce the number of decisions required by the enterprise, this paper analogizes the number of decisions to the number of sampling tests, and ensures the accuracy of decision-making on the basis of reducing the number of decisions through the mathematical modeling method of hypothesis testing[9]. The main content of the paper can be summarized as follows: firstly, the basic principles of the decision tree model and hypothesis testing are introduced, and a mathematical model of hypothesis testing is proposed based on the principle that any step of the overall optimal solution is the optimal solution; then the model is applied to the sampling method of a specific scenario to determine its effectiveness.

2 RIEF DESCRIPTION OF THE APPLICATION METHODOLOGY

2.1 Basic Decision Tree Model

Decision tree model is an ancient and traditional modeling approach, which can be traced back to the 1960s, and in the 1980s, with the key algorithms ID3, CART and C4.5 proposed decision tree model gradually tends to mature. Currently, decision trees have a wide range of applications in both machine learning and artificial intelligence[10], and decision tree model building techniques have been widely used to build classification models.Ghiasi M M et al. applied decision tree modeling to the diagnosis of coronary artery disease[11], and decision tree model building techniques have been widely used to construct classification models. Decision tree models are divided into two main processes[12]: the construction process and the classification process, the construction process usually starts from an empty tree, and the appropriate decision nodes are deduced through the corresponding computation; the classification process has to categorize new instances with only all their attribute values, starting from the root of the construction tree and following a path that corresponds to the observed values of the attributes in the nodes inside the tree. The previously mentioned algorithms ID3, CART and C4.5 differ in the selection of decision nodes, and this paper focuses on the basic process of ID3 (information gain).

The essence of ID3 algorithm is information gain, in order to explain the information gain more rationally, the concept of “entropy” is introduced here. Entropy is considered to be used to describe the degree of inaccuracy of a random variable in mathematical statistics, and its formula is:

$$H(X) =-\sum_{i=1}^{n} p_i \, log_2 \, p_i \tag{1}$$

where X represents the random variable and $H(X)$ is the determined value of entropy. The value of entropy is zero when the probability is 0 and 1, when the uncertainty of the random variable is the lowest; the value of entropy has a maximum value when the probability is 0.5, when the uncertainty of the random variable is the highest[13]. Considering that most of the studies are basically two variables, the joint probability distribution of two different variables is:

$$P\left(X = x_i,\ Y = y_j\right) = p_{ij}, i, j = 1,2, \cdots n \tag{2}$$

X、Y represent two basic variables.

The concept of conditional entropy is introduced here, i.e., the entropy of event Y occurring under the condition that event X has occurred, which is given by.

$$H(Y|X) = \sum_{i=1}^{n} p_i H(Y|X = x_i) \tag{3}$$

conditional entropy has the same mathematical properties as entropy, when the probability is more certain then the value of conditional entropy is smaller, when the probability tends to 0.5, the value of conditional entropy is larger.
Based on the model expression above, the information gain is represented by the reduction of uncertainty in the information Y that can be obtained after the condition X is known, where the reduction of entropy is the information gain.
If we denote the information gain of feature A on the training set D as $g(D, A)$, it is calculated as:

$$g(D, A) = H(D) - H(D|A) \tag{4}$$

the overall idea of ID3 algorithm is to calculate the information gain of each feature quantity from the training set, compare and select the largest information gain, take it as a pivot point of the decision tree, and finally construct a complete decision tree model through the constant repetition of the above methods. The specific model building process is given by the following figure:

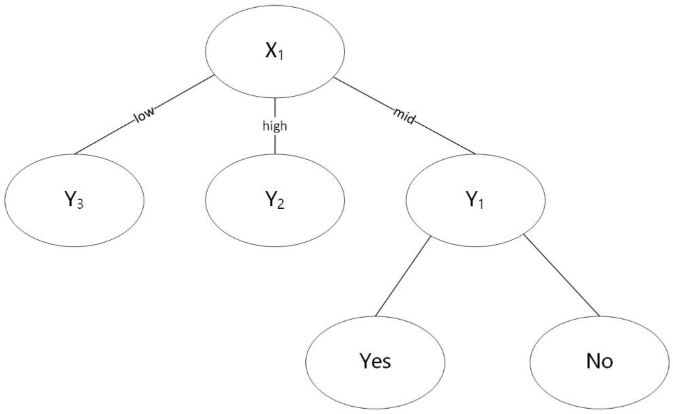

Figure 1 Decision Tree Decision Process

It can be clearly seen through the above Figure 1, first of all, through the calculation of information gain to find out the root node with the largest information gain is recorded as X_1, through this node to calculate the conditional entropy of the remaining events under the conditions of X_1, to find out the information gain for the middle of the event Y_1 as the second node, through the node can be very good to make the best decision, and finally, when a new event needs to be decided, it can be decided through the above obtained conditions for decision making. Of course, in general, the decision tree will be more complex, this paper only as the simplest example.

2.2 Hypothesis Testing Fundamentals

The basic steps of hypothesis testing and its applied principles are[14-15]:
(i) The original hypothesis H_0 as well as the alternative hypothesis H_1 are formulated with full consideration and utilization of the background according to the actual situation and the requirements of the problem;
(ii) Based on the specifics of H_0, choose the appropriate statistical test size, i.e., the total sample size N, and require that the specific probability distribution of N be determined provided that H_0 holds;
(iii) Given a significance level of $\propto$, identify the corresponding small probability event and determine the corresponding rejection domain;
(iiii)Make a specific sample, calculate the specific value of the corresponding statistical test quantity based on the sample value, and from this value determine whether the sample value falls in the rejection domain.
In order to minimize the number of firms sampled, the total number of samples to be tested should first be determined before sampling can be carried out. Therefore, this paper adopts the method of normal approximation, for the total number of samples N, there is the following formula:

$$N = \frac{Z^2 \cdot p_0 \cdot (1 - p_0)}{E^2} \tag{5}$$

P_0 is the probability, Z is the corresponding quantile of the normal distribution, and E is the corresponding error.

3 PRINCIPLE DERIVATION

3.1 Availability of a Basic Sampling Program

For the selection of E, in the formula established above, Z、P_0 are all determined values, so the functional relationship between N and E can be established, in order to find out the optimal error rate, through the mathematical knowledge, as well as the minimization of the objective function model, the function should be taken to the largest value of the slope as the optimal error rate, after finding out the optimal error, you can carry out the next step of the calculations, where this paper demonstrates that The confidence level is 95% and 90% two cases.

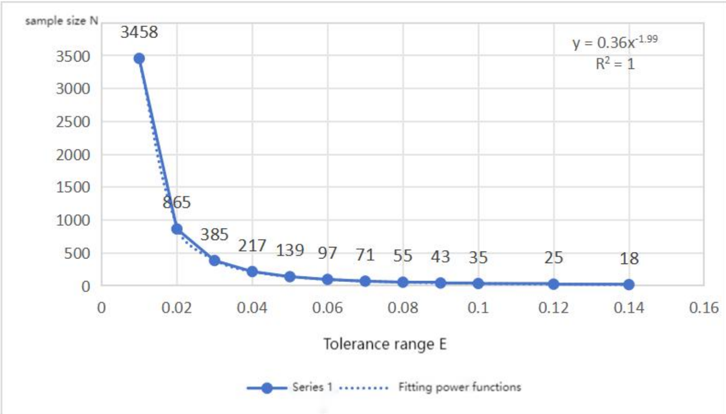

Figure 2 Error Versus Sample Size for a 95% Confidence Level

According to Figure 2, it can be seen that with 95% confidence level N and Esatisfy the relationship equation:

$$N = 0.36E^{1.99} \tag{6}$$

in order to find out the optimal error rate, through mathematical related knowledge, and minimizing the objective function model, the value with the largest slope of this image should be taken as the optimal error, which can be derived as E=0.1;

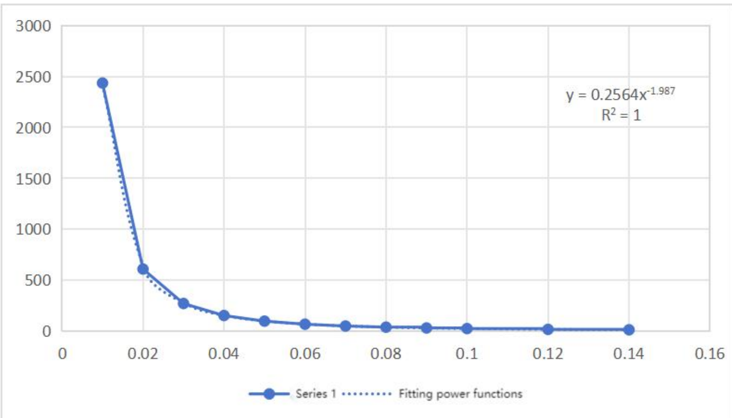

Figure 3 Error Versus Sample Size for a 90% Confidence Level

According to Figure 3, it can be seen that at a confidence level of 90% N and E satisfy the relationship equation:

$$N = 0.256E^{1.987} \tag{7}$$

in the same way as in the first case, the value with the largest slope of this image serves as the optimal error, which is still E = 0.1. After finding the optimal error, the solution of the problem becomes very simple, and the final result required by the statement of the problem can be given by discussing the following two cases.

1. Constructing hypothesis tests:

Original hypothesis H_0, alternative hypothesis H_1

2. Calculation of sample size

Using the normal approximation of distribution method described above, the specific sample size can be calculated using the previous equation (5)

3. Sampling modeling

Since it is a P_0 small probability event, we use a normal distribution to model it. Assuming that the samples are randomly drawn in the sample, using the normal distribution, we can get the minimum number of samples in the sample with P_0 probability.

3.2 Scenario-Specific Optimal Decision Problems

In order to better verify the effectiveness of the model, this paper simulates the establishment of the enterprise production process decision-making problem. Two kinds of spare parts and finished product defective rate is known:

(1) Whether or not the part (Part 1 or Part 2) is tested; if a part is not tested, the part will go directly to assembly; otherwise, the detected nonconforming part will be discarded;
(2) Whether to test each piece of assembled finished product, if not, the assembled finished product directly into the market; otherwise, only qualified finished products enter the market;
(3) Whether to disassemble the detected unqualified finished products, if not, directly discard the unqualified finished products; otherwise repeat steps (1) and (2) for the disassembled spare parts;
(4) For non-conforming products purchased by users, the enterprise will exchange them unconditionally and incur certain exchange losses (such as logistics costs, enterprise reputation, etc.). Repeat step (3) for returned nonconforming products.
In this paper, the enterprise production process of each stage of the decision-making ideas are mainly whether to spare parts 1 for testing, whether to spare parts 2 for testing, whether to assemble the finished product for testing, for the customer returned to the unqualified products whether to exchange, the basic ideas flow chart is as follows:

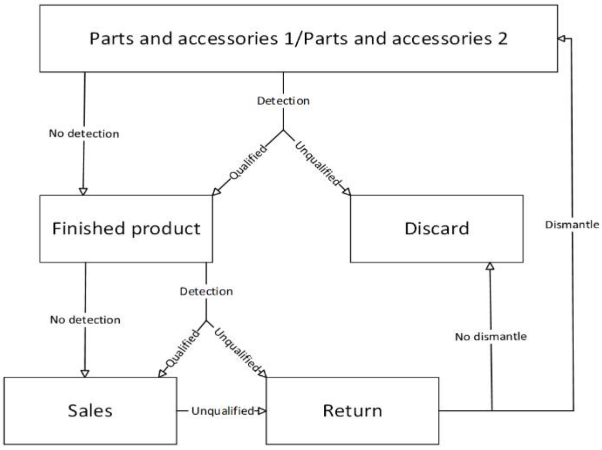

Figure 4 Decision-Making Process for parts 1 and 2

With the help of the Figure 4, we can intuitively observe the interrelationship between the decisions and the sequence of decisions. In order to let the enterprise make the optimal decision, this paper starts from the basic profit model, firstly calculates the decision cost in each decision situation, according to the basic relationship between the decisions obtained from the flow chart, re-establishes the cost model, and finally uses the algorithm of the decision tree model to calculate the corresponding optimal decision in different situations.
To simplify the difficulty required for decision tree modeling, the decisions are first carefully divided as follows:

1. Whether or not to test part1
2. Whether or not to test part2
3. Whether the finished product is tested
4. Whether to disassemble the detected substandard products
5. Whether the returned nonconforming products are disassembled or not

We introduce the decision variable X_i , where i= 1, 2, 3, 4, 5,when X_i=0,it means no testing,when X_i=1,it means testing.Analysis of the decisions made, for the newly established first three decisions, that is, on parts 1, 2 and finished products whether to test this, these three whether to test there is no necessary connection between, therefore, can be considered that these three cases are independent of each other; if the implementation of decision 3, then to the user's hands must be complete that is, there is no need to implement the decision 5, on the contrary, it is necessary to implement decision 5 implementation.
After the above analysis of the type of situation, a wide range of decision-making types are streamlined, for each situation, basically can be streamlined into the following 16 basic decision-making scenarios, in order to be more convenient to record the decision-making scenarios, this paper takes the form of the representation of the $(x_1, x_2, x_3, x_4, x_5)$, through the value of the x_i to indicate whether to carry out the decision-making, and each bracketed number before the first decision on behalf of the first few kinds of decision-making, the 16 basic decision-making scenarios as follows for demonstration (Table 1):

Table 1 16 Decision-Making Methods

1.(0,0,0,0,0)	2.(1,0,0,0,0)	3.(0,1,0,0,0)	4.(1,1,0,0,0)
5.(0,0,1,0,0)	6.(1,0,1,0,0)	7.(0,1,1,0,0)	8.(1,1,1,0,0)
9.(0,0,1,1,0)	10.(1,0,11,0)	11.(0,1,1,1,0)	12(1,1,1,1,0)
13.(0,0,0,0,1)	14.(1,0,0,0,1)	15.(0,1,0,0,1)	16.(1,1,0,0,1)

Now you need to establish the cost - profit function, the annex describes the finished product defective rate is the assembly of the second rate, according to the question stem conditions, as long as there is a failure of spare parts, the finished product is also unqualified, so it can be associated with the real finished product defective rate should be

greater, so this paper first consider the calculation of the finished product of the actual rate of defective, so far, the following begins to describe the process of modeling.
The actual defective rate of finished products:

$$p = (1-x_1)\,p_1 + (1-x_2)\,p_2 - (1-x_1)\,(1-x_2)\,p_1 p_2 \tag{8}$$

the number of non-conforming finished products is:

$$N_{f3} = N_f - N_f \cdot (1-p) \tag{9}$$

the number of qualified finished products is:

$$N_{f2} = N_f \cdot (1-p) \tag{10}$$

spare parts1 purchase cost:

$$C_{p1} = C_1 \cdot N_1 \tag{11}$$

spare parts2 purchase cost:

$$C_{p2} = C_2 \cdot N_2 \tag{12}$$

finished assembly costs:

$$C_a = a \cdot N_f \tag{13}$$

spare parts 1 Inspection costs:

$$C_{d1} = x_1 \cdot d_1 \cdot N_1 \tag{14}$$

spare parts 2 Inspection costs:

$$C_{d2} = x_2 \cdot d_2 \cdot N_2 \tag{15}$$

finished product testing costs:

$$C_{fi} = x_3 \cdot d_f \cdot N_f \tag{16}$$

disassembly costs:

$$C_d = x_4 \cdot e(p_f \cdot N_{f2} + N_{f3}) \tag{17}$$

processing of returned costs:

$$C_r = x_5\,(I + C_1 + C_2 + a) \cdot (p_f \cdot N_{f2} + N_{f3}) \tag{18}$$

in the description of the topic, for Decision 4 and Decision 5, when choosing to implement on Decision 4 or Decision 5, there is a possibility to return Decision 1, Decision 2 or Decision 3, so the iterative problem may occur, so this paper adopts the recursive method to calculate the recursive profit in the recursive process rp.
Then the total income is:

$$T_r = s \cdot (N_f - (p_f \cdot N_{f2} + N_{f3})) + rp \tag{19}$$

the total cost is

$$T_r = s \cdot (N_f - (p_f \cdot N_{f2} + N_{f3})) + rp \tag{20}$$

the total profit objective function is:

$$W = T_r - T_c \tag{21}$$

the model is brought into the algorithm of the decision tree model, in which the eigenvalues are selected as Decision 1 to Decision 5 assumed in the previous paper, and the target variables are selected as the total profit objective function model established in this paper.
In order to visualize the optimal decision-making in the six cases more visually, more detailed graphs of the curves are plotted in this paper:

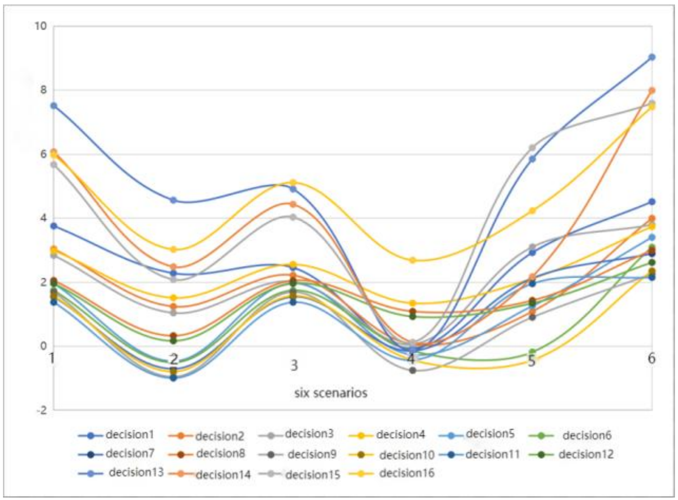

Figure 5 Visual Model of Decision-Making

The above Figure 5 shows the final profits of the sixteen different decision scenarios in each case. From the graph, it can be seen that in each case, the decision scheme corresponding to the point with the highest final profit is the optimal decision scheme for that case.

3.3 Determination of Business Decisions under Specific Conditions

Suppose that the finished product consists of n spare parts, assembled through m processes, and the defective rate of each spare part, semi-finished product and finished product is known. The introduction of the mathematical concept of semi-finished products makes the production process to go through the process, and increase the number of spare parts to , therefore, consider the optimization of the decision tree model, based on the overall optimal solution of the overall optimal principle of the optimum of any step, the complex decision-making steps will be split into parts to semi-finished products and semi-finished products to the finished product of the m steps, and production process of the production process of the decision-making scheme flowchart, the establishment of the diagram of the optimal solution of each step of the mathematical model. Mathematical model. In the case of knowing the defective rate of spare parts, semi-finished products and finished products, this paper firstly gives the analysis of the following figure:

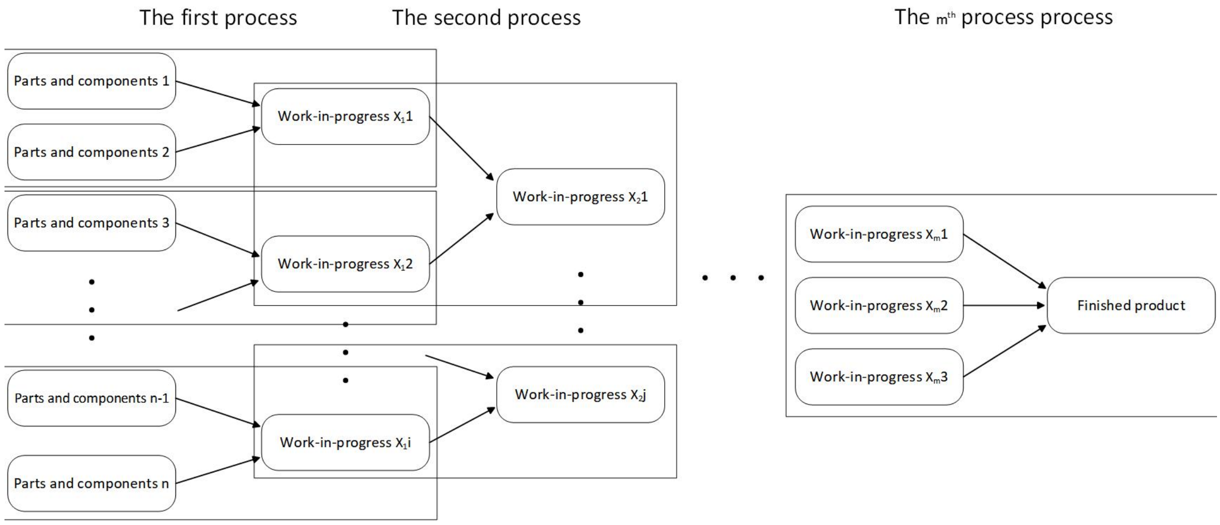

Figure 6 Specific Steps in Decision-Making

As shown in Figure 6 considering the variety of processes, this paper is based on the principle of local optimization, using the model of decision tree, the steps of the process are split step by step, and the optimal solution is sought for each process of assembling spare parts into semi-finished products. The principle of optimization shows that when a solution to a problem requires more than one step to make decisions to achieve a certain result[16], then each of these decisions must be the optimal decision in its corresponding state, in turn, the optimal decision-making is applied to this problem, should be composed of semi-finished parts in step one of the optimal decision-making.

Following 3.2 careful division of decisions, here we divide them into:

1.Whether the spare parts are tested
2.Whether semi - finished products x_{1i} are tested
3.Whether or not testing of non - conforming semi - finished products x_{1i} is carried out
4.Whether returned semi - finished products x_{1i} are dismantled
5.Whether semi - finished product x_{2j} is tested
6.Whether to dismantle substandard semi - finished product x_{2j}
7.Whether returned semi - finished product x_{2j} is dismantled
m.Whether the finished productis tested
m+1.Whether to dismantle substandard finished products
m+ 2.Whether the returned finished productis disassembled

For the values of the decision variable x_i, under the conditions of this question, i ranges from $1-m+1$. The specific mathematical model is as follows:

$$Frist\ process\ costs = N_K \sum_{i=1}^{K} C_K + x_1 \sum_{i=1}^{K} d_K + a_{zf1} + x_2 d_{f1} + x_3 e_{zf1} + x_4 I_{zf1} \tag{22}$$

$$Second\ process\ costs = a_{zf2} + x_5 d_{zf2} + x_6 e_{zf2} + x_7 I_{zf2} \tag{23}$$

$$Mth\ process\ costs = a_{zfm} + x_m d_{zfm} + x_{m+1} e_{zfm} + x_{m+2} I_{zfm} \tag{24}$$

through the derivation of the above formula, it can be concluded that in order to satisfy the optimal decision-making conditions, the assembly process of semi-finished product 1 should make the lowest cost decision-making, i.e., decision-making 16, in which the decision-making situation is as follows: spare parts 1, spare parts 2, spare parts 3, and semi-finished product 1 are inspected, but semi-finished product 1 is not disassembled; the assembly process of semi-finished product 3 should make the decision-making process at the lowest cost, i.e., decision-making 4. In this case, the decision is: to test parts 7 and 8, and not to test and disassemble semi-finished product 3.
The decision making on whether to test the finished product or not is carefully divided, and the decision making that needs to be done for this process is divided into:
15. Whether the finished product is tested
16. Whether to dismantle substandard finished products
17. Whether the returned finished product is disassembled
Decision-making in the process of semi-finished products to finished products, after the analysis of the decision tree model, can be divided into the following four kinds of decision-making programs, the representation follows the expression of problem two, at this time the value of i is 15-17, four kinds of decision-making programs are shown below (Table 2):

Table 2 4 Decision-Making Methods

1.(0,0,0)	2.(1,0,0)	3.(1,1,0)	4.(0,0,1)

The equation for the decision making process from semi-finished product to finished product is shown below:
Finished assembly costs:

$$C_a = a \cdot N_f \tag{25}$$

finished product testing costs:

$$C_{fi} = x_{15} \cdot d_f \cdot N_f \tag{26}$$

disassembly costs:

$$C_d = x_{16} \cdot e(p_f \cdot N_f) \tag{27}$$

processing of returned costs:

$$C_r = x_{17}(I + 88 + a) \cdot (p_f \cdot N_f) \tag{28}$$

total cost:

$$T_c = C_{fi} + C_d + C_r \tag{29}$$

provided that the model function of the cost is known, substituting the model established above into the decision tree modeling algorithm yields a visual graph of all the decisions made in the case:

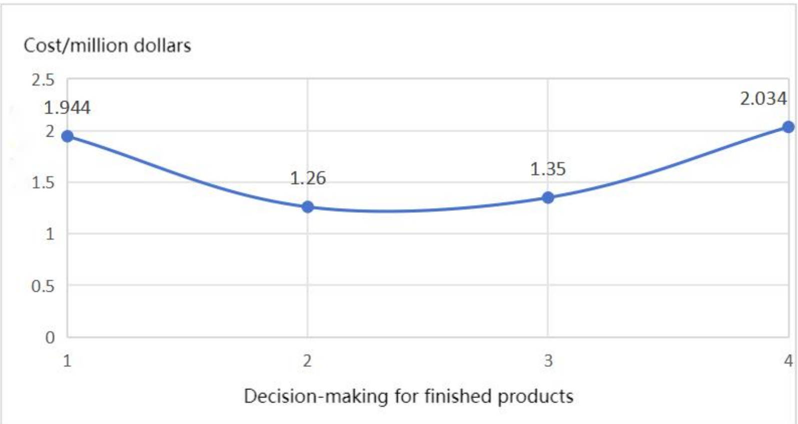

Figure 7 Decision-Making Situation for Finished Products

As shown in Figure 7, in order to meet the optimal decision-making conditions, should make the lowest cost decision-making that is decision-making 4, at this time, the decision-making situation is: only the finished product testing, the unqualified finished product is not disassembled, and returned from the hands of the customer's finished product is also not disassembled.
In summary, the optimal decision-making scheme is to test parts 1, parts 2, parts 3 and semi-finished product 1 but not disassemble semi-finished product 1; to test parts 4, parts 5, parts 6 and semi-finished product 2 but not disassemble semi-finished product 2; to test parts 7 and 8 and not to test and disassemble semi-finished product 3; to test only the

finished product, and not to disassemble the unqualified Finished products are not disassembled, and finished products returned from customers are not disassembled.
After obtaining the locally optimal solution, the mathematical model of the cost can be obtained based on the decision situation as:

$$N_k = \times \sum_{i=1}^{8}(C_i + d_i) + V \times \sum_{j=1}^{3}(C_{fi} + d_{fi}) + V_z{}' \times (C_f + d_f) \tag{30}$$

4 CONCLUSION

Enterprise decision-making is a core component of enterprise management, which involves all levels from strategic planning to daily operations. Effective decision-making can help enterprises cope with complex business environments, optimize resource allocation, enhance competitiveness and achieve sustainable development. Therefore, the accuracy of the final results of decision-making and the efficiency of decision-making can directly affect the development results of enterprises.
This paper starts from the perspective of optimizing enterprise decision-making, firstly introduces the accuracy and reasonableness of the decision tree model in decision-making application, and establishes the corresponding enterprise decision-making model according to the specific scenarios of enterprise decision-making needs; then verifies and calculates the newly established model through the decision-making problems of specific scenarios, in the process of which the decision-making problem is transformed into the sampling detection problem, and the basic principles of mathematical statistics are used to simplify the problem; finally gives the specific conditions of enterprise decision-making, adopts the principle that any step is optimal based on the overall optimal solution, and gives the corresponding conclusions. The problem is simplified; finally, the specific conditions of enterprise decision-making are given, and the principle that any step is optimal based on the overall optimal solution is adopted to make the localization optimal, and the corresponding conclusions are given. The results show that the calculation method established in this paper in 3.2 with the decision tree model algorithm as the core, while drawing conclusions, also according to the test program that comes with the algorithm to calculate that the mean square deviation value of each of the optimal decisions obtained is less than 1%, so this is a great help to the reliability of the model. Decision tree model has obvious advantages in the problem of enterprise decision-making, it optimizes the cumbersome steps in enterprise decision-making, and makes the enterprise decision-making problem clearer and clearer.
Decision tree modeling can be useful in finance, healthcare, marketing and manufacturing, especially in dealing with small amounts of data. In finance, it can be used to assess the credit risk of an individual and select a better investment portfolio, predicting the return and risk through the future; in medicine, it can be used to a large extent to help patients with diagnosis of illnesses and medical assistance; and in technology research, it can be used to provide training value and research significance to machine learning or data mining algorithms. In research, it can be used to provide training value and research significance to machine learning or data mining algorithms.

COMPETING INTERESTS

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

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THE IMPACT OF PATIENT CAPITAL ON ESG RATING DIVERGENCE

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Abstract: The ESG ratings issued by ESG rating agencies have emerged as a vital reference for investors and creditors when making decisions. However, the differences in ESG ratings provided by various agencies not only bring noise into the capital market but also affect the development of patient capital. This study takes Chinese A-share listed companies from 2015 to 2022 as the sample and uses a fixed-effects model to empirically examine the influence of ESG rating divergence on patient capital. The findings show that ESG rating divergence leads to a reduction in patient capital. Further analysis indicates that ESG rating divergence intensifies the degree of information asymmetry in the market and lowers stock liquidity, which in turn reduces patient capital. This impact is more significant in non-state-owned enterprises and companies with high-quality ESG information disclosure. This research offers empirical evidence for the standardization of the ESG rating system construction, the enhancement of patient capital, and the advancement of high-quality economic development.
Keywords: Patient capital; ESG rating divergence; Market information asymmetry; Stock liquidity

1 INTRODUCTION

As China's economy enters a stage of high-quality development, traditional growth models have become unsustainable, with issues such as rising labor costs tightening resources and environmental constraints becoming increasingly prominent. Patient capital, as a form of long-term-oriented investment, can provide continuous financial support to enterprises, promoting their long-term development and innovation capabilities [1].

Patient capital refers to funds willing to make long-term investments, not pursuing short-term returns but expecting greater benefits in the future [2]. Due to the characteristics of low risk and long cycles, ESG investment aligns well with the value concepts of patient capital such as institutional investment, social security funds, and pension funds, making ESG investment an important field for the allocation of patient capital. A survey by Mercer Investment shows that 89% of pension institutions indicate that they will incorporate ESG factors into their investments, a proportion higher than other types of institutions. Taking the Japanese Government Pension Investment Fund as an example, with a total asset size of $1.61 trillion, about $99.22 billion is invested in ESG indices, accounting for nearly 12.3%.

However, existing research has found that different ESG rating agencies do not have high consistency in rating the same company, and there is a significant phenomenon of ESG rating divergence [3]. The rating divergence of agencies may affect investors' decisions, especially when the differences are large. Kotsantonis (2019) found that ESG rating differences are one of the main barriers to ESG investment and may reduce investors' willingness to invest in companies with rating differences [4].

This issue needs further study to discover whether ESG rating divergence will affect patient capital and what its mechanism of action is. Current research on ESG rating divergence mainly focuses on the causes of ESG rating divergence and its impact on capital market efficiency, companies, and auditors' risk response behavior, as well as investor behavior, with little research exploring its impact on patient capital. In light of this, this study uses companies listed in China's A-share from 2015 to 2022 as a research sample to explore the influence of ESG rating divergence on patient capital and its working mechanism.

2 MODEL CONSTRUCTION

2.1 Data Sources

This study selects A-share listed companies in China that have been rated by at least two of the four rating agencies, Huazheng, WIND, SynTao, and MengLang, from 2015 to 2022.The data was screened in the following steps:
(1) Excluding the ST or*ST companies in special treatment status;
(2) Excluding the data from listed companies belonging to the financial sector;
(3) Excluding the data with incomplete information on key variables;
(4) Excluding companies with ESG score records of less than two years.

Following the selection process, the study ultimately included 1,127 companies listed on the Chinese A-share market as subjects of analysis. The ESG ratings for these corporations were sourced from databases provided by Huazheng, WIND, SynTao Green, and MengLang. Concurrently, the companies' informational and financial records were obtained from the CSMAR database.

2.2 Variable Selection

The dependent variable is the institutional holding ratio, calculated as the total number of shares held by institutional investors divided by the total number of circulating shares. Investors with a stable equity stake often have a strategic development perspective, enabling them to conduct comprehensive and in-depth analysis of companies, and are more willing to actively supervise and govern companies effectively. Therefore, the institutional holding ratio is a good measure of patient capital.
The independent variable is ESG rating divergence. This study uses four approaches to measure corporate ESG rating divergence: Huazheng ESG rating, WIND ESG rating, Shangdao Ronglv ESG rating, and Menglang FIN-ESG rating. The first three are categorized into nine levels, with ratings from C to AAA assigned values from 1 to 9, while Shangdao Ronglv ESG rating is categorized into ten levels, with ratings from D to A+ assigned values from 0 to 9. After organizing the four ESG rating methods, the standard deviation of the ESG rating scores is computed to get the data for ESG rating divergence.
A set of control variables is called a control variable. This work controls the parameters at the corporate level and refers to Cai and others' studies when choosing control variables [5]. And descriptive statistics are showed in Table 1.

Table 1 Descriptive Statistics

Symbols	Observations	Maximum	Minimum	Average	Standard deviation	median	variance
I	12104	1.898	0	0.417	0.231	0.426	0.053
D	12107	4.243	0.5	1.277	0.563	1.258	0.317
Size	12105	28.607	16.412	22.731	1.414	22.573	1.999
Lev	12105	178.345	0.008	0.474	1.656	0.449	2.742
ROA	12105	12.211	-9.117	0.03	0.179	0.033	0.032
ListAge	12104	2.222	-0.997	0.051	0.079	0.049	0.006
FirmAge	12105	168.498	-0.997	0.209	2.27	0.081	5.153
Opcf	12105	2.89	1.386	2.12	0.202	2.197	0.041
Mfee	12105	0.955	0.088	0.557	0.154	0.554	0.024
Board	12105	41.595	0.018	1.387	1.899	0.847	3.607
Growth	12105	3.497	0	2.533	0.663	2.565	0.44
BM	11986	4.447	-5.921	-0.021	0.441	0.001	0.194
Dturn	11932	3404.611	0.001	0.721	38.106	0.059	1452.035

2.3 Basic Regression

Because of the existence of ESG rating divergence, investors have lower trust in ESG ratings, making themselves more cautious when implementing ESG integration. This distrust may lead investors to pay less attention to ESG investments and reduce the investment of patient capital [6-7]. ESG rating divergence amplifies the synchronicity of company stock prices, affecting the market's effective pricing of ESG information and reducing the pricing efficiency of the capital market, thereby decreasing the investment of patient capital [8]. Hence, this study hypothesize that:
H_1: An increase in corporate ESG rating divergence will reduce patient capital.
To explore the effects of ESG rating divergence on patient capital, this paper establishes a panel linear regression model as follows:

$$I_{it} = \beta_0 + \beta_1 D_{it} + \beta_n Controls_{it} + \sum Year + \sum Industry + \varepsilon_{it} \quad (1)$$

where i is the sample number, t is the time, and the dependent variable represents the institutional holding ratio of the i sample company in year t. The independent variable represents the ESG rating divergence of the i sample company in year t. $Controls_{it}$ is a set of control variables used in this paper, Industry and Year represent the dummy variables for industry and year, respectively. The coefficient β_1 is used to reflect the extent of the effects of corporate ESG rating divergence on patient capital.

2.4 The Mediating Effect of Market Information Asymmetry

ESG rating divergence widens market info asymmetry. The notable rise in rated firms' stock price synchronicity reflects ESG rating divergence's "noise effect," intensifying market information asymmetry [9]. Moreover, ESG rating divergence reduces capital market info efficiency. This asymmetry makes it harder for investors to accurately assess companies' values, thereby decreasing patient capital. Thus, the paper puts forward the hypothesis:
H_2: Corporate ESG rating divergence can reduce patient capital by increasing market information asymmetry.
Listed companies' transparency gauges the degree of information asymmetry, with stock exchanges' disclosures as the benchmark. Grades A, B, C, D correspond to 4, 3, 2, 1. To examine how corporate ESG rating divergence impacts market information asymmetry, the paper sets up the mechanism regression model below:

$$CO_{it} = \beta_0 + \beta_1 D_{it} + \beta_n Controls_{it} + \sum Year + \sum Industry + \varepsilon_{it} \quad (2)$$

2.5 The Mediating Effect of Stock Liquidity

ESG rating divergence reduces stock liquidity. A higher ESG rating can improve stock liquidity, while ESG rating divergence increases the operating risk of companies, reduces positive market expectations, and increases the market's risk aversion, leading to a decrease in stock liquidity. Low liquidity means that investors have difficulty buying and selling stocks in the short term, increasing the uncertainty and risk of investment, and thus reducing patient capital. Based on this, this paper hypothesize that:

H_3: Corporate ESG rating divergence would reduce patient capital by decreasing stock liquidity.

This paper draws on the Roll model proposed by Roll (1984) to measure stock liquidity [10].

$$\text{Roll} = \begin{cases} 2\sqrt{-\text{cov}(\Delta P_t, \Delta P_{t-1})}, & -\text{cov}(\Delta P_t, \Delta P_{t-1}) < 0 \\ 0 \quad , & -\text{cov}(\Delta P_t, \Delta P_{t-1}) \geq 0 \end{cases} \tag{3}$$

To explore the impact of corporate ESG rating divergence on market information asymmetry, this study establishes the following mechanism regression model:

$$\text{LIQ}_{it} = \beta_0 + \beta_1 D_{it} + \beta_n \text{Controls}_{it} + \sum \text{Year} + \sum \text{Industry} + \varepsilon_{it} \tag{4}$$

3 RESULTS

3.1 Basic Regression Results

The baseline regression results of the basic regression are shown in Table 2, showing the impact of corporate ESG rating divergence on patient capital. The ESG rating divergence has a negative effect on patient capital, which is significant at the 1% level, and this result remains significant at the 1% level even after controlling for other variables and fixing for industry and year, thus validating the hypothesis. This indicates that there is a significant effect of corporate ESG rating divergence on patient capital; the greater the ESG rating divergence, the smaller the patient capital.

Table 2 Basic Regression Results

	I			
D	-0.012*** (-3.74)	-0.019*** (-5.432)	-0.150*** (-4.65)	-0.291*** (-7.85)
Size	0.072*** (43.021)		0.075*** (44.56)	
Lev	0.004*** (3.424)		0.004*** (3.49)	
ROA	0.008*** (6.668)		0.082*** (6.69)	
ListAge	0.044*** (12.02)		0.052*** (14.28)	
FirmAge	-0.008 (-0.986)		0.001 (0.001)	
Opcf	0.124*** (5.18)		0.151*** (6.26)	
Mfee	0.001** (2.009)		0.001** (1.82)	
Board	0.116*** (12.583)		0.126*** (13.44)	
Growth	-0.003*** (-3.482)		-0.003*** (-3.61)	
BM	-0.017*** (-13.268)		-0.013*** (-10.90)	
Dturn	-0.025*** (-5.882)		-0.027*** (-6.25)	
Industry	YES	YES	NO	NO
Year	YES	YES	NO	NO
N	11815	12104	11815	12104
R^2	0.271	0.005	0.271	0.005

Note: ***,** and* represent significance at 1%, 5% and 10%, respectively, and the same below.

3.2 Mechanism Analysis Results

3.2.1 Market information asymmetry

According to the regression results in Table 3, corporate ESG rating divergence significantly increases the degree of market information asymmetry. The increase in information asymmetry due to ESG rating divergence reduces the efficiency with which ESG information is conveyed to investors, making it difficult for rating results to accurately reflect and predict future market information about companies. Investors may adopt a more cautious attitude towards these companies, leading to a decrease in patient capital.

Table 3 The Regression Results of Mechanism Analysis

	CO			
D	-0.235***	-0.248***	-0.231***	-0.245***
	(-11.616)	(-16.873)	(-16.32)	(-16.73)
Controls	YES	NO	YES	NO
Industry	YES	YES	NO	NO
Year	YES	YES	NO	NO
N	11815	12107	11815	12107
R^2	0.056	0.023	0.056	0.023

3.2.2 Stock liquidity

According to the regression results in Table 4, corporate ESG rating divergence significantly reduces stock liquidity. ESG rating divergence increases the uncertainty of the market regarding the operational risks of companies, reduces positive market expectations, and thus leads to a decrease in stock liquidity. Low stock liquidity typically implies lower market activity and poorer pricing efficiency, which can prompt more patient capital to decrease its holdings in stocks.

Table 4 The Regression Results of Mechanism Analysis

	LIQ			
D	0.001***	0.002***	0.001***	0.001***
	(4.407)	(7.882)	(4.46)	(6.62)
Controls	YES	NO	YES	NO
Industry	YES	YES	NO	NO
Year	YES	YES	NO	NO
N	11815	12106	11815	12106
R^2	0.183	0.003	0.183	0.003

3.3 Heterogeneity Analysis Results

3.3.1 Heterogeneity analysis based on corporate property rights attributes

This paper introduces two dummy variables for state-owned enterprises (SOEs) and non-state-owned enterprises. When SOE equals 1, the enterprise is a state-owned company; when SOE equals 0, the enterprise is non-state firm. According to Table 5, compared to state-owned firm, the impact of ESG rating divergence on patient capital is more significant in non-state firm, which validates the hypothesis. Ma Wenjie (2023) pointed out that domestic rating agencies tend to give higher ESG ratings to state-owned company and lower ratings to non-state-owned firm. Institutional investors have a preference for companies with good ESG performance, which can attract more institutional capitals and thus mitigate the influence of ESG rating divergence on patient capital for state-owned enterprises.

3.3.2 Heterogeneity analysis based on corporate information disclosure quality

This paper constructs a dummy variable, GRI, based on whether a company's ESG disclosure complies with the globally acknowledged GRI Sustainability Reporting Framework, to measure the quality of corporate ESG information disclosure. A value of 1 indicates compliance with the GRI framework, while 0 indicates non-compliance. According to Table 5, compared to companies that disclose following the GRI Sustainability Reporting Framework, the impact of ESG rating divergence on patient capital is more significant in companies that do not comply with the GRI framework, which validates the hypothesis. The reason for this is that adhering to the internationally recognized GRI Sustainability Reporting Framework for information disclosure can provide ESG rating agencies with more standardized corporate ESG information, reducing the subjectivity of their ratings and enhancing the credibility of corporate information. This, in turn, reduces the likelihood of ESG rating divergence and its impact on patient capital.

Table 5 The Regression Results of Heterogeneity Analysis

SOE=1	I		GRI=1	I	
D	-0.012	-0.006	D	-0.02	-0.008
	(-1.685)	(-1.266)		(-1.276)	(-0.834)
Controls	YES	NO	Controls	YES	NO
Industry	YES	YES	Industry	YES	YES
Year	YES	YES	Year	YES	YES
N	4375	4506	N	1552	1623
R^2	0.274	0.001	R^2	0.225	0.001
SOE=0	I		GRI=0	I	
D	-0.006	-0.013***	D	-0.012***	-0.019***
	(-1.415)	(-3.019)		(-3.402)	(-4.966)
Controls	YES	NO	Controls	YES	NO
Industry	YES	YES	Industry	YES	YES
Year	YES	YES	Year	YES	YES
N	7440	7598	N	10254	10472

R^2	0.181	0.001	R^2	0.237	0.005

3.4 Robustness Tests

3.4.1 Changing the sample size

On September 30, 2018, the China Securities Regulatory Commission (CSRC) provided clear guidance for the public disclosure of ESG information by listed companies. On June 21 of the same year, all listed companies included in the MSCI index were subject to ESG ratings, promoting the integration of the A-share market with international markets. Therefore, the year 2018 marks a significant milestone in the development of ESG in China. Based on this, this paper excludes samples before 2018 and uses samples from the five-year period of 2018-2022 to test the regression. Table 6 shows that after excluding some samples, the coefficient of D remains significant, indicating that the effect of corporate ESG rating divergence on patient capital still exists after reconsidering the sample, thus verifying the robustness.

Table 6 The Result of Robustness Testing

	I			
D	-0.012***	-0.025***	-0.169***	-0.038***
	（-3.68）	（-6.746）	（-5.00）	（-9.81）
Controls	YES	NO	YES	NO
Industry	YES	YES	NO	NO
Year	YES	YES	NO	NO
N	11101	11330	11101	11330
R^2	0.260	0.001	0.260	0.001

3.4.2 Changing the explanatory variable

Referring to the research by He Taiming (2023), this paper adds the ESG ratings from Bloomberg and FTSE Russell to the existing ESG rating divergence [11]. The Bloomberg ESG rating takes the specific score and rounds it to the nearest 10%, and the FTSE Russell ESG rating takes the specific score and doubles it (i.e., multiplies by 200%) for the sample data. This paper calculates the standard deviation of the ESG rating scores from the six types of index to calculate data on ESG rating divergence. According to Table 7, after changing the explanatory variable, the increase in ESG rating divergence remains highly significant in enhancing corporate financing constraints, thus verifying the robustness.

Table 7 The Result of Robustness Testing

	I			
Ds	-0.006*	-0.148***	-0.006**	-0.152***
	（-1.671）	（-3.885）	（-2.00）	（-4.12）
Controls	YES	NO	YES	NO
Industry	YES	YES	NO	NO
Year	YES	YES	NO	NO
N	13867	14197	13867	14197
R^2	0.250	0.001	0.250	0.001

4 CONCLUSION AND RECOMMENDATIONS

This study selected A-share listed companies that were rated by at least two of the four rating agencies, Huazheng, WIND, Shangdao Ronglv, and Menglang, over the eight-year period from 2015 to 2022. This paper conducted an empirical research on the effect of corporate ESG rating divergence on patient capital and the mechanisms through which this impact occurs, leading to the following conclusions:

(1) An increase in corporate ESG rating divergence reduces patient capital.

(2) Corporate ESG rating divergence reduces patient capital by increasing market information asymmetry and decreasing stock liquidity.

(3) ESG rating divergence has a more significant reduction influence on patient capital for non-state-owned enterprises and companies with poor ESG information disclosure quality.

Policy Recommendations:

(1) Strengthen the regulation and standardization of ESG rating agencies: Given the potential impact of ESG rating divergence on patient capital, regulatory authorities should enhance the oversight of rating agencies to ensure the transparency and fairness of the rating process. Additionally, efforts should be made to establish unified ESG rating standards to reduce rating divergence, thereby reducing market information asymmetry, bolstering investor confidence, and attracting more patient capital into the market.

(2) Improve the quality of corporate information disclosure: Companies should enhance the quality and transparency of their information disclosure, especially for non-state-owned enterprises and those with poor ESG information disclosure quality. This will help reduce information asymmetry, increase stock liquidity, and thus attract and maintain the investment of patient capital.

(3) Encourage a long-term investment-oriented capital market environment: Policymakers should use incentives such as tax benefits and investment protection to encourage institutional investors to engage in long-term investments. At the

same time, a market mechanism conducive to long-term investment should be established and improved, providing more protection and incentives for long-term investors, promoting the formation and growth of patient capital, and supporting high-quality economic development.

COMPETING INTERESTS

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

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INNOVATION IN TAX ADMINISTRATION MODELS IN THE CONTEXT OF THE DIGITAL ECONOMY

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Abstract: Against the backdrop of the rapid development of the digital economy, traditional tax administration models face multiple challenges, including base erosion, information asymmetry, and outdated management technologies. This paper systematically analyzes the impact of characteristics inherent to the digital economy—such as virtuality, data-driven nature, and network externalities—on tax administration, highlighting the limitations of traditional models in areas like data integration, risk identification, and cross-border coordination. Based on theories from information economics, behavioral economics, big data, and artificial intelligence, practical pathways for innovating tax administration models are proposed: building a smart taxation system to enhance administrative efficiency through big data analytics and AI technologies; strengthening international cooperation to promote the coordination of international tax rules and information sharing; and improving legal frameworks to clarify the legal status of digitalized administration. The driving role of technological innovation and institutional optimization in modernizing tax administration is validated through domestic and international case studies (e.g., Shenzhen's smart tax system, U.S. big data risk control, Singapore's blockchain invoice management). The research concludes that innovating tax administration models is imperative for adapting to the digital economy, requiring synergistic advancement across technological empowerment, institutional safeguards, and international cooperation to achieve comprehensive improvements in tax fairness, administrative efficiency, and the business environment.
Keywords: Digital economy; Innovation in tax administration models; Smart taxation; Information economics

1 INTRODUCTION

Since the beginning of the 21st century, the digital economy has surged like an irresistible tide, developing at an astonishing pace and permeating every sphere of the socio-economic landscape. This new economic form, supported by information technologies such as the Internet, big data, and artificial intelligence, has not only profoundly transformed people's modes of production and lifestyles but also posed severe challenges to traditional tax administration models. Traditional tax administration, built upon a relatively stable real economy foundation, finds its methods and approaches inadequate in the face of the digital economy, revealing numerous mismatches and shortcomings. Therefore, innovating tax administration models to adapt to the development of the digital economy has become an issue that urgently needs to be addressed. Against this backdrop, the purpose of this paper is to explore innovative pathways for tax administration models in the context of the digital economy. Through an in-depth analysis of the characteristics of the digital economy, it becomes apparent that its virtuality, cross-border nature, and immediacy render traditional tax administration methods difficult to apply effectively. Consequently, it is necessary to innovate at the theoretical level by reexamining the basic principles of taxation and the construction of tax systems so as to make them more consistent with the practical realities of the digital economy. At the practical level, this paper will investigate how to leverage modern information technologies, such as big data analytics, cloud computing, and blockchain, to enhance the efficiency and equity of tax administration. Big data analytics can assist tax authorities in grasping taxpayers' true circumstances more accurately and improving the precision of tax administration; cloud computing can achieve real-time sharing and efficient processing of tax data, thereby enhancing the operational efficiency of tax administration; meanwhile, blockchain technology can strengthen the transparency and security of tax administration, reducing the risk of tax fraud and evasion. Through the exploration of these innovative pathways, this paper aims to provide theoretical support and practical guidance for improving the efficiency and fairness of tax administration. This not only contributes to the modernization of the tax administration system, making it better suited to the demands of the digital economy's development, but also promotes the healthy growth of the digital economy, optimizes the tax environment, strengthens the stability of national fiscal revenues, and provides solid support for sustainable socio-economic development. In summary, faced with the challenges and opportunities brought by the digital economy, innovation in tax administration models is an inevitable choice. This paper will systematically analyze the innovation of tax administration models in the context of the digital economy from both theoretical and practical dimensions, with the hope of offering valuable references for the reform and development of China's tax administration system.

2 DIGITAL ECONOMY CHARACTERISTICS, TAX CHALLENGES, AND RESEARCH ON THE LIMITATIONS OF TRADITIONAL ADMINISTRATION MODELS

2.1 Digital Economy and Traditional Tax Administration Models

The digital economy, as an entirely new economic form, has gradually emerged alongside the rapid development of information technology. Many scholars have defined it from different perspectives. Some, from a technology-driven standpoint, believe that the digital economy is a series of economic activities that take digitized knowledge and information as key production factors, use modern information networks as important carriers, and regard the effective use of information and communication technology as a significant driving force for efficiency improvement and economic structure optimization. Others focus on the digital transformation of economic activities to define the digital economy. The digital economy encompasses all economic activities that employ digital technology for production, exchange, distribution, and consumption, including emerging fields such as e-commerce, digital finance, and digital entertainment, as well as the transformation and upgrading of traditional industries through digitalization. From this perspective, the digital economy is not merely a collection of emerging digital industries but a brand-new economic model that permeates every sector of the economy. International organizations have also standardized and elaborated on the concept of the digital economy. The Organisation for Economic Co-operation and Development (OECD) defines the digital economy as a broad term that covers all economic activities based on digital technologies, including the production and application of digital technologies and the economic and social impacts that result. The United Nations Conference on Trade and Development (UNCTAD) emphasizes that the digital economy comprises economic activities conducted using digital technologies and the extensive influence of digital technologies on economic and social development. Data is the core production element of the digital economy, characterized by high mobility, replicability, and non-exclusivity. In the digital economy, enterprises collect, analyze, and utilize vast amounts of data to understand market demand, optimize production processes, and innovate products and services. For instance, e-commerce platforms analyze users' browsing history and purchasing behavior to achieve precise marketing and personalized recommendations, thereby improving user shopping experiences and corporate sales efficiency. Data-driven decision-making enables firms to formulate strategies and operational plans more scientifically, enhancing resource allocation efficiency and thus gaining a competitive advantage in the market[1]. The transactional activities within the digital economy mostly occur in virtual cyberspace, unrestricted by time and location. Enterprises and consumers can conduct transactions of goods and services via the Internet anytime and anywhere, greatly reducing transaction costs. For example, online education platforms break through the geographic limitations of traditional education, allowing students to access quality educational resources at any time and place; remote office software enables employees to work from home or other locations, increasing work flexibility and efficiency. However, virtualization also brings problems, such as difficulty in verifying the identity of transaction parties and challenges in ensuring the authenticity and security of transaction information. The digital economy is built on information technology, characterized by rapid innovation and a continuous emergence of innovative outcomes. New business models, technological applications, and products and services spring up endlessly, driving rapid economic development and social progress. For instance, the emergence of blockchain technology has brought decentralization, immutability, security, and transparency to the financial sector, potentially resolving trust issues in traditional finance; artificial intelligence technology applied in healthcare, transportation, and security has improved the intelligence level and service quality in these fields. Innovation is the driving force of digital economic development; enterprises must continuously innovate in order to survive and develop in fierce market competition. The digital economy exhibits significant network externalities, meaning that the value of a product or service for one user increases as the number of users of that product or service grows. For example, the more users a social networking platform has, the richer the social interactions among users, and the greater the value of the platform; the more merchants and consumers on an e-commerce platform, the more diverse the product selection becomes, and the higher the efficiency and success rate of transactions. Network externalities make it easy for monopolistic patterns to form in the digital economy, allowing a few large enterprises to dominate the market with their vast user bases and network effects.

The traditional tax administration model was gradually formed and developed during the industrial economy era, relying primarily on paper documentation, manual operations, and on-site management. Its basic characteristic is to center around tax authorities by establishing tax administration institutions, staffing professional tax personnel, and conducting management activities such as taxpayer registration, filing, collection, and inspection according to tax laws and regulations. In the registration stage, taxpayers must visit the tax authority's office to complete tax registration procedures, submit relevant paper documents and materials, and have their information reviewed and entered by the tax authority. In the filing stage, taxpayers fill out tax return forms in accordance with prescribed deadlines and formats and submit them to the tax authority in paper or electronic form. In the collection stage, the tax authority issues a tax payment notice based on the taxpayer's filing information, and the taxpayer pays the tax at a designated bank. In the inspection stage, tax personnel conduct field investigations and review accounting books, etc., to examine and verify taxpayers' compliance with tax obligations. After long-term practice and refinement, the traditional tax administration model has formed a relatively stable and mature process flow and institutional system. Tax personnel, having undergone professional training, are familiar with tax laws, regulations, and administration procedures, effectively ensuring the normal conduct of tax administration work. Meanwhile, the preservation of paper materials and archives provides reliable evidence and basis for tax administration, facilitating post facto audits and supervision by tax authorities. Face-to-face communication between tax authorities and taxpayers is an important advantage of the traditional administration model. Tax personnel can directly communicate with taxpayers to understand their production and operation conditions and tax needs, providing personalized tax guidance and services. Such communication helps enhance taxpayers' understanding of and compliance with tax policies, reducing tax errors and disputes. Tax personnel can also conduct on-site inspections of an enterprise's production and operation locations to examine and verify the company's financial status, production processes, and inventory conditions, identifying potential tax issues. On-site inspections facilitate the acquisition of first-hand information, improving the accuracy and effectiveness of tax administration.

The traditional tax administration model relies heavily on manual operations and paper-based information exchange, resulting in low administration efficiency. Taxpayers must spend considerable time and effort visiting tax authorities to complete various procedures, and tax authorities, in turn, must invest significant human and material resources in document review, data entry, and management. For example, during the tax filing and payment process, taxpayers may need to shuttle multiple times between their enterprise, the tax authority, and the bank, increasing both monetary and time costs. Under the traditional administration model, tax authorities have relatively limited channels for obtaining taxpayer information, relying mainly on taxpayer filings and on-site inspections. Due to inadequate information collection and processing capabilities, tax authorities find it difficult to comprehensively and promptly grasp taxpayers' production, operation, and financial information, leading to information asymmetry. Such information asymmetry may allow taxpayers to conceal income or overstate costs, thereby evading tax obligations. The traditional tax administration model requires building a large administration apparatus and staffing a significant number of tax personnel, as well as investing heavily in office equipment, premises, and funding. These factors contribute to the high cost of tax administration. Moreover, because of low administration efficiency, tax authorities need to spend more time and effort completing administration tasks, further increasing administration costs[2].

2.2 Impact of the Digital Economy on Tax Administration

Under the digital economy model, the virtualization and mobility of transactional activities render traditional tax jurisdiction rules difficult to apply. Traditional tax jurisdiction is primarily based on principles of territoriality and personality, using standards such as an enterprise's place of registration, the location of its permanent establishment, or the source of its income. However, digital economy enterprises can conduct business globally via the Internet, with business activities potentially involving multiple countries and regions; the identities and locations of transaction parties are difficult to determine, and the source of income cannot be accurately identified. For example, an online gaming company may have users in multiple countries and regions, but its servers and operation centers may be located elsewhere, creating difficulties for each country in determining tax jurisdiction. The development of the digital economy challenges traditional tax jurisdiction rules and requires the international community to jointly explore and formulate new rules to resolve conflicts in tax jurisdiction.

Digital economy enterprises can exploit their virtualization and mobility to engage in base erosion and profit shifting through transfer pricing and the use of tax havens, thereby reducing their tax obligations in high-tax countries and regions. For instance, some multinational digital enterprises transfer intangible assets such as intellectual property to subsidiaries in low-tax jurisdictions, then shift profits to those low-tax regions by charging royalties, thereby lowering their overall tax burden. In addition, the business models in the digital economy are complex and varied; some emerging business models and transaction methods are difficult to regulate and supervise under traditional tax regulations, providing opportunities for enterprises to engage in base erosion and profit shifting. Transactional activities in the digital economy mostly occur in virtual cyberspace, with transaction information existing in digital form, exhibiting concealment and dispersion. Tax authorities find it difficult to obtain comprehensive and accurate transaction information, exacerbating information asymmetry in tax administration. For example, a large number of small-value transactions on e-commerce platforms may not have detailed transaction records, making it hard for tax authorities to grasp their true status; some digital economy enterprises use encryption technology to protect transaction information, further increasing the difficulty for tax authorities to access information. Tax administration information asymmetry makes it difficult for tax authorities to accurately assess enterprises' tax obligations, leading to potential tax revenue loss. Strengthening information sharing and communication between tax authorities and enterprises and improving the informatization level of tax administration are necessary[3].

"Smart taxation" and tax administration model reform have a complementary and mutually reinforcing relationship. On the one hand, "smart taxation" provides the modern information foundation and development direction for tax administration model reform. As a tax ecosystem that integrates collection, management, and service, "smart taxation" serves as the goal and blueprint for the reform of tax administration models in the new era. It offers a modern information technology foundation and important guidance for applying digital information technology in the tax field, and represents the ultimate objective for the modernization of tax administration models. Figure 1 illustrates the relationship between "smart taxation" and the tax administration model. On the other hand, tax administration model reform is the pathway to realizing "smart taxation." The tax administration model encompasses the normative forms and combinations that tax authorities adopt in terms of tax collection, administration, and inspection, as well as the organizational structure of tax administration. Reforming the traditional tax administration model must be based on "smart taxation," fully utilizing digital governance thinking and promoting the reengineering of administration model processes through information technologies such as the Internet.

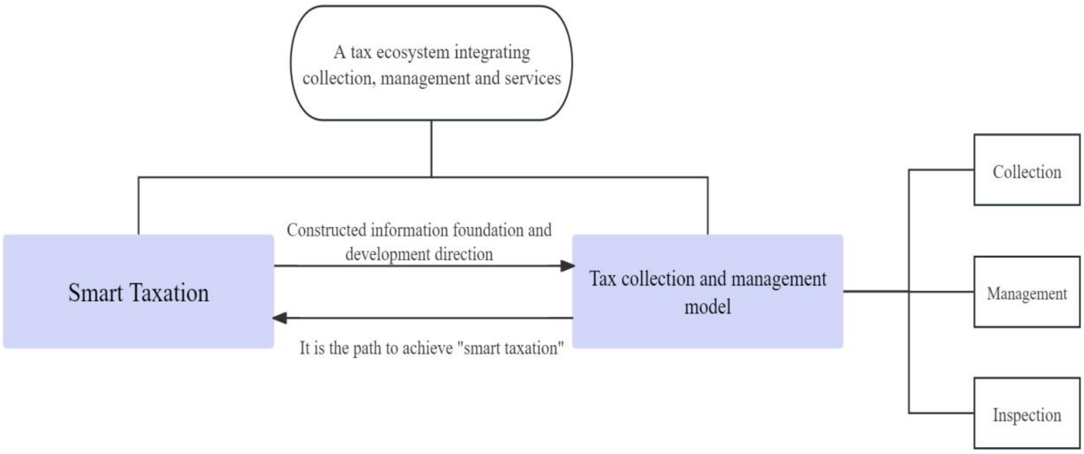

Figure 1 The Relationship between "Smart Taxation" and Tax Collection and Management Models

The development of the digital economy imposes higher demands on tax administration technology. Tax authorities need to leverage advanced information technologies such as big data, artificial intelligence, and blockchain to enhance the efficiency and accuracy of tax collection and administration. For example, through big data analytics, tax authorities can conduct comprehensive and in-depth analysis of corporate transaction data to identify potential tax risks; the application of artificial intelligence enables the automation and intelligence of tax administration, thereby improving efficiency and service quality. However, the current level of information technology and talent pool within tax authorities remains insufficient to fully meet the demands of digital economy tax administration. Increased investment in information technology and talent development is essential. Elevating the technical capabilities of tax administration is crucial for addressing the challenges posed by the digital economy. Tax authorities must continuously innovate administrative approaches and methods to advance the modernization of tax administration.

2.3 Limitations of the Traditional Tax Administration Model in the Context of the Digital Economy

The development of the digital economy has led to an increasing number of transactional activities being conducted via the Internet and electronic platforms, with the transaction process becoming ever more virtualized and digitized. The traditional tax administration model, which is mainly based on tangible transactions and physical business premises, finds it difficult to effectively regulate virtual transactions of digital products and services. For instance, the sale of digital products can be completed instantaneously through online platforms, with the parties involved in the transaction possibly located in different regions or even different countries, making it difficult for tax authorities to determine the place where the transaction occurred, the taxpayer, and the tax liability.

The digital economy generates massive volumes of data characterized by diversity, rapid change, and complex interconnections. The data-processing capability of the traditional tax administration model is limited, making it difficult to effectively collect, analyze, and utilize these vast amounts of data. As a result, tax authorities cannot identify tax risks and anomalies in a timely manner from the huge volume of data, thereby affecting the accuracy and timeliness of tax administration.

The cross-border and mobile nature of the digital economy has made international tax issues increasingly prominent. The traditional tax administration model, which is primarily based on the principles of territoriality and personality, struggles to adapt to the cross-border transaction characteristics of the digital economy. In the context of the digital economy, enterprises can conduct business globally via the Internet, making the allocation of profits and tax jurisdiction difficult to determine. Differences in tax policies and administration standards among countries and regions lead to challenges in international tax coordination and are prone to triggering disputes over international taxation.

The digital economy has given rise to many emerging business models, such as the sharing economy and platform economy[4]. These new business models are characterized by innovation, flexibility, and rapid change, which the traditional tax administration model cannot regulate and supervise in a timely and effective manner. For example, sharing-economy platforms involve a large number of individual operators and frequent transactions, making it difficult for tax authorities to carry out comprehensive tax registration and tax return management. At the same time, the income recognition and cost accounting methods of these emerging business models differ from those of traditional enterprises, posing new challenges to tax administration.

2.4 Current Research Status at Home and Abroad

Foreign scholars paid attention early to the impact of the digital economy on traditional tax administration models. In a series of reports, the OECD (Organisation for Economic Co-operation and Development) pointed out that the mobility, virtuality, and complexity of the digital economy make traditional tax administration rules—based on physical presence—difficult to apply. For instance, transactions in digital products and services can cross borders instantaneously, leading to difficulties in determining the source of income and consumption location, which in turn triggers conflicts over international tax jurisdiction. Avi-Yonah argued that digital economy enterprises often transfer profits by establishing entities in low-tax jurisdictions or through intellectual property transfer, eroding national tax bases, and that traditional transfer pricing rules are challenging to enforce effectively in the digital economy environment. To address the challenges of the digital economy, many explorations in innovating tax administration models have taken place abroad. The European Union led the way in implementing the Value-Added Tax Digital Services Tax (DST), requiring digital service providers to pay VAT in the place where the service is consumed. Picciotto found that this consumption-based taxation model to some extent resolves the difficulties of taxing cross-border digital services, but it also faces issues such as increased compliance costs for enterprises and difficulties in international coordination. Moreover, some countries have begun exploring the establishment of digital-economy tax information–sharing platforms to strengthen tax-information exchange internationally. Cripe in the United States pointed out that information sharing can enhance tax authorities' ability to supervise multinational digital enterprises and reduce revenue leakage.

Foreign scholars pay great attention to the application of new technologies in tax administration. Because of its decentralization and immutability, blockchain technology is considered capable of constructing a trusted tax administration system. Nakamoto proposed that leveraging blockchain technology can achieve real-time sharing and verification of tax information, improving the efficiency and transparency of tax administration. Artificial intelligence and big data analytics technologies are also widely applied to tax-risk assessment and tax forecasting. For example, the Australian Taxation Office uses big data analytics to monitor taxpayers' transaction data in real time, accurately identifying potential tax risks, and Smith believes that this practice effectively improves the precision of tax administration.

Domestic scholars have also conducted in-depth studies on the impact of the digital economy on tax administration. Li Xuhong pointed out that the development of the digital economy has changed traditional production, transaction, and consumption models, causing profound changes in the objects, scope, and methods of tax administration. The light-asset operation model of digital-economy enterprises and the high proportion of intangible assets present challenges to the traditional tax administration, which is based on tangible assets. Additionally, the rise of platformization and sharing-economy models in the digital economy has increased the difficulty of tax administration; for instance, there are significant loopholes in the tax administration of individuals participating in sharing-economy activities. Regarding directions for innovating tax administration models, domestic scholars have proposed a series of recommendations. Liu Shangxi argued that a modernized tax administration system that adapts to digital-economy development should be built, achieving a shift from invoice-based to data-driven taxation. This requires strengthening the digitalization of tax administration, integrating various internal and external data resources of tax authorities, and establishing a unified tax big-data platform. Other scholars have suggested drawing on international experience and combining it with China's national conditions to explore tax administration models suited to China's digital-economy development, such as establishing a special tax administration regime for the digital economy, clarifying the tax obligations and administration processes for digital-economy enterprises.

Domestically, there is also abundant practice and research on tax administration innovation driven by new technologies. Tax authorities actively promote electronic invoicing and the intelligent upgrading of tax administration information systems, improving the efficiency and convenience of tax administration. Zhang Bin found that the popularization of electronic invoicing effectively reduces invoicing management costs and tax risks, and that using artificial intelligence and big data technologies to analyze invoice data can accurately identify unlawful behaviors such as false invoicing. In addition, the application of blockchain technology in the tax domain has gradually received attention; some local tax authorities have launched blockchain invoicing pilot projects to achieve full-process supervision of invoices through blockchain technology, improving the authenticity and credibility of invoices.

With the globalization of the digital economy, domestic scholars have also recognized the importance of international tax coordination and cooperation. Zhu Qing pointed out that China should actively participate in the formulation of international tax rules, strengthen tax-information exchange and administration cooperation with other countries, and jointly address the international tax challenges brought by the digital economy. In the context of the digital economy, international tax competition is intensifying. Through international tax coordination and cooperation, double taxation and revenue leakage can be avoided, protecting China's tax interests. Overall, domestic and foreign scholars have conducted extensive research and exploration regarding the innovation of tax administration models in the context of the digital economy, achieving certain results. However, as the digital economy develops rapidly and new business forms and models continue to emerge, tax administration model innovation still faces many challenges, requiring further in-depth research and practice[5].

3 IMPACT OF THE DIGITAL ECONOMY ON TAX ADMINISTRATION

3.1 Base Erosion and Profit Shifting

Under the traditional economic model, tax administration is mainly based on an enterprise's physical presence or permanent establishment, allowing tax authorities to relatively clearly define the enterprise's business activities and profit sources. However, the rapid development of the digital economy has disrupted this traditional model. The digital economy relies on digitized knowledge and information as key production factors and conducts economic activities through information networks; it is characterized by virtuality, mobility, and concealment, posing numerous challenges to traditional tax administration rules and giving rise to base erosion and profit-shifting issues. There are many specific ways in which the digital economy leads to base erosion and profit shifting. In the digital economy, intangible assets such as software, algorithms, and data play a core role; these intangible assets are highly mobile and difficult to value, allowing enterprises to easily transfer intangibles to low-tax jurisdictions or tax havens. For example, a technology company that develops a popular software product may carry out research and development in multiple countries, but the company could transfer ownership of the software via intellectual property rights to a subsidiary in a lower-tax region. In this way, the profits generated by the software are concentrated in the low-tax jurisdiction, eroding the tax base that should have been taxed in the R&D location or the market location. Multinational enterprises can also achieve profit shifting through licensing of intangible assets. For instance, a multinational digital enterprise may license its core algorithms to subsidiaries located in different countries; by adjusting the licensing fees, it shifts profits from high-tax countries to low-tax countries. If the subsidiary in the high-tax country is charged an excessively high licensing fee, its profits decrease, reducing its taxable income, while the subsidiary in the low-tax country can retain more profit, thereby lowering the overall tax burden. The rise of digital platforms has made cross-border transactions more convenient and frequent. These platforms can provide services globally without needing to establish physical entities in every market. For example, some e-commerce platforms enable transactions between sellers and buyers around the world, yet the platform itself may only be registered in a few low-tax jurisdictions. Because the platform does not establish a permanent establishment in the location where transactions occur, under traditional tax rules, the tax authorities in the transaction location may be unable to tax the platform's profits, leading to local tax base loss. Digital platforms can also shift profits through segregating business functions and pricing strategies: the platform may allocate different business segments to different subsidiaries and then adjust internal transfer prices to transfer profits. For example, advertising services, technical support services, and other functions might be assigned to separate subsidiaries; by raising or lowering internal transaction prices, profits become concentrated in the low-tax jurisdiction subsidiary, thereby eroding the tax base of high-tax jurisdictions. Data is a significant asset in the digital economy, yet its value is not fully reflected in tax administration; enterprises, in collecting and using user data, can generate enormous commercial value, but there are no clear rules for the tax treatment of data itself. For example, social media platforms collect personal information and behavioral data from users and conduct targeted advertising, earning substantial profits. However, because data ownership and value are difficult to define, tax authorities find it hard to accurately tax the profits generated by data, resulting in tax base erosion. Multinational enterprises can also transfer profits through cross-border data flows: they can locate data storage and processing centers in low-tax jurisdictions, concentrating the value and profit generated by data in those regions, thereby reducing tax obligations in high-tax countries. For developing countries, due to relatively weak digital economy regulatory capabilities, the issue of tax base erosion brought by the digital economy may be more severe. Reduced tax revenues affect the government's ability to provide public services—such as education, healthcare, and infrastructure construction—potentially limiting such investments and impacting economic development and social stability. Digital economy enterprises reduce their tax burden through base erosion and profit shifting, while traditional enterprises, whose business models are relatively fixed, cannot engage in similar operations, resulting in unfair tax burdens between digital economy enterprises and traditional enterprises. This unfairness affects the fairness of market competition, hinders the development of traditional enterprises, and is not conducive to the healthy and sustainable development of the digital economy[6]. The global nature of the digital economy makes base erosion and profit shifting an international issue. Different countries have differing understandings and implementations of digital economy tax rules, easily leading to international tax disputes. For example, some countries, in order to protect their tax base, may adopt unilateral tax measures—such as imposing a digital services tax—potentially provoking countermeasures by other countries, thus undermining the international tax order and increasing compliance costs for multinational enterprises. The international community needs to strengthen cooperation and jointly formulate unified digital economy tax rules. For example, the OECD has been promoting reform of digital economy tax rules and proposed the "Two-Pillar" solution. The first pillar aims to reallocate taxing rights of multinational enterprises, ensuring that market jurisdictions have greater taxing rights over multinational enterprise profits; the second pillar sets a global minimum tax rate to prevent multinational enterprises from avoiding tax by shifting profits to low-tax jurisdictions. Through international cooperation, countries can reduce tax competition and disputes, preserving the international tax order. Each country needs to adjust domestic tax policies according to the characteristics of the digital economy. For example, it is necessary to refine the definition of permanent establishment to include virtual presence of digital economy enterprises, establish clear rules for the tax treatment of data—defining the value of data and the scope of taxation—and strengthen tax administration capacity for digital economy enterprises, improving tax authorities' informatization level and professional expertise. Multinational enterprises are required to disclose their global business activities and profit distribution more transparently. By establishing a sound information disclosure system, tax authorities can better understand enterprise operations, identify base erosion and profit-shifting behaviors, and thereby strengthen tax administration. For instance, some countries require multinational enterprises to submit country-by-country reports detailing their revenues, profits, assets, personnel, and other information in each jurisdiction.

3.2 Complexity of Data and Information

3.2.1 Challenges posed by massive data volumes

In the digital economy environment, the volume of enterprise transaction data grows explosively. Taking e-commerce platforms as an example, every day thousands of transactions occur, each containing rich information such as product details, transaction time, transaction location, and consumer information. For tax authorities to comprehensively collect this data requires consuming vast amounts of human, material, and time resources. At the same time, the cross-border and cross-regional nature of the digital economy means the sources of data are broad and dispersed; tax authorities must collaborate with relevant agencies in different regions and countries, coordinating data collection efforts, which further increases the difficulty of data collection. Massive data also requires sufficient storage space. Tax authorities' existing data storage systems may be unable to meet the demands of data storage in the digital economy era. As data volumes continue to increase, storage costs also rise, including expenses for purchasing and maintaining hardware equipment and the energy consumption of data storage. Moreover, the security of data is a critical concern: large volumes of stored data increase the risk of data breaches. If a data breach occurs, it not only harms taxpayers' interests but also undermines tax authorities' credibility. Faced with massive data, tax authorities' data-processing capabilities face a severe test. Traditional data-processing methods and technologies are inefficient when handling large-scale data, making it difficult to quickly and accurately extract useful information from massive datasets. For example, in conducting tax risk assessments, a large volume of transaction data must be analyzed and compared; if data-processing speeds cannot keep pace, tax administration will lag, preventing timely detection and prevention of tax risks.

3.2.2 Challenges arising from data complexity

Data in the digital economy originate from diverse sources—enterprise financial systems, e-commerce platforms, social media, etc.—and data from different sources exhibit various formats. For example, financial data may exist as spreadsheets, while social media data may be in the form of text, images, or videos. Tax authorities need to process and analyze these differently formatted data uniformly, requiring diverse data-processing technologies and tools, which increases the difficulty of data processing. Transactions in the digital economy often involve multiple parties and multiple stages, making the interrelationships among data complex. For instance, in the sharing economy model, a sharing platform may connect numerous service providers and consumers; during transactions, the flows of funds, logistics, and information intertwine to form complex network relationships. Tax authorities, to accurately understand these interrelationships among data and determine taxpayers' tax obligations, must possess strong data-analysis and data-mining capabilities. Due to the virtuality and concealment of the digital economy, the authenticity and reliability of data are hard to guarantee. Some enterprises may evade taxes by tampering with data or concealing transactions. For example, enterprises might inflate costs or understate revenue in financial statements or shift profits through related-party transactions. Tax authorities, in judging the authenticity and reliability of these data, need to invest more effort in investigation and verification, increasing the cost and difficulty of tax administration[7].

3.2.3 Suggestions for addressing the challenges of data complexity

Tax authorities should increase investment in infrastructure for data storage, processing, and analysis, build modern data centers, and adopt advanced big-data and cloud-computing technologies to enhance data-storage and processing capabilities. At the same time, they should strengthen data-security management and establish a sound data-security protection system to ensure the security of taxpayer data. Tax authorities should also strengthen data-literacy training for tax personnel and cultivate a group of interdisciplinary talents who understand both tax business and data analysis. Through professional training and practical exercises, tax personnel's capabilities in data collection, processing, analysis, and mining can be improved, enabling them to better address the challenges posed by data complexity in the digital economy era. The cross-border characteristic of the digital economy necessitates international cooperation and communication in tax administration. Tax authorities should actively participate in the formulation of international tax rules, strengthen information sharing and collaboration with tax authorities of other countries, and jointly tackle the tax administration challenges brought by the digital economy. For example, by signing bilateral or multilateral tax administration mutual assistance agreements, they can enhance cross-border data exchange and sharing, improving the efficiency of administering taxes on multinational enterprises. Tax authorities should accelerate the digital transformation of tax administration, using advanced information technology tools to achieve intelligent and automated tax administration. For example, developing intelligent tax administration systems that automatically collect, analyze, and provide risk warnings based on enterprise data can improve the efficiency and accuracy of tax administration. At the same time, tax authorities should strengthen information interfacing with enterprises, achieving real-time data sharing and reducing the time costs of data collection and processing. The massive volume and complexity of data in the digital economy bring many challenges to tax administration, but they also present opportunities for innovation. Tax authorities should proactively respond to these challenges, strengthen data infrastructure construction, cultivate high-quality data talent, enhance international cooperation and communication, and promote the digital transformation of tax administration to meet the development requirements of the digital economy era.

3.3 Lagging Administration Technologies

3.3.1 Challenges in data acquisition and integration

In the context of the digital economy's rapid development, existing tax administration technologies reveal significant shortcomings in many areas and cannot effectively address the new challenges posed by the digital economy. The business models of the digital economy result in transaction data being scattered across various digital platforms, social networks, and e-commerce systems. Tax authorities face many obstacles in acquiring these data; numerous digital platforms, for reasons of commercial interest and data security, are unwilling to proactively provide complete and accurate transaction data to tax authorities. For example, some cross-border e-commerce platforms possess vast amounts of transaction information, but due to international data privacy regulations and commercial competition factors, tax authorities find it very difficult to obtain comprehensive transaction records, resulting in many potential tax sources being beyond supervision. Even if tax authorities acquire partial data, data from different sources differ greatly in format, standards, and quality, making integration of these data a formidable task. For instance, data from online transaction platforms might be formatted entirely differently from the data in traditional enterprise financial systems, requiring tax authorities to invest extensive human, material, and time resources to clean, transform, and match data to ensure consistency and usability. These data-integration difficulties hinder tax authorities from comprehensively and accurately understanding taxpayers' operational status and tax-paying capacity.

3.3.2 Difficulties in transaction identification and tracking

In the digital economy, there are numerous virtual goods and service transactions—such as digital music, in-game virtual items, and virtual currencies. These virtual transactions often lack traditional physical forms and transaction vouchers, making it challenging for tax authorities to accurately identify their nature and amount. For example, some transactions of in-game items by players may occur solely through in-game virtual currency without clear invoices or contracts, making it very difficult for tax authorities to track these transactions and determine their taxable amounts. With the globalization of the digital economy, cross-border transactions are becoming increasingly frequent. Digital services can be transmitted instantly worldwide via the Internet, and the parties involved in transactions may be located in different countries and regions, making cross-border transaction tracking extraordinarily complex for tax authorities. For example, a foreign software company providing software services to domestic users through an online platform makes it difficult for tax authorities to accurately understand where the transaction took place, the identities of the transacting parties, and the flow of funds, thus complicating the determination of tax jurisdiction and the taxable amount and making international tax leakage likely.

3.3.3 Inadequate risk assessment and early-warning capabilities

Existing tax risk assessment models are mainly built on traditional economic models and cannot adapt to the characteristics of the digital economy. The business models, profit approaches, and financial conditions of digital economy enterprises differ significantly from those of traditional enterprises, and traditional risk-assessment indicators—such as debt-to-asset ratio and profit margin—lose applicability in the digital economy domain. For instance, some emerging sharing-economy platforms have asset structures that are primarily light-asset based, making traditional leverage indicators unable to accurately reflect their operational risks and tax-paying capacity. Tax authorities lack specialized risk-assessment models for the digital economy and cannot accurately identify the tax risks of digital economy enterprises. In the digital economy environment, enterprises' business activities change rapidly, and tax risks exhibit high uncertainty and concealment. Current tax-early-warning mechanisms mainly rely on ex-post data monitoring and analysis, making it difficult to provide timely warnings of potential tax risks. For example, some digital enterprises may hide profits and evade tax obligations through complex related-party transactions and tax-planning strategies, but tax authorities' warning systems often detect anomalies only after enterprises have completed transactions and reported taxes. By that time, tax revenue has already been lost, making it difficult to effectively prevent tax risks.

3.3.4 Challenges in information security and privacy protection

During the tax administration process, tax authorities need to collect and process vast amounts of taxpayer data, which include enterprise trade secrets and personal privacy information. With the development of the digital economy, cyberattacks and data breaches occur frequently, and tax authorities' data security faces severe threats. If a tax authority's information system is attacked and taxpayer data leaked, it not only harms taxpayers' interests but also severely impacts the credibility of the tax authority. For example, hackers might attack a tax authority's database, obtaining sensitive taxpayer information for illegal activities. In the digital economy era, taxpayers are increasingly concerned about personal privacy and data security. While tax authorities need to collect relevant taxpayer information during administration, they must also comply with strict privacy protection regulations. Effectively protecting taxpayers' privacy while meeting administration needs becomes a significant challenge for tax authorities. For instance, when tax authorities obtain taxpayers' digital transaction data, they must ensure that data usage complies with privacy protection rules and avoid excessive collection and misuse of taxpayer information, but achieving this balance in practice is often difficult. In summary, existing administration technologies exhibit clear deficiencies in data acquisition and integration, transaction identification and tracking, risk assessment and early warning, and information security and privacy protection, making it challenging to effectively address the challenges posed by the digital economy. Tax authorities need to accelerate innovation and upgrading of administration technologies to meet the needs of the digital economy's development.

4 THEORETICAL FOUNDATIONS FOR INNOVATION IN TAX ADMINISTRATION MODELS

4.1 Information Economics Theory

In tax administration, information asymmetry is a ubiquitous problem. Taxpayers generally know more about their own operating status, income levels, and taxpaying capacity than tax authorities do, and this information asymmetry can lead to adverse selection and moral hazard behaviors on the part of taxpayers. Adverse selection manifests when taxpayers conceal true tax-related information, choosing to underreport income or overstate costs to reduce their tax liabilities. Moral hazard refers to taxpayers, after paying taxes, engaging in tax evasion or other illegal behaviors due to lack of effective oversight. Such behaviors not only cause revenue loss but also undermine tax equity principles and disrupt the normal order of tax administration. For example, some small enterprises may conceal income by issuing no invoices or maintaining two sets of books, making it difficult for tax authorities to accurately grasp their real tax situation. Meanwhile, tax authorities face an informational disadvantage because their channels for obtaining information are limited, making it hard to conduct comprehensive and accurate oversight of all taxpayers.

Tax authorities can use modern information technology to broaden their information-gathering channels. On one hand, they can strengthen information sharing with departments such as industry and commerce, banks, and customs by building information-exchange platforms to obtain taxpayers' registration data, transaction records, import-export information, and more. For example, tax authorities could cooperate with banks to regularly obtain taxpayers' bank-account transaction data, thereby more accurately understanding the flow of funds and business activities of taxpayers. On the other hand, authorities can encourage taxpayers to proactively provide accurate tax information and grant certain tax incentives or rewards to those who truthfully report, thus improving taxpayer compliance. At the same time, they should strengthen the collection and use of third-party information—such as data provided by industry associations or accounting firms—to enrich the information resources available to tax authorities[8].

By applying data-mining and machine-learning techniques to the large volume of collected information, authorities can filter and analyze data to identify potential tax-risk points. By building tax-risk assessment models, they can quantitatively evaluate taxpayers' tax behaviors and assign risk levels. For instance, based on taxpayers' financial indicators and operational data, tax authorities can predict their taxpaying capacity and compare it with actual tax payments; any anomalies can trigger timely warnings. High-risk taxpayers can then be subject to targeted supervision and verification, improving the precision and effectiveness of tax administration. At the same time, by analyzing tax data, authorities can summarize weaknesses and problems in the tax-administration process, providing a basis for adjusting tax policies and optimizing administration models.

An effective information-incentive mechanism should be established whereby taxpayers who voluntarily disclose information and cooperate with tax authorities receive rewards—such as simplified filing procedures or access to tax-consultation services—while those who hide information or evade taxes face strict penalties, increasing the cost of noncompliance. Through such a clear system of rewards and punishments, taxpayers can be guided to comply consciously with tax laws and regulations, thereby raising overall compliance rates. It is also important to strengthen the construction of a tax-credit system by including taxpayers' credit information in the broader social-credit framework and linking it with credit information from finance, industry, and commerce. Taxpayers with good credit can receive more policy support and conveniences, while those with poor credit face joint penalties, creating a societal atmosphere in which everyone participates in tax administration.

By effectively obtaining, analyzing, and utilizing information, tax authorities can more accurately understand taxpayers' situations, reduce the frequency of on-site inspections, and lower administration costs. At the same time, authorities can use information technology to automate and make tax-administration processes more intelligent—such as by offering online filing and electronic payment—to increase processing efficiency and convenience for taxpayers. Information economics theory thus helps to address information asymmetry problems, enabling tax authorities to treat different taxpayers more fairly. By accurately assessing each taxpayer's capacity, authorities can ensure that every taxpayer bears tax liabilities commensurate with their actual ability, preventing unfair tax burdens. Based on information economics theory, tax administration can shift from the traditional "audit-based" model to a risk-management–oriented model, where authorities focus more on monitoring high-risk taxpayers to achieve precise administration. Meanwhile, using big data, cloud computing, and other technologies, authorities can develop personalized tax-administration services to meet different taxpayers' needs, thereby improving the quality and level of tax administration.

4.2 Behavioral Economics Theory

Behavioral economics, as a practical branch of economics, integrates behavioral analysis theory with economic operating rules, combining psychology and economic science to identify errors or omissions in contemporary economic models, thus amending mainstream economic assumptions about human rationality, self-interest, complete information, utility maximization, and consistent preferences. Traditional economics assumes that people are fully rational and always make optimal choices in decision-making[9]. However, behavioral economics, through extensive experiments and empirical research, finds that, in reality, people are often influenced by cognitive biases and emotional factors, so their decisions do not always align with the rational assumptions of traditional economics.

In traditional tax administration, it is usually assumed that taxpayers are fully rational and can accurately understand tax policies and conscientiously fulfill their tax obligations. However, behavioral economics research shows that when faced with complex tax regulations, taxpayers often have cognitive limitations. For example, many taxpayers may struggle to understand certain professional terms and complex calculation methods in tax laws, leading them to make errors or omissions when filing returns. Based on this, tax authorities can innovate their taxpayer service models. On one hand, they can simplify tax-filing procedures and forms, and use plain and easy-to-understand language and formats to explain tax policies to taxpayers. For instance, they can transform tax regulations into clear charts or videos and disseminate them widely through official websites and social media, helping taxpayers better understand and comply with tax policies. On the other hand, authorities can offer personalized tax guidance services. Based on each taxpayer's industry characteristics and business scale, they can provide targeted interpretations of tax policies and instructions for filing, reducing the risk of errors due to insufficient understanding.

Prospect theory is a key component of behavioral economics, which posits that people often focus more on avoiding losses than on acquiring gains, and their sensitivity to losses is greater than to gains. In tax administration, this means taxpayers' perception of penalties (losses) is stronger than their perception of benefits from tax incentives (gains). Tax authorities can use prospect theory to guide compliance: when publicizing tax policies, they should not only emphasize the benefits of lawful tax payment—such as good tax credit bringing more business opportunities—but also highlight the severe consequences of noncompliance, like hefty fines, late-payment penalties, and credit damage. Additionally, by intensifying punishment for tax-violation behaviors and raising the cost of illegality, taxpayers will be more cautious when weighing the risks of noncompliance. Furthermore, taxpayers who proactively correct tax violations can receive lighter penalties or partial waivers of late-payment charges, incentivizing positive behavior and compliance.
Behavioral economics research also finds that people's behavior is often affected by social norms. In tax administration, if a favorable social atmosphere of paying taxes is fostered—where taxpayers feel that paying taxes is socially recognized and that nonpayment will be socially condemned—this can promote cooperation among taxpayers and enhance compliance. Tax authorities can reinforce social norms by various means, such as conducting tax-credit rating exercises and publicly listing enterprises and individuals with high tax credit, awarding them honors and rewards as positive examples. Simultaneously, publicly disclosing those with poor credit pressures them to correct noncompliant behavior under societal scrutiny. In addition, authorities can use community outreach and school education to cultivate citizens' tax awareness and sense of responsibility from a young age, making tax payment a deeply ingrained social moral norm.
Mental accounting theory holds that people manage and make decisions by mentally categorizing funds from different sources and for different uses. In tax administration, taxpayers also have different mental perceptions of tax-related funds. Tax authorities can apply mental accounting theory to optimize tax-incentive mechanisms. For example, for corporate R&D expense super-deduction policies, instead of waiting to deduct incentives in the annual tax-reconciliation process, authorities can provide an immediate proportional deduction when enterprises incur R&D expenses, enabling enterprises to feel the benefit of tax incentives more quickly and improving their perception and enthusiasm. For individual income–tax special additional deductions, authorities can optimize filing processes and information systems so that taxpayers can more easily claim deductions and enjoy benefits, thereby increasing taxpayer satisfaction and compliance.
Applying behavioral economics theory to innovate tax administration models requires extensive taxpayer behavior data. However, obtaining comprehensive and accurate behavior data is challenging, and analyzing and mining such data requires specialized technical expertise and talent. Innovating tax policies based on behavioral economics often involves integrating multiple factors, making implementation complex. For example, when formulating personalized tax service policies, authorities must consider different taxpayers' diverse needs, placing higher demands on management and service capabilities. Creating a favorable social atmosphere for tax compliance and changing taxpayers' habits and mindsets cannot happen overnight; it requires long-term publicity and education, facing the challenge of slow shifts in social perceptions. Tax authorities should increase investment in data collection and management, building a comprehensive taxpayer information database. At the same time, they should actively introduce advanced data-analysis technologies and tools—such as big-data analytics and artificial intelligence—to enhance their capability to analyze and mine taxpayer behavior data, providing strong data support for innovating tax administration models. Tax authorities must also strengthen training for personnel, improving their understanding and application of behavioral economics theory. Through professional training courses and academic exchanges, tax staff can master the basic principles and methods of behavioral economics and apply them to actual tax administration work. Additionally, authorities should formulate long-term taxpayer publicity and education plans, continuously conducting outreach through multiple channels—such as public-service advertisements and tax-knowledge contests—to gradually change taxpayers' mindsets and habits, fostering a positive social atmosphere for tax compliance. Behavioral economics provides new perspectives and theoretical foundations for innovating tax administration models. By researching and applying relevant behavioral economics theories, tax authorities can better understand taxpayers' behavioral characteristics and decision-making processes, thereby formulating more scientific and effective tax policies and measures to improve tax administration efficiency and taxpayer compliance.

4.3 Big Data and Artificial Intelligence Theory

In tax administration, tax authorities face massive amounts of taxpayer data, including financial statements, invoice information, and transaction records. Big data technology can mine valuable information from these multi-source, heterogeneous datasets. For example, by mining an enterprise's invoice data, authorities can identify the enterprise's transaction counterparts, transaction frequency, and transaction amounts, thereby understanding the business scope and operating scale. Based on data-mining methods such as association analysis and clustering analysis, authorities can identify taxpayers' abnormal behaviors. For instance, by clustering financial indicators of enterprises in the same industry, authorities can group similarly performing enterprises together; if a particular enterprise's financial indicators differ significantly from its peers, it may indicate tax risk, and that enterprise can be flagged for close monitoring. Using time-series analysis and other data-mining techniques, authorities can predict future tax-revenue trends based on historical tax data. For example, by analyzing corporate income–tax revenue data in a given region over past years and combining it with local economic development plans and industrial policies, authorities can forecast income–tax revenue growth for the coming years, providing a basis for tax-administration decision-making[10].

Within tax authorities, siloed business systems and data barriers often exist between different internal systems and between tax authorities and other government departments (such as industry and commerce or customs). Big-data integration theory can consolidate these disparate datasets, breaking down information silos. For instance, by integrating tax-registration data with industry-and-commerce registration data, authorities can ensure the accuracy and consistency of taxpayer information, avoiding tax-administration loopholes caused by inconsistent data. By merging various types of data, authorities can build more comprehensive taxpayer profiles. For example, integrating enterprise financial data, social-security data, and customs import-export data enables more accurate assessments of an enterprise's operating status and taxpaying capacity, thus achieving more precise tax administration.

Every data point in big data may contain hidden value. In tax administration, analyzing large volumes of taxpayer data can reveal hidden tax-administration issues and potential sources of increased revenue. For instance, by analyzing e-commerce platform transaction data, authorities might discover emerging industries and new business-model blind spots in tax administration and adjust tax policies and measures promptly. Leveraging the value of big data can optimize tax-administration processes and improve efficiency. For example, by analyzing taxpayer filing data in real time, authorities can quickly identify filing errors and anomalies, automatically remind taxpayers to make corrections, reduce manual-review workloads, and improve the efficiency and quality of tax administration.

Machine-learning algorithms can build tax-risk assessment models based on historical tax data and taxpayer characteristics. For example, using algorithms such as logistic regression or decision trees to analyze taxpayers' financial indicators and tax-credit records can assess taxpayers' risk levels. Based on risk classifications, authorities can implement segregated management—focusing on monitoring and inspecting high-risk taxpayers. With machine-learning models continuously monitoring in real time, when a taxpayer's behavior becomes anomalous, the system can automatically issue an alert. For instance, if a company's number of issued invoices suddenly increases dramatically or its tax-burden ratio drops significantly, the system can promptly send out a warning to the tax authorities to investigate and verify, thereby preventing tax risks. Clustering algorithms in machine learning can automatically classify taxpayers. For example, based on characteristics such as industry type, operating scale, and tax credit, taxpayers can be grouped into different categories, enabling authorities to implement differentiated administration strategies and improve the precision and effectiveness of administration.

Tax policies and regulations are often highly specialized and complex, making them difficult for taxpayers to understand. Natural-language processing (NLP) technology can semantically analyze and interpret tax policies and regulations, presenting them to taxpayers in plain and easy-to-understand language. For example, using text-summarization techniques to extract key information from tax policies and push it to taxpayers via SMS or official WeChat accounts can increase taxpayers' awareness and compliance. Building NLP-based intelligent-consultation systems allows taxpayers to input questions by voice or text; the system can automatically recognize the inquiry and provide accurate answers. For instance, if a taxpayer asks about the eligibility and application process for a particular tax incentive, the intelligent-consultation system can quickly retrieve detailed answers from its knowledge base, improving the efficiency and quality of taxpayer services. NLP technology can also automate the recognition and processing of tax documents. For example, using optical-character-recognition (OCR) technology to convert paper tax documents into electronic text, then applying text classification and information-extraction techniques to automatically identify document types and extract key information can achieve automated processing of tax documents, reducing manual workload and error rates.

Knowledge graphs can connect and integrate various pieces of taxpayer information—such as basic information, tax records, and related enterprises—into a complete knowledge network. By analyzing the knowledge graph, tax authorities can discover potential relationships among taxpayers, for instance, equity relationships or business connections between enterprises. This helps authorities detect related-party transactions and transfer-pricing issues in tax administration and strengthen tax oversight over enterprise groups. Based on reasoning mechanisms powered by knowledge graphs, authorities can infer unknown information and potential tax risks from known taxpayer data and tax rules. For example, if a knowledge graph shows that a certain enterprise has close business dealings with several high-risk enterprises, tax authorities can infer that it may also pose tax risks, prompting focused attention and investigation. Knowledge graphs can support tax-authority decision making. When formulating tax-administration strategies, authorities can analyze information in the knowledge graph to understand the characteristics and tax-risk distributions of taxpayers across different industries and categories, thereby formulating more scientific and reasonable administration strategies and improving overall tax-administration effectiveness.

5 PRACTICE PATHS FOR INNOVATION IN TAX COLLECTION AND ADMINISTRATION MODELS

5.1 Building an Intelligent Taxation System

In the digital era, tax collection and administration face challenges such as massive amounts of data and complex business processes, and traditional administration models can no longer meet the needs for efficient and precise administration. By leveraging big data and artificial intelligence technologies to construct an intelligent taxation system, the goal is to achieve intelligence, automation, and precision in tax collection and administration, improving collection efficiency, reducing administration costs, enhancing taxpayer service quality, and strengthening the scientific basis and fairness of tax administration.

Tax authority internal system data: integrate taxpayer registration information, declaration information, invoice information, and other data from internal databases such as the Golden Tax System and the Tax Administration System. For example, using data interfaces to clean and uniformly format data from different periods and versions of the Golden Tax System to ensure data consistency and accuracy. External third-party data: establish data-sharing mechanisms with industries, commerce, customs, banks, and other departments to obtain taxpayer registration records, import-export transactions, and capital flow information. For example, collaborating with banks to obtain real-time information on taxpayer account fund changes to provide more comprehensive data support for tax base monitoring. Internet data: employ web-scraping technologies to collect publicly available information about taxpayers on the Internet, such as corporate news reports, product sales information, and social media activity, to assist tax authorities in understanding companies' operating conditions and market reputation. Formulate unified data standards and specifications to perform extract, transform, and load (ETL) operations on all collected data. For example, standardize taxpayer names and addresses provided by different departments to remove duplicates, errors, and incomplete data. Classify and encode data, establishing a data dictionary to facilitate subsequent data queries and analyses. For example, classify and encode invoice information by industry and invoice type to improve data retrieval efficiency. Through mining the correlations among different business datasets of taxpayers, uncover potential tax risks. For example, analyze the relationships among a company's sales data, cost data, and invoice data to determine whether the company is issuing false invoices or concealing income. Cluster taxpayers based on factors such as operating scale, industry characteristics, and tax credit to provide a basis for implementing differentiated tax administration strategies. For example, group small and micro enterprises in the same industry into one cluster and formulate targeted tax incentive policies and administration measures according to their characteristics. Use time-series analysis and other methods to forecast trends in tax revenue and tax base changes. For example, predict the growth trend of tax revenue in a given region over the next period to provide a reference for tax planning. Employ machine learning algorithms such as decision trees and neural networks to build tax-risk assessment models. By learning and training on historical data, the model can automatically identify taxpayers' risk levels and generate risk warning information. For instance, use a decision tree algorithm to analyze a company's financial indicators and operational behavior to assess the possibility of tax evasion. Natural language processing technology: apply it to tax consultation and policy interpretation. For example, develop an intelligent tax customer-service system that uses natural language processing technology to understand taxpayers' inquiries and provide accurate, timely responses. At the same time, perform semantic analysis on tax policy texts to extract key information and offer taxpayers clearer policy interpretations. Based on the risk warning information generated by the data analysis layer, tax authorities promptly take corresponding countermeasures. For low-risk taxpayers, issue risk notifications via SMS or email; for high-risk taxpayers, carry out special investigations and tax audits. For example, when the risk assessment model identifies that a company's value-added tax burden rate is significantly lower than the industry average, the system automatically issues a warning, enabling tax personnel to closely monitor and investigate that company. Provide customized tax services based on taxpayers' personalized needs and behavioral characteristics. For example, push suitable tax policies and tax-processing guides to taxpayers according to their historical filing records and preferences. At the same time, use artificial intelligence technology to automate tax processes—for instance, automatically filling out tax declaration forms and automatically auditing invoices—to improve tax-processing efficiency. Offer data support and analytical recommendations for tax authorities' administration decisions. For example, by analyzing tax data from different regions and industries, evaluate the implementation effects of tax policies to provide a basis for policy adjustments and optimization. Concurrently, use forecasting models to predict the demand for tax administration resources and allocate administration forces rationally[11].

The implementation steps for the intelligent taxation system are divided into five phases.Planning and Design Phase (Months 1–3):1.Establish a project team for building the intelligent taxation system, clarifying each member's responsibilities and division of labor.2.Conduct comprehensive requirements research, communicating with various business departments within the tax authority and taxpayer representatives to understand their functional requirements and expectations for the intelligent taxation system. 3. Develop the overall architecture and technical solutions for the smart tax system, defining its functional modules, data workflows, and technology selection.4.Develop a project implementation plan and schedule, defining tasks and milestones for each phase.

Data Integration and Platform Construction Phase (Months4–6):1.According to the data collection layer design, establish data-sharing mechanisms with each data provider and complete data collection and integration.2.Build a big data storage and processing platform—such as a Hadoop distributed file system and Spark computational framework—to provide strong computing and storage capabilities for subsequent data analysis.3.Develop data standardization and preprocessing tools to clean, transform, and load the collected data, establishing a unified data warehouse.

Algorithm Development and Model Training Phase (Months7 –9):1.Organize professional data scientists and algorithm engineers to develop big data analysis algorithms and AI models according to the design of the data analysis layer.2.Use historical data to train and optimize models, continuously adjusting model parameters to improve accuracy and reliability.3.Test and validate the developed algorithms and models to ensure their effectiveness in practical application.

System Launch and Trial Operation Phase (Months 10–11) 1. Deploy the completed intelligent taxation system into the production environment, performing final checks and tests before going live.2.Select certain regions or business segments for trial operation, collect user feedback and system operation data, and promptly identify and resolve issues in the system. 3. Based on trial operation results, optimize and adjust the system to ensure stability and reliability.

Full Promotion and Continuous Optimization Phase (Month 12 and beyond):1. Promote the intelligent taxation system nationwide, covering all tax departments and taxpayers.2.Establish system operation, maintenance, and monitoring mechanisms, regularly evaluate performance and data quality, and promptly address system failures and data anomalies.3. Continuously monitor developments in big data and AI technologies, introduce new technologies and algorithms, and upgrade and optimize the intelligent taxation system to adapt to the ever-changing needs of tax collection and administration.

Based on the macro environment of tax collection and administration and the micro-level subjects, and integrating technological innovation elements, construct a systematic foundational theoretical framework for tax collection and administration models in the digital economy era. This specifically includes: the mechanism by which the tax ecosystem in the digital economy era affects tax collection and administration models; the behavioral model theory of tax collection and taxpayer subjects; and the mechanism by which technological innovation impacts tax collection and administration models, as shown in Figure 2.

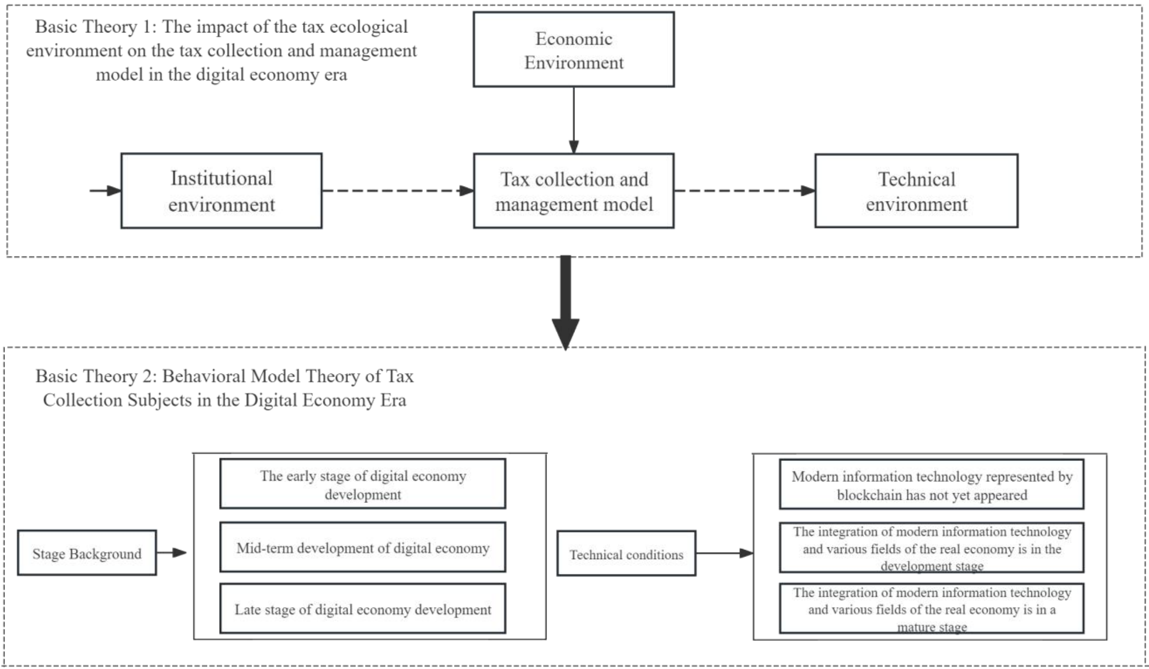

Figure 2 Basic theoretical Framework of Tax Collection and Management Model in the Digital Economy Era

Enhance collaboration with research institutions and enterprises in the fields of big data and artificial intelligence technologies, introducing advanced technologies and talent to ensure the technical sophistication and innovation of the smart tax system. Establish robust technology R&D and testing environments to thoroughly evaluate and validate new technologies and algorithms, guaranteeing their stability and reliability in practical applications. Strengthen data security and privacy protection through encryption, access control, and other measures to safeguard taxpayer data. Intensify training for tax officials in big data and AI technologies, elevating their technical application capabilities and data analysis proficiency—e.g., by organizing regular specialized training sessions and workshops with expert instructors. Recruit professionals in big data, AI, and software engineering to bolster the technical workforce of tax authorities, providing talent support for the construction and operation of the smart tax system. Implement incentive mechanisms to encourage active participation in building and innovating the smart tax system, recognizing and rewarding those who make outstanding contributions in technology application or operational innovation."Smart Taxation" is an innovative tax administration approach that fully adopts the "Internet+" mindset, transcending traditional service models by integrating tax modernization with mobile internet, big data, and cloud computing technologies. With the operation of the "Golden Tax Phase III System," tax authorities nationwide have begun exploring the "Internet + Taxation" concept, applying big data analytics, cloud computing, blockchain, and AI to tax administration, delivering an enhanced experience for taxpayers. According to survey results, 41.37% of respondents believe that "Smart Taxation" effectively "optimizes administration processes and significantly improves efficiency." Figure 3 illustrates the progress in tax administration transformation driven by "Smart Taxation" in surveyed regions.

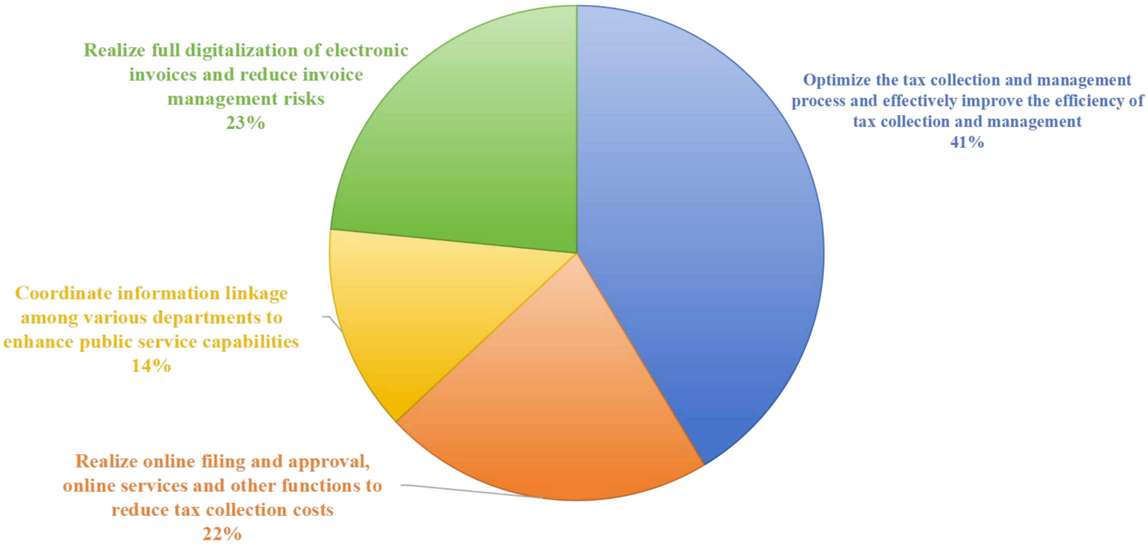

Figure 3 The Progress that "Smart Taxation" has brought about in the Transformation of the Tax Collection and Management Model in the Surveyed Areas

Develop and refine management systems and operational procedures related to the smart tax system, clarifying responsibilities and workflows for all departments and positions to ensure standardized system operations. Establish robust mechanisms for data sharing and exchange, defining rights and obligations of data providers and users to guarantee lawful and compliant data utilization. Strengthen coordination and collaboration with relevant agencies by instituting cross-departmental tax administration cooperation frameworks, collectively advancing the development and implementation of the smart tax system.

5.2 Strengthening International Cooperation

With the deepening of economic globalization, the business activities of multinational enterprises have become increasingly complex, and tax collection and administration face numerous challenges. Participating in the formulation of international tax rules is an important pathway for strengthening international cooperation and addressing the difficulties of cross-border tax administration. Currently, international tax rules are primarily led and formulated by international organizations such as the Organisation for Economic Co-operation and Development (OECD). China should actively participate in this process and fully express the interests and demands of developing countries during the formulation of international tax rules. For example, in the development of digital economy tax rules, the rapid growth of the digital economy challenges traditional principles for allocating tax jurisdiction. Multinational digital enterprises can conduct business without establishing physical entities, making it difficult for source countries to tax their income. As a major digital economy power, China should actively engage in the formulation of digital economy tax rules and promote the establishment of fair and reasonable digital economy tax administration regulations, thereby safeguarding the tax rights and interests of China and other developing countries in the digital economy field. At the same time, coordination and cooperation with other developing countries must be strengthened[12]. Developing countries often occupy a relatively weak position in cross-border tax administration and face issues such as tax base erosion. By enhancing cooperation among developing countries, they can form a united front and gain greater voice in the formulation of international tax rules. For example, a tax coordination mechanism for developing countries could be established to jointly study cross-border tax administration issues and propose solutions that align with the interests of developing countries.

Tax information exchange is a crucial aspect of international tax cooperation and plays a key role in combating cross-border tax evasion. China should further improve its tax information exchange mechanism and sign tax information exchange agreements with more countries and regions. Currently, China has established tax information exchange relationships with multiple countries and regions, but there remains room for improvement. The scope and depth of information exchange should be expanded to include not only taxpayers' basic information but also their transaction information, capital flow details, and so on, so as to obtain a more comprehensive understanding of the operations and tax compliance of cross-border taxpayers. Information technology should be leveraged to enhance the efficiency of tax information exchange. An efficient tax information exchange platform should be established to ensure rapid transmission and processing of information. For example, an intelligent tax information analysis system could be developed to automatically filter and analyze exchanged information, promptly identifying potential tax risks. Confidentiality in handling tax information must be reinforced. Tax information involves taxpayers' privacy and trade secrets, so confidentiality regulations must be strictly enforced. A comprehensive tax information confidentiality system should be formulated, and related personnel should receive education and management on confidentiality to prevent leaks of tax information.

International mutual assistance in tax administration is an effective means of resolving cross-border tax administration difficulties. China should actively engage in tax administration mutual assistance with other countries, including assistance in tax collection and service of tax documents. In terms of assisting with tax collection, when Chinese tax authorities discover that a cross-border taxpayer has taxes due and unpaid abroad, they can request assistance from the tax authorities of the partner country through the international mutual assistance mechanism. Meanwhile, China should actively cooperate with other countries' requests for mutual assistance in tax administration to jointly maintain international tax order. An international tax administration mutual assistance coordination mechanism should be established, clarifying the responsibilities and division of labor of each department in the mutual assistance process, and strengthening internal coordination and cooperation. At the same time, communication and collaboration with other countries' tax authorities should be enhanced by establishing regular exchange mechanisms to promptly resolve issues arising in mutual assistance for tax administration. Training for personnel involved in international tax administration mutual assistance should be strengthened. Tax officials should improve their professional level in international mutual assistance for tax administration, become familiar with the rules and procedures for international mutual assistance, and handle related matters proficiently.

Strengthening international cooperation to address cross-border tax administration challenges requires a large number of international tax professionals. In higher education, international tax curricula and instruction should be strengthened. Courses in international taxation, multinational enterprise tax planning, international tax treaties, and the like should be offered to cultivate students' global tax perspective and professional abilities. Practical teaching components should also be emphasized—through internships, case studies, and so forth—to improve students' hands-on skills. Tax authorities should bolster international tax training for in-service personnel. Regular international tax business training sessions should be organized, with domestic and international experts invited to lecture on the latest developments and administrative experiences in international taxation. Tax officials should be encouraged to participate in international tax seminars and training exchanges to broaden their global outlook. An international tax talent exchange mechanism should be established: outstanding tax officials should be dispatched to tax authorities in other countries for exchange and study to learn about their advanced tax administration experiences and technologies. Conversely, foreign tax experts could be invited to China to lecture and exchange ideas, promoting exchange and cooperation among international tax professionals.

5.3 Improving Laws and Regulations

Clarify the legality and legitimacy of innovations in tax collection and administration models so that innovative measures have legal backing, thereby reducing legal risks and uncertainties during the innovation process. Unified legal standards and norms can constrain the behaviors of tax authorities and taxpayers, ensuring that innovations in tax collection and administration models occur in a fair, just, and transparent environment. A stable legal environment can provide tax authorities and relevant departments with confidence and motivation to innovate and encourage them to actively explore new administration methods and technological means. With the rapid development of information technology, tax collection and administration models are also shifting toward digitalization and intelligence. Laws and regulations should adapt to this trend and clarify the legal status and application rules for digital administration methods such as electronic invoices, electronic filing, and big data analysis. Modern tax administration requires collaborative cooperation among tax authorities and other departments, such as banks, industry and commerce authorities, and customs, to share information and conduct joint enforcement. Laws and regulations should specify the responsibilities and cooperation mechanisms of each department to promote cross-departmental information flow and operational coordination. During the innovation of tax collection and administration models, the legitimate rights and interests of taxpayers must be fully protected. Laws and regulations should clarify taxpayers' rights and obligations, standardize tax authorities' enforcement procedures, and establish sound mechanisms for protecting taxpayers' rights and interests. The existing Tax Collection and Administration Law, Enterprise Income Tax Law, Individual Income Tax Law, and other relevant laws and regulations should be comprehensively reviewed to assess whether they meet the needs of innovating tax collection and administration models. Clauses that do not align with innovation requirements should be revised and improved in a timely manner. Laws and regulations should explicitly state the legal efficacy of digital vouchers such as electronic invoices, electronic contracts, and electronic signatures, and regulate digital tax filing and payment processes to provide legal support for digital administration. Relevant laws and regulations should be revised to clarify the scope, methods, and procedures for information sharing between tax authorities and other departments, ensuring the legality and security of information sharing. At the same time, taxpayer information confidentiality provisions must be strengthened to prevent information leakage and misuse.

With the widespread application of big data, artificial intelligence, and other technologies in tax collection and administration, specialized data management regulations need to be formulated to standardize the collection, storage, use, and security management of tax data, ensuring data quality and security. To strengthen collaborative cooperation between tax authorities and other departments, regulations on cooperative collaboration in tax collection and administration should be enacted, specifying each department's responsibilities and collaboration mechanisms and establishing sound cross-departmental information-sharing platforms and joint enforcement mechanisms. Special regulations for protecting taxpayers' rights and interests should be established to further clarify taxpayers' rights and obligations, institute robust mechanisms for taxpayer complaints, appeals, and remedies, and enhance the protection of taxpayers' legitimate rights and interests. For new issues and situations arising during the innovation of tax collection and administration models, timely interpretative legal documents should be issued to clarify legal application standards and operational norms, providing clear guidance for tax authorities and taxpayers. Through multiple channels, laws, and regulations governing taxation and policies on innovating tax collection and administration models should be widely publicized to increase legal awareness and compliance consciousness among tax authorities and taxpayers, thereby fostering a sound environment governed by the rule of tax law. Legal and regulatory training and guidance should be provided to tax officials and taxpayers to enhance their understanding and application of new laws and regulations, ensuring their effective implementation.

With the development of economic globalization, international cooperation in tax collection and administration has become increasingly important. China should actively participate in the formulation of international tax rules to promote the establishment of a fair, reasonable, and transparent international tax order. Tax administration mutual assistance agreements should be signed with other countries and regions to strengthen international tax cooperation and jointly combat international tax avoidance. At the same time, drawing on advanced international experiences, China should improve its own tax laws, regulations, and administration models. Strengthening exchanges and cooperation with other countries and regions in tax law and regulation, promoting international coordination of tax laws and regulations, and reducing international tax disparities and conflicts will provide multinational enterprises with a more stable and transparent tax environment.。

6 CASE STUDIES

6.1 Shenzhen Municipality's Digital Innovation in Tax Collection and Administration

As a pioneer city of China's reform and opening-up and an important highland of technological innovation, Shenzhen's economy has developed rapidly, with numerous market entities and complex business forms. The traditional tax collection and administration model could not meet the ever-growing demands of tax management. To adapt to the digital era, the Shenzhen tax authorities actively explored digital innovations in tax collection and administration. The Shenzhen tax authorities integrated internal tax administration data, taxpayer declaration data, invoice data, and so on, and at the same time achieved data sharing with external departments such as market supervision, public security, and banks, thereby building a massive big-data-based tax administration platform. By analyzing and mining this vast volume of data, they can accurately identify taxpayers' risk levels and focus supervision on high-risk taxpayers. For example, by analyzing invoice data, illegal activities such as issuing false invoices can be detected in a timely manner. To improve tax service efficiency and taxpayer satisfaction, Shenzhen launched intelligent tax services. Taxpayers can handle most tax-related business via mobile apps and online tax platforms, achieving "contactless" tax services. Additionally, an intelligent customer service system was introduced to provide taxpayers with 24-hour online consultation, quickly answering their queries. For instance, if a taxpayer encounters problems when filing a tax return, they can immediately seek help through intelligent customer service. Leveraging big data analysis and artificial intelligence technologies, the Shenzhen tax authorities achieved precise supervision of taxpayers. By monitoring taxpayers' operational and financial data in real-time, abnormal behaviors can be detected promptly, and risk warnings issued. For example, if a company's financial indicators show abnormal fluctuations, the system automatically issues a warning, allowing tax officials to investigate and verify the situation immediately[13].

The digital innovation practice has significantly improved the tax collection and administration efficiency of Shenzhen's tax authorities. Through big data analysis and intelligent tax services, manual operations and tax processing time have been reduced, thereby increasing work efficiency. For example, transactions that once required taxpayers to visit tax service halls can now be quickly handled online, greatly shortening the time spent on tax procedures. The precise supervision model enables tax authorities to more accurately identify taxpayers' risk points, improving the precision of tax administration. By promptly cracking down on illegal activities such as issuing false invoices, tax order is maintained and state tax revenues are safeguarded. Intelligent tax services and high-quality consultation services provide taxpayers with more convenient and efficient tax handling experiences, boosting taxpayer satisfaction. Taxpayers can conduct tax-related business anytime and anywhere, and their issues can be resolved promptly, reducing the cost of tax processing.

6.2 Haier Group's Tax Service Center Innovation

Haier Group, as a large multinational enterprise, operates across multiple industries and regions. As the company's scale expanded continuously, the traditional tax management model faced high management costs, low efficiency, and difficulties in controlling risks. To optimize tax management, Haier Group established a Tax Service Center. Haier's Tax Service Center organized and optimized tax processes for all subsidiaries within the group, formulating unified tax operation processes and standards. Through standardized processes, the efficiency and accuracy of tax handling were improved. For example, in invoice management, unified procedures for issuing, certifying, and reimbursement of invoices were established, reducing human error and risks. Centralizing all subsidiaries' tax-related business in the Tax Service Center allowed for professionalization and economies of scale in tax services. The Tax Service Center was staffed with professional tax personnel who were well-versed in tax policies and regulations, thereby improving the quality of tax handling. For example, in tax filing, the Tax Service Center handled filings uniformly, avoiding tax risks caused by subsidiaries filing late or inaccurately. Haier's Tax Service Center introduced advanced information management systems, achieving centralized management and sharing of tax data. Through these information systems, the tax status of each subsidiary could be monitored in real time, enabling timely identification of potential tax risks. For instance, by analyzing tax data through these systems, abnormal enterprise tax burdens and other issues can be detected immediately.

By unifying processes, centralizing handling, and implementing information-based management, Haier Group reduced tax management costs. The number of tax personnel across subsidiaries was reduced, work efficiency was improved, and costs from penalties due to improper tax handling were avoided. Standardized processes and professional handling significantly enhanced the efficiency and quality of tax management. Tax filings became timelier and more accurate, and tax risks were effectively controlled. Through real-time monitoring and data analysis, Haier Group could promptly identify and resolve tax risk issues, strengthening its tax risk control capabilities. At the same time, the Tax Service Center could stay abreast of changes in tax policies and provide enterprises with reasonable tax planning advice, thereby reducing the tax burden on the company.

6.3 United States: Application of Big Data and Risk Management in Tax Collection and Administration

The United States Internal Revenue Service (IRS) established a massive database that integrates taxpayers' filing information, financial transaction data, third-party reporting data, and other multi-source data. By applying advanced data analysis technologies, the IRS creates precise profiles of taxpayers' behaviors and risks. For example, machine learning algorithms analyze taxpayers' income sources, spending patterns, and historical tax records to identify potential tax fraud and evasion behaviors. The IRS uses risk assessment models to categorize taxpayers into low-risk, medium-risk, and high-risk groups based on their risk levels. For low-risk taxpayers, administrative processes are simplified and more self-service options are provided; for high-risk taxpayers, audits and investigations are intensified. This differentiated management approach improves administrative efficiency by concentrating limited resources on high-risk areas. Through big data analysis and risk management, the IRS can promptly detect and correct taxpayers' noncompliant behaviors, effectively improving tax compliance. Statistics show that in recent years the U.S. tax collection rate has increased, reducing tax leakage. Precise risk management allows the IRS to allocate administrative resources rationally, reducing unnecessary interference with low-risk taxpayers while intensifying enforcement against high-risk cases, thereby enhancing overall administration efficiency.

6.4 Australia: Innovation in Digital Services and Taxpayer Collaboration Models

The Australian Taxation Office (ATO) launched a powerful digital taxation service platform that allows taxpayers to conveniently complete tax filing, pay taxes, and query tax information. The platform also provides personalized tax advice and reminder services to help taxpayers better fulfill their tax obligations. The ATO proactively builds collaborative relationships with taxpayers and implements Tax Compliance Agreement (TCA) projects. For large enterprises and high-net-worth individuals, the ATO signs TCAs with them, clarifying the rights and obligations of both parties and jointly formulating tax compliance plans. This collaborative model encourages taxpayers to proactively disclose tax risks, improving transparency and efficiency in tax administration. The introduction of the digital service platform has greatly increased taxpayers' processing efficiency, reducing both time and cost for tax procedures. Taxpayers' satisfaction with tax services has significantly improved. Innovation in the taxpayer collaboration model motivates taxpayers to comply more proactively with tax regulations and actively cooperate with tax authorities. The implementation of TCAs has achieved good results, with participating enterprises' tax compliance notably increasing.

6.5 Singapore: Application of Artificial Intelligence and Blockchain Technologies in Tax Collection and Administration

The Inland Revenue Authority of Singapore (IRAS) introduced artificial intelligence technology and developed an intelligent tax assistant. Taxpayers can interact with the tax assistant via voice or text to obtain tax consultations and guidance. The tax assistant uses natural language processing technology to accurately understand taxpayers' questions and provide timely, accurate responses. IRAS is exploring the use of blockchain technology to establish an invoice management system. The distributed ledger feature of blockchain technology ensures the authenticity, integrity, and immutability of invoice information, effectively preventing invoice fraud and false issuance. Simultaneously, the blockchain invoice management system enables real-time sharing and circulation of invoice information, improving the efficiency of invoice management. The AI-powered tax assistant provides taxpayers with more convenient and efficient services, reducing the consultation burden on tax personnel. Taxpayers can access tax information anytime and anywhere, enhancing their tax service experience. The application of the blockchain invoice management system effectively curbs illegal activities in the invoice domain, enhancing the accuracy and reliability of tax collection and administration.

6.6 Comparative Analysis and Insights

The United States focuses on big data and risk management, integrating multi-source data for risk assessment and precise enforcement; Australia emphasizes building digital service platforms and innovating taxpayer collaboration models; Singapore leads in applying artificial intelligence and blockchain technologies, providing intelligent services to taxpayers and ensuring the security of invoice management. The U.S. risk management model highlights categorized management and differentiated supervision of taxpayers; Australia's collaborative model emphasizes building mutual trust with taxpayers to jointly promote tax compliance; Singapore's technology-driven model improves administrative efficiency and service quality through the deployment of cutting-edge technologies. These successful international case studies all demonstrate that innovation in tax collection and administration cannot be separated from advanced technological support. Each country should select appropriate technological means according to its national conditions and administrative needs, continuously enhancing the informatization and intelligence levels of tax collection and administration. At the same time, focusing on taxpayer service and collaboration, and improving taxpayers' compliance awareness and proactiveness, are crucial pathways for achieving tax administration objectives. By comparing and analyzing the above international examples, China can draw on their advanced experiences, combined with its own realities, to promote innovation in tax collection and administration, improve administrative efficiency and service quality, and foster healthy development of the taxation sector.

By conducting an in-depth analysis of a series of domestic and international tax collection and administration case studies, numerous valuable insights can be summarized for innovating tax collection and administration models. These insights encompass multiple dimensions, including concepts, technologies, systems, and cooperation, and are instrumental in constructing a more efficient, fair, and modern tax collection and administration system. Some successful overseas cases show that treating taxpayers as clients and conducting tax administration with a focus on meeting taxpayer needs can significantly improve taxpayers' compliance and satisfaction. Tax authorities should abandon the traditional "management-centered" mindset and adopt a "service-centered" approach—proactively understanding taxpayers' difficulties and demands, and providing more convenient, efficient, and personalized services. For example, the Australian Taxation Office offers customized tax guidance and consultation services for enterprises of different scales and industries, helping businesses better understand and fulfill their tax obligations. Simplifying tax procedures is key to reducing taxpayers' burdens and improving administrative efficiency. Domestic and international advanced experiences indicate that using information technology to optimize tax procedures—promoting online tax services, mobile tax services, and other diversified channels—allows taxpayers to "use the Internet more and travel less." For example, the IRS in the United States has established a comprehensive electronic tax system through which taxpayers can complete most tax-related matters online, greatly saving time and costs. Through analysis and mining of vast amounts of tax-related data, tax authorities can accurately identify taxpayers' risk conditions and implement precise supervision. For instance, Her Majesty's Revenue and Customs (HMRC) in the United Kingdom uses big data analysis to monitor taxpayers' transaction data and financial data in real time, promptly detecting abnormal transactions and potential tax risks, thereby enhancing the targeting and effectiveness of tax administration. Simultaneously, artificial intelligence can be deployed for intelligent consultation and automated approval processes to improve service efficiency and quality. Blockchain technology, with its decentralized, immutable, and traceable characteristics, holds broad application prospects in tax collection and administration; several countries have already begun exploring blockchain-based invoice management and tax audit innovations. For example, South Korea's tax authorities have piloted a blockchain-based electronic invoice project, ensuring the authenticity and integrity of invoice data and effectively preventing invoice fraud and tax evasion. A sound legal and regulatory framework is the foundation and guarantee for tax collection and administration, and should draw on foreign experiences while being tailored to China's circumstances[14]. Tax laws and regulations should be updated and improved in a timely manner to clarify responsibilities and powers in tax collection and administration, and to standardize administrative procedures and enforcement behaviors. For example, Japan has established a relatively comprehensive tax legal system that makes detailed provisions for every link in tax collection and administration, providing strong support for law-based administration by tax authorities. Strengthening supervision and restraint over tax enforcement is an important measure to ensure fairness and justice in tax collection and administration. A sound enforcement supervision mechanism should be established, with both internal and external oversight, to prevent abuse of power and unjust enforcement. For instance, Germany's tax authorities have set up dedicated supervisory bodies to oversee the actions of tax enforcement officers throughout the process and to promptly correct and handle any identified issues. Tax collection and administration involve multiple departments, so enhancing collaboration and information sharing among departments is crucial. Successful practices in some domestic regions show that establishing cross-departmental collaboration mechanisms in tax collection and administration—achieving real-time information sharing and operational coordination among tax authorities, industry and commerce authorities, and banks—can effectively improve administration efficiency and close tax loopholes. For example, Shenzhen has built a multi-department joint tax administration information-sharing platform, enabling real-time sharing of enterprise registration, tax filing, and capital flow information, thus providing strong support for tax collection and administration. In the context of economic globalization, tax administration issues of multinational enterprises have become increasingly prominent. Strengthening international cooperation in tax collection and administration and jointly combating international tax avoidance is an inevitable requirement for safeguarding national tax rights and interests. China should actively participate in the formulation of international tax rules, strengthen cooperation with other countries and regions in tax collection and administration, and engage in tax information exchange and cross-border mutual assistance in tax administration. For example, the OECD's Base Erosion and Profit Shifting (BEPS) Action Plan provides an important framework and guidance for countries to strengthen international tax cooperation. The complexity and professionalism of tax collection and administration work demand that tax personnel possess solid professional knowledge and skills. Professional training for tax officials should be intensified to improve their tax business capabilities, information technology application skills, and data analysis abilities. For instance, the Singapore Tax Academy offers systematic professional training courses in areas such as tax policy, administrative regulations, and information technology, continuously enhancing tax personnel's comprehensive quality. Tax officials should be encouraged to cultivate an innovative mindset and actively explore new administration methods and technological means. An innovation incentive mechanism can be established to recognize and reward units and individuals who have achieved outstanding results in tax collection and administration innovation, fostering a positive atmosphere for innovation. In summary, domestic and international tax collection and administration case studies provide China with abundant experiences and insights for innovating tax collection and administration models. China should combine these advanced practices with its national conditions and continuously advance innovation and improvement in tax collection and administration models to meet the new requirements of economic and social development, enhance the quality and efficiency of tax collection and administration, and provide strong support for stable growth of state fiscal revenue and healthy socioeconomic development.

7 CONCLUSION

This paper focuses on issues related to tax collection and administration models. Through in-depth research and analysis of tax collection and administration theory, current domestic and international models, and practical case studies, the following main research conclusions are drawn, while fully emphasizing the importance of innovating tax collection and administration models. Although traditional tax collection and administration models have played a role in long-term practice, their limitations have become increasingly apparent with rapid socioeconomic development. In terms of administrative methods, they have relied primarily on manual operations and exhibit low levels of informatization, resulting in low administrative efficiency and difficulty in handling massive tax data and complex business processes. For example, tax personnel must spend substantial time collecting, organizing, and reviewing paper documents, which not only increases workload but also easily leads to human errors. In terms of enforcement strength, the traditional model relies on ex-post inspections and spot checks, lacking real-time monitoring and dynamic management of taxpayer behavior, which causes a lag in tax collection and administration and makes it difficult to effectively prevent tax risks and combat tax evasion. Moreover, under the traditional model, information sharing between tax authorities and other departments is poor, creating information silos that prevent full integration of social resources for comprehensive tax governance, leading to higher administrative costs and suboptimal results. With the rapid advancement of information technology and the widespread application of emerging technologies such as big data and artificial intelligence, innovative tax collection and administration models have emerged. These innovative models place informatization at the core, establishing intelligent tax collection and administration systems that achieve automated collection, analysis, and processing of tax data, thereby greatly improving administrative efficiency. For example, big data analysis technology can be used to create precise profiles of taxpayers' operating conditions and tax records, promptly identifying potential tax risk points and providing strong support for precise supervision by tax authorities. Innovative models emphasize a taxpayer-centric approach, focusing on providing personalized and convenient tax services. By building online tax platforms, mobile tax terminals, and other diversified channels, taxpayers can handle various tax-related business anytime and anywhere, reducing both time and cost and increasing taxpayer satisfaction. In addition, innovative models promote information sharing and collaborative cooperation between tax authorities and other departments, optimizing the allocation of social resources and forming a powerful synergy for comprehensive tax governance. Through research on advanced international tax collection and administration models, we find that countries such as the United States and Australia have accumulated rich experiences in the informatization of tax collection and administration, risk management, and taxpayer services. For example, the United States has established a comprehensive tax information management system that achieves nationwide centralized management and sharing of tax data; Australia has adopted advanced risk management models to categorize and grade taxpayers for management, improving the utilization efficiency of administrative resources. Simultaneously, some domestic regions are actively exploring innovations in tax collection and administration models and have achieved significant results. For instance, Shanghai and Shenzhen have carried out intelligent tax construction, employing blockchain, artificial intelligence, and other technologies to enhance the intelligence level of tax collection and administration and optimize the business environment for taxation. These domestic and international innovative practices provide valuable references and experiences for China to comprehensively promote innovation in tax collection and administration models. Innovating tax collection and administration models is an inevitable requirement for adapting to new socioeconomic development contexts. With deeper economic globalization and the vigorous rise of the digital economy, enterprises' business models and transaction methods have become increasingly complex and diverse, and traditional tax collection and administration models can no longer meet administrative needs. Innovative tax collection and administration models can effectively respond to new challenges brought by economic development and ensure stable growth of tax revenue. Innovation in tax collection and administration models is a key measure to improve the efficiency and quality of tax collection and administration. By introducing advanced technological means and management concepts, innovative models can achieve automated, intelligent, and precise tax collection and administration, reduce manual intervention and errors, enhance administrative efficiency and quality, and lower administrative costs. Innovation in tax collection and administration models is an important pathway to optimize the business environment for taxation and improve taxpayer satisfaction. Innovative models, centered on taxpayers, provide more convenient, efficient, and personalized tax services, which enhance taxpayers' compliance and satisfaction and foster harmonious tax administration–taxpayer relationships. Innovation in tax collection and administration models is an essential component of advancing the modernization of the national governance system and governance capacity. Taxation serves as the primary source of state fiscal revenue and an important tool of macroeconomic regulation; thus, innovating its collection and administration models is crucial for improving state governance capacity and achieving sustainable socioeconomic development. In conclusion, innovation in tax collection and administration models carries significant practical and far-reaching strategic importance. We should fully recognize the limitations of traditional models, actively learn from advanced domestic and international experiences, and accelerate the promotion of innovations in tax collection and administration models to adapt to new socioeconomic development contexts and requirements.

COMPETING INTERESTS

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

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SERVICE QUALITY IMPROVEMENT STRATEGIES FOR RAIL TRANSIT STATIONS BASED ON PASSENGER EXPERIENCE

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Abstract: With the rapid expansion of urban rail transit, station service quality has become an important issue for improving overall operational efficiency and passenger travel experience. This study focuses on the service quality issues of rail transit stations during peak hours, analyzing factors such as passenger flow congestion, inadequate facility capacity, delayed information dissemination, and security management. Through both quantitative and qualitative analysis, the study identifies weak points in station services and proposes multi-dimensional improvement strategies, including passenger flow diversion, facility optimization, introduction of intelligent devices, and upgrades to the information release system. The research results indicate that implementing these optimization measures can significantly improve station throughput efficiency, reduce passenger waiting times, and enhance the overall passenger travel experience. Furthermore, this study provides valuable experience for other urban rail transit stations and contributes to the sustainable development of rail transit systems.
Keywords: Urban rail transit; Service quality; Passenger flow management; Facility optimization; Information release; Peak hours

1 INTRODUCTION

1.1 Research Background

With the acceleration of urbanization and the increasing demand for transportation in densely populated areas, rail transit has become a core component of the public transportation system in many cities[1-4]. Rail transit offers advantages of efficiency, environmental friendliness, and convenience, and especially in large cities, it has become a vital tool for alleviating traffic congestion and reducing carbon emissions. However, with the rapid expansion of rail transit, the service quality of stations has increasingly revealed issues that need to be addressed, especially during peak hours when the operational capacity of stations faces significant pressure. Entrance and exit points, transfer corridors, and security check areas often become bottlenecks during peak periods, as facility capacity and passage efficiency are insufficient to meet the growing passenger demand[5-7].

Improving station service quality not only affects passengers' travel experience but also has a profound impact on the overall operational efficiency and safety of the rail transit system. During peak hours, the high passenger volume causes station facilities to become overloaded, leading to phenomena such as long queues and delays, which negatively affect overall operational efficiency and passenger satisfaction. Therefore, optimizing the service quality of rail transit stations, especially during peak hours, has become an important issue in the field of transportation management[8-10].

1.2 Research Objectives and Significance

The primary goal of this study is to analyze the service quality issues faced by rail transit stations during peak hours and propose practical improvement strategies. By studying the operational status of a specific rail transit station, this research identifies the weak points in the current services and provides targeted optimization proposals aimed at improving the station's passenger flow management capabilities, facility passage efficiency, and overall information release and security management. The specific objectives include:

1. In-depth analysis of the current service situation at the station, identifying the main problems during peak hours;
2. Proposing multi-dimensional optimization strategies, including passenger flow diversion, facility optimization, and information management;
3. Evaluating and verifying the feasibility and effectiveness of these strategies in improving station service quality.

This study not only provides concrete optimization suggestions for a specific station but also offers practical experience for rail transit systems in other cities, particularly in balancing passenger flow with facility capacity during peak hours. The results of this research contribute to improving the operational efficiency of urban rail transit and enhancing passengers' travel experience, providing theoretical support and practical guidance for the sustainable development of rail transit systems.

1.3 Research Methodology

This study combines both quantitative and qualitative analytical methods to systematically investigate the service quality of rail transit stations. By collecting historical passenger flow data, facility usage information, and passenger feedback, the study identifies the current issues in service quality. Based on existing research findings both domestically and internationally, a series of targeted optimization strategies are designed to improve station operational efficiency and passenger satisfaction.

Data analysis includes detailed examination of various service indicators, such as passenger flow, facility passage capacity, and queue waiting times, to reveal the key factors affecting service quality. By establishing simulation models, the study evaluates the effects of different optimization plans on improving station service quality. Furthermore, passenger feedback is gathered through surveys and interviews to further understand passengers' evaluations of station services and refine strategies based on their feedback.

Finally, through data validation and the evaluation of actual operational effects, this study will determine the feasibility and implementation effectiveness of the proposed optimization strategies, ensuring that the solutions achieve significant results in practical application.

2 ANALYSIS OF STATION SERVICE STATUS

2.1 Station Overview

The rail transit station analyzed in this study, located at a critical transportation hub, is situated at the intersection of several important lines. The station is equipped with multiple entrances and exits, security check devices, automatic ticket vending machines, entry and exit gates, escalators, and other facilities. The daily passenger flow is approximately 80,000, and during peak hours, the station's entry and exit flow increases significantly, reaching 12,000 to 15,000 passengers. The station's facilities are relatively well-equipped, but with the increase in passenger volume, some facilities fail to meet demand during peak times, leading to congestion and passenger delays.

The station's location plays an important role as a transportation hub and is connected to multiple bus lines, making it a crucial interchange point for passengers traveling to and from the city center. However, as passenger volume continues to increase, the passage capacity of existing facilities gradually reveals its limitations. Particularly during peak hours, some key facilities (such as entrance and exit points, transfer corridors, and security check devices) fail to cope effectively with the surge in passenger flow. To address this situation, it is necessary to analyze the station's passenger flow characteristics and facility operational efficiency to provide data support and theoretical basis for subsequent optimization strategies.

2.2 Passenger Flow Characteristics Analysis

The passenger flow characteristics of the station show significant temporal fluctuations, especially during peak hours, when the sharp increase in passenger flow puts tremendous pressure on station facilities. By analyzing the station's entry and exit passenger flow data, it is found that passenger flow varies greatly at different times, with peak hour flow primarily concentrated at critical locations such as entry and exit points, transfer corridors, and security check areas. These areas experience particularly severe congestion.

From the daily passenger flow distribution, the station's passenger flow is relatively stable, but during the morning peak (7:00 – 9:00) and evening peak (17:00 – 19:00), passenger flow reaches its maximum. Especially at the entry points and transfer areas, passenger delays are significant, leading to decreased travel efficiency. The passenger flow issues during peak hours can be categorized into the following aspects:

1. Entry and Exit Points: During peak hours, congestion at the entry and exit points is particularly severe, as the passenger flow at these points increases sharply, causing long queues, increased waiting times, and impacting the efficiency of passenger transfers and flow.
2. Transfer Areas: Transfer corridors are one of the most critical areas of the station. Especially during peak hours, passengers tend to concentrate in limited corridors, leading to long queues and congestion.
3. Security Check Devices: During peak periods, the number and processing capacity of the station's security check devices are insufficient to meet the surge in passenger flow, resulting in long waiting times at security checks, which further impacts overall passage speed.

Table 1 Distribution of Passenger Flow at the Station (By Time Period)

Time Period	Average Inflow (Passengers)	Average Outflow (Passengers)
Morning Peak (7:00-9:00)	12,000	13,500
Evening Peak (17:00-19:00)	14,500	15,000
Weekend (12:00-14:00)	16,000	14,500
Holiday (10:00-12:00)	18,000	17,000

As shown in Table 1, the analysis of passenger flow data across different time periods reveals a significant increase in passenger volume during morning and evening peak hours. Notably, there is greater fluctuation in passenger flow during holidays and weekends, placing higher demands on the station's facility configuration and operational management.

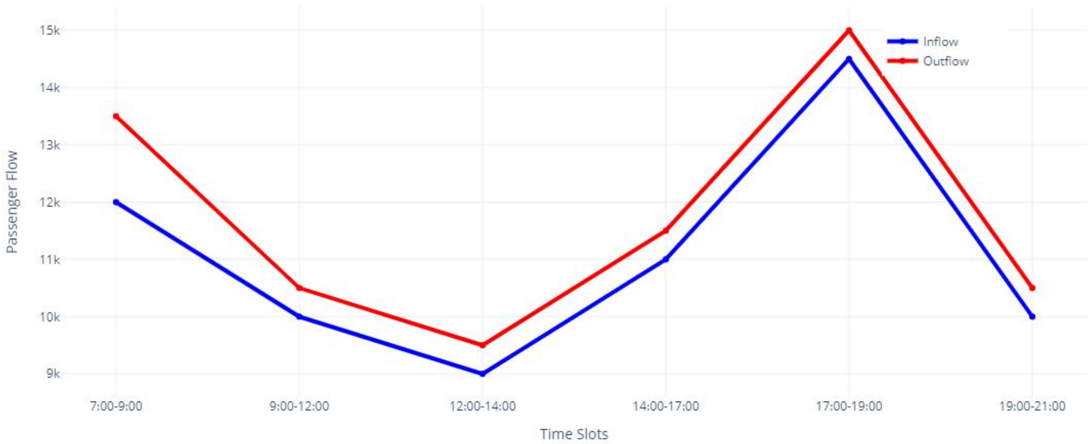

Figure 1 Fluctuation of Passenger Flow and Distribution of Congested Areas at the Station

The figure 1 shows the fluctuation of passenger flow at the station during different time periods, highlighting the congestion at key areas such as the entrance, transfer area, and security check during peak hours. It is clearly visible that the passenger flow pressure at the entry and transfer corridors is most prominent, especially during peak hours.

2.3 Service Quality Issues

Through an in-depth analysis of the station's current status, we identified several key issues affecting service quality during peak hours:

1. Passenger Flow Congestion: The station's main entry and exit points, transfer corridors, and security check areas face tremendous passenger flow pressure during peak hours. Due to the station's facilities not being adequately designed to handle peak hour demands, congestion often occurs at these areas, leading to severe passenger delays and queuing, which further impacts overall passage efficiency.
2. Insufficient Facility Capacity: The number of facilities such as automatic ticket vending machines, security devices, and entry/exit gates are insufficient during peak hours, unable to meet the surge in passenger demand. Particularly in the security check and ticketing areas, the limited capacity of these facilities restricts the quick flow of passengers, causing long waiting times and negatively affecting passenger experience.
3. Delayed Information Release: The station's real-time information release system fails to provide passengers with necessary information in a timely manner, especially during peak times and emergencies. Passengers are unable to obtain critical data such as train schedules or transfer information. The failure to update information promptly causes passenger anxiety and unnecessary waiting, further reducing travel efficiency.
4. Security Management Issues: During peak hours, the station's security checks face immense pressure. Due to limited numbers of security devices and insufficient staffing, the efficiency of security checks is low, leading to long waiting times for passengers. Particularly during busy periods, the security check process fails to operate efficiently, exacerbating passenger delays.

Table 2 Summary of Service Quality Issues at the Station

Service Issue	Influencing Factor	Impact Result
Passenger Flow Congestion	Insufficient facility capacity, unreasonable passageway setup	Passenger delays during peak hours, overall passage efficiency decreases
Insufficient Facility Capacity	Inadequate number of devices, unreasonable facility layout	Long waiting times for security checks and ticketing, affecting passenger experience
Delayed Information Release	Incomplete real-time information release system	Passengers cannot obtain timely train information, affecting travel efficiency
Security Management Issues	Insufficient staffing, inefficient security check processes	Extended security check times, potentially affecting station safety

As shown in Table 2, the main issues affecting station service quality are identified, along with detailed explanations of their influencing factors and consequences. Through in-depth analysis of these problems, the critical aspects in need of urgent improvement within station services have been clearly defined.

By analyzing the station's current service status, we have clearly identified the main issues affecting service quality during peak hours, including passenger flow congestion, insufficient facility capacity, delayed information release, and security management. The concentration of passenger flow has led to facility overload, especially in critical areas such as transfer corridors and security check points, resulting in passenger delays and queuing, which affects overall operational efficiency. These issues not only reduce the passenger travel experience but also increase the operational pressure on the station.

To effectively address these problems, this study will propose optimization strategies based on the identified issues, aiming to improve service quality at the station during peak hours, optimize facility configuration and passage capacity, enhance passengers' travel experience, and provide references for future rail transit stations.

3 SERVICE QUALITY IMPROVEMENT STRATEGIES

Based on the analysis of the station's current service status, the service quality during peak hours is influenced by multiple factors, particularly in areas such as passenger flow management, facility capacity, information release, and security management. To solve these problems and improve the station's service quality, this study proposes the following series of optimization strategies. These strategies aim to improve the station's operational efficiency, enhance passengers' travel experience, and provide references and insights for other similar stations.

3.1 Optimizing Passenger Flow Organization

Optimizing passenger flow organization is the primary strategy for improving station service quality. Especially during peak hours, proper passenger flow guidance and diversion can effectively alleviate congestion at the station and enhance overall passage efficiency. Specific optimization measures include:
Setting Up Diverting Channels: During peak hours, additional temporary channels should be set up to divert passenger flow from the main entry and exit points to alternate routes, avoiding excessive congestion in certain areas. Adding extra channels at entry points and transfer areas can effectively alleviate passenger flow pressure.
Optimizing Transfer Corridor Design: As transfer corridors are key parts of the station, they must handle a large passenger flow during peak hours. Increasing the number of transfer corridors, widening their width, and reasonably setting passenger flow direction can effectively reduce queuing times during transfers and relieve congestion in transfer areas.
Increasing Staff for Guidance: During peak hours, increasing the number of staff, especially in high-traffic areas such as entry points, transfer corridors, and security check areas, is essential. Staff can guide and direct passengers on-site to help them flow smoothly, ensure orderly passage, and reduce waiting times.

Figure 2 Diagram of Passenger Flow Diversion Plan

The figure 2 shows a plan for alleviating passenger flow pressure at the station during peak hours by setting up diversion channels and optimizing the design of transfer corridors. Through this approach, the station can effectively divert passenger flow for entry, exit, and transfers, reducing congestion.

3.2 Enhancing Facility Passage Capacity

Improving the passage capacity of station facilities is key to solving congestion problems during peak hours. By increasing facility capacity and introducing intelligent systems, the station's passenger flow handling capability can be significantly enhanced. Specific optimization measures include:
Increasing Security Check Devices and Ticket Machines: The current number and passage capacity of security check devices and automatic ticket vending machines are insufficient during peak hours. Adding more security channels, automatic ticket machines, and manual ticket windows can maintain high passage efficiency during passenger surges and reduce waiting times.
Introducing Intelligent Security Check Devices: Introducing intelligent security check devices such as facial recognition and QR code scanning can improve security check passage capacity, reduce bottlenecks in manual security checks, and enhance overall security check efficiency.
Improving Vertical Transportation Capacity: During peak hours, vertical transportation (such as escalators and stairs) often becomes a bottleneck for passenger flow. Installing additional escalators and optimizing their operation times (e.g., increasing the number of escalators in operation during peak hours) can significantly improve the efficiency of passengers moving up and down between levels.

Table 3 Comparison of Facility Optimization Before and After

Facility Type	Passage Capacity Before Optimization (Passengers/Hour)	Passage Capacity After Optimization (Passengers/Hour)
Entry Gates	12,000	18,000
Security Check Devices	2,500	4,500
Ticket Vending Machines	1,800	3,000
Escalators	5,000	8,000

As shown in Table 3, measures such as increasing the number of facilities and introducing intelligent security check equipment can significantly improve the passage capacity of various station facilities. Especially during peak hours, the enhancement of facility capacity will effectively reduce passenger waiting times and delays.

3.3 Security Management and Emergency Response

Security management during peak hours not only affects passengers' travel experience but also directly impacts the station's safety and operational efficiency. To ensure that the station's security management can efficiently cope with the pressures during peak hours, the following strategies are proposed:

Increasing Security Personnel: During peak hours, the number of security personnel should be increased, especially in key areas of the station such as entry points and transfer corridors. By adding more security staff, the efficiency of security checks can be effectively improved, reducing passenger waiting times.

Intelligent Security Check Systems: Introducing intelligent security devices, such as facial recognition and smart metal detectors, can enhance security check efficiency and reduce passenger queuing times. These devices will allow the station to improve security processing capacity without significantly increasing labor costs.

Establishing an Emergency Response Mechanism: To address emergencies during peak hours (such as equipment malfunctions or accidents), the station should develop a comprehensive emergency response plan. Through simulation drills and emergency exercises, the emergency handling capabilities of security and other staff can be improved, ensuring that the station can respond quickly and effectively to emergencies.

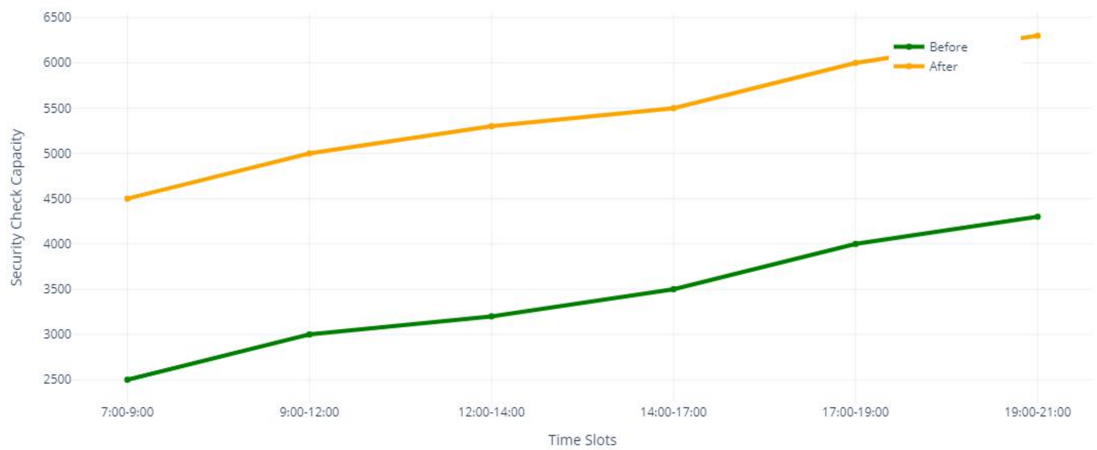

Figure 3 Comparison of Security Check and Emergency Response Optimization Before and After

The figure 3 shows the comparison of the security check and emergency response systems before and after optimization. Increasing security check devices and personnel will effectively improve security check efficiency, reduce waiting times during peak hours, and enhance the station's emergency response capabilities.

3.4 Enhancing Information Release and Passenger Guidance

Optimizing the information release system is crucial to improving passengers' travel experience. The station should strengthen the information release system to ensure that passengers can access accurate travel information at any time, thus improving overall travel efficiency. Specific optimization measures include:

Real-Time Information Release: Install additional electronic displays in the station to promptly update key information such as train schedules, passenger flow data, and equipment malfunctions. By providing real-time information, passengers can adjust their travel plans according to the situation, reducing unnecessary waiting times.

Mobile Application Support: Develop a dedicated station app that provides real-time train schedules, passenger flow monitoring, travel route planning, and other functions to help passengers obtain all the necessary information before their trip.

On-Site Guidance Personnel: Increase the number of staff at congested areas and key locations within the station to provide on-site guidance, helping passengers quickly find the appropriate passageways and routes, and reducing delays and waiting times.

Table 4 Comparison of Information Release Optimization Before and After

Information Release Method	Release Frequency Before Optimization	Release Frequency After Optimization	Optimization Effect
Electronic Displays	Updated once per hour	Updated every 10 minutes	Improved information accuracy and timeliness
Mobile Application Update Frequency	Updated once per day	Real-time updates	Enhanced passengers' ability to plan their travel
On-Site Guidance Personnel Configuration	1 person per area during peak hours	3 people per area during peak hours	Improved passenger experience in congested areas

As shown in Table 4, the optimization of the information release system will significantly enhance passengers' access to travel information, reduce their anxiety, and help them plan their trips more efficiently.
The service quality improvement strategies proposed above focus on the key issues faced by the station during peak hours. These strategies include optimizing passenger flow organization, enhancing facility passage capacity, strengthening security management and emergency response, and improving the information release system. The implementation of these strategies will effectively alleviate congestion during peak hours, enhance passengers' travel efficiency, and subsequently improve the overall operational efficiency and passenger satisfaction of the station. As these optimization measures are implemented, the station's service quality will be significantly improved, providing strong support for the sustainable development of the urban rail transit system.

4 CONCLUSION

This study takes a specific urban rail transit station as a case study. Through an in-depth analysis of the station's service status during peak hours, the study identifies key issues affecting service quality, including passenger flow congestion, insufficient facility capacity, delayed information release, and security management. In response to these issues, this study proposes a series of feasible service quality improvement strategies, including optimizing passenger flow organization, increasing facility capacity, introducing intelligent equipment, and improving security management and information release systems.
The research results indicate that the station's service quality during peak hours can be significantly improved through multi-dimensional strategic optimization. Firstly, by rationally diverting passenger flow and optimizing transfer corridors, congestion at entry points and transfer areas can be effectively alleviated. Secondly, increasing the number of facilities, especially security check devices and automatic ticket vending machines, will enhance the station's passage capacity during peak hours and reduce passenger waiting times. Thirdly, the introduction of intelligent security check devices significantly optimizes the security check process and improves overall operational efficiency. Furthermore, upgrading the information release system and establishing an emergency response mechanism also effectively reduce unnecessary waiting and anxiety for passengers, improving travel efficiency.
In conclusion, the optimization strategies proposed in this study not only solve the bottleneck issues at the station during peak hours but also enhance passengers' travel experience, further improving the station's operational efficiency and the overall service quality of the urban rail transit system. These measures will lead to significant improvements in the station's service quality in the near future, providing references and insights for other urban rail transit stations.

COMPETING INTERESTS

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

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HOW DIGITAL TRADE POLICIES INFLUENCE THE DEVELOPMENT OF URBAN DIGITAL ECONOMIES

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Abstract: Digital trade plays a crucial role in global economic development, and the impact of related policies on urban digital economies has become a prominent research area. This study conducts qualitative analysis of digital trade policy documents in China, identifying core mechanisms driving urban digital economy growth. Using panel data from 280 Chinese cities (2010-2021), we apply the Difference-in-Differences method, treating Cross-border E-commerce comprehensive pilot areas as a quasi-natural experiment to evaluate digital trade policy impacts on urban digital economic development. Findings reveal that pilot areas significantly boost urban digital economy development. Heterogeneity analysis shows this effect is particularly pronounced in eastern coastal regions, megacities, and the Yangtze River Delta. Mechanism analysis suggests digital trade policies foster urban digital economic development by advancing digital infrastructure, promoting service industry agglomeration, and improving business environments.
Keywords: Digital trade policy; Digital economy; Cross-border e-commerce

1 INTRODUCTION

With the advancement of global economic integration and information technology, digital trade has become a crucial driver of digital economic growth. The Chinese government has prioritized the digital economy, as evidenced by the Three-Year Action Plan for Digital Commerce (2024-2026), which promotes cross-border e-commerce and digital trade through innovation, data-driven strategies, and institutional reform.

The cross-border e-commerce (CBEC) comprehensive pilot areas are a central instrument in advancing China's digital trade and urban digital economy. Serving as both platforms and policy laboratories, these pilots have expanded from the first one launched in Hangzhou in 2015 to 165 across all 31 provinces. These pilots have facilitated the development of a regulatory framework for global cross-border e-commerce, promoting industrial digitalization and sustainable trade. As their scope broadens, critical questions arise: What impact do digital trade policies have on urban digital economies? Through which mechanisms? Are these effects heterogeneous? These questions warrant empirical investigation to assess policy effectiveness and guide future improvements.

Digital trade has received extensive academic attention. The OECD-WTO-IMF Handbook (2020) defines it as trade conducted via digital ordering or delivery, comprising digital goods, digital services, and platform-enabled transactions. Li and Fu align these categories with the digitalization of goods [1], services, and cross-border e-commerce, respectively. Within this framework, countries have adopted distinct digital trade strategies. The United States focuses on liberalization by reducing digital trade barriers Meltzer [2]; the European Union aims to build a digital single market, placing emphasis on data protection and cybersecurity [3]; Japan prioritizes technological innovation and infrastructure, often advancing digital trade through trade agreements [4]. In China, Chen and Luo identify digital trade—particularly cross-border e-commerce—as a key driver of foreign trade growth [5].

The concept of the digital economy was introduced by Don Tapscott [6], who defined it as the integration of digital technologies and intelligent systems. The U.S. Department of Commerce highlighted its role in economic development. Mesenbourg expanded its scope to include digital infrastructure [7], business networks, and e-commerce transactions. Scholars have since developed various measurement frameworks. Bukht and Heeks proposed a layered model based on infrastructure and technology adoption [8]. Zhang and Shen employed factor analysis to construct a digital economy index [9], while Liu et al. (2020) applied the NBI weighting method to assign indicator weights [10].

Digital trade, the digital economy, and cross-border e-commerce form a dynamic and interdependent system. López González and Ferencz argue that digital trade is a core element of the digital economy [11], driving global competitiveness. Zhang and Xia highlight their shared reliance on internet technologies [12], with digital trade fostering innovation and accelerating traditional industry digitalization, thus propelling overall digital economy growth. Cross-border e-commerce plays a key role in enhancing digital trade efficiency and transforming industries [13]. China's CBEC policies, which have evolved from taxation to logistics and regulation [14], reduce transaction costs and promote stable trade [15]. CBEC pilot areas, part of China's national strategy since 2015, have boosted trade competitiveness and supported digital economic growth [16]. Digital trade enhances the digital economy through mechanisms such as optimizing global resource allocation [17], matching cross-border supply and demand [18], and reshaping industrial supply chains [19]. Li and Zhang emphasize the importance of institutional innovation [20], infrastructure development, and cross-border data flows in driving digital economic transformation.

Existing literature reveals several areas for further exploration. While most research centers on national-level digital trade policies, fewer studies examine urban-level impacts, particularly the role of local governments and CBEC policies on city-level digital economies. Moreover, although the link between digital trade and digital economy development has been acknowledged, existing studies are largely descriptive. More empirical research is needed to provide deeper insight into these dynamics.

Building on the Solow growth model, this study proposes that CBEC pilot areas promote urban digital economy development through three key mechanisms: digital infrastructure, service industry agglomeration, and business environment optimization. Infrastructure investment enhances production capacity, agglomeration reflects labor and talent input, while business environment optimization reduces transaction costs. These mechanisms work synergistically to drive digital growth.

This study examines digital trade policy impacts using both qualitative and quantitative methods. Policy text analysis of 64 national documents identifies three key themes: digital infrastructure, service industry agglomeration, and business environment optimization, which align with our theoretical framework. Using panel data from 280 cities (2010-2021) and treating CBEC pilot areas as a quasi-natural experiment, we employ a difference-in-differences approach. Results show CBEC pilot areas significantly boost urban digital economies, particularly in eastern coastal regions, megacities, and the Yangtze River Delta. This study contributes city-level evidence and a Solow-based framework linking policy tools to capital, labor, and cost efficiency.

2 THEORETICAL MODEL AND RESEARCH HYPOTHESES

2.1 Qualitative Analysis

Policy text analysis is a key method for examining how digital trade policies affect urban digital economy development. This study systematically analyzes 64 policy documents issued between 2014 and 2024 by the State Council, Ministry of Finance, and General Administration of Customs (see Table 1). Three core policy themes emerge: digital infrastructure, service industry agglomeration, and business environment optimization. As shown in Table 2, these themes reflect the main mechanisms through which digital trade policies promote urban digital growth.

Table 1 Summary of Cross-Border E-Commerce-Related Policy Documents from 2014 to 2024

NO.	Year	Document Title	Issuing Institution
1	2015	Approval for the Establishment of the China (Hangzhou) Cross-Border E-Commerce Comprehensive Pilot Areas	State Council
2	2015	Opinions on Vigorously Developing E-Commerce and Accelerating the Cultivation of New Economic Drivers	State Council
3	2018	Notice on Issuing the Work Plan for Optimizing Port Business Environment and Promoting Cross-Border Trade Facilitation	State Council
4	2023	Notice on Improving the Supervision of Cross-Border E-Commerce Retail Imports	Ministry of Finance, General Administration of Customs, State Taxation Administration
...	...	...	...
64	2024	Opinions on Expanding Cross-Border E-Commerce Exports and Promoting Overseas Warehouse Construction	Ministry of Finance and 9 Other Departments

Policy text analysis reveals three core themes with varying frequencies but complementary impacts. Service industry agglomeration is the most prominent theme (4.85%), with high-frequency terms such as "service," "cluster," and "synergy" indicating policy support for industry concentration in logistics and finance, promoting knowledge spillovers and resource sharing that reflect a focus on human capital and industrial synergy. Digital infrastructure appears in 3.55% of documents, emphasizing core infrastructure—electronic payments, data platforms, and network technologies—that generate network effects and economies of scale, reducing barriers to digital transformation. Although business environment optimization accounts for only 2.57% of policy documents, its institutional impact is notable through customs reform, regulatory harmonization, and tax incentives that reduce transaction costs, mitigate information asymmetry, and create a stable, predictable environment.

Together, these three themes form an integrated policy framework: infrastructure offers technological support, clustering improves factor allocation, and business environment reforms reduce frictions. Collectively, they correspond to capital accumulation, labor input, and transaction efficiency—core elements of economic growth theory and a basis for the study's model.

Table 2 Frequency Analysis of Key Policy Terms

Theme	Related Keywords (Sorted by Frequency and Relevance)	Theme Frequency
Digital Infrastructure	Electronics, Payment, Information, Platform, Data, Network, Technology, System, Digitization, Cloud Computing, Logistics Information, Blockchain, API Integration, Smart Devices, Cybersecurity	3.55%
Service Industry	Service, Business, Enterprise, Institution, Operations, Goods, Synergy, Cluster,	4.85%

agglomeration	Warehousing, Logistics, Supply Chain, Finance, Marketing, Consulting, Training, Innovation, Cooperation, Brand, Cross-Border Service Ecosystem	
Business Environment	Customs, Supervision, Regulations, Pilot, Declaration, Policy, Tax, Compliance, Intellectual Property, Risk Prevention, Administrative Licensing, Standardization, Trade Facilitation, Dispute Resolution, Local Policy Support	2.57%

Note: Word Frequency Analysis: High-Frequency Terms

2.2 Theoretical Model

Building on the policy analysis above, this study employs the Solow growth model to examine the impact pathways through which digital trade policies influence urban digital economic development [21]. The model highlights capital accumulation, labor input, and technological progress as key growth drivers, aligning with our three policy themes.

2.2.1 Construction of the production function

In the standard Solow model, total output Y is determined by capital K and labor L, with the production function defined as:

$$Y = AK^{\alpha}L^{1-\alpha} \tag{1}$$

In this model, Y represents the total output of the digital economy, while A denotes the level of technology, capturing exogenous technological progress. K stands for capital input, and L represents labor input. The parameter α is the output elasticity of capital, with $1-\alpha$ representing the output elasticity of labor.

In the digital economy, capital K primarily refers to investments in digital infrastructure, such as 5G networks and data centers. Labor L represents the agglomeration of service industries and the input of high-skilled talent. Improvements in the business environment are captured by reduced transaction costs, denoted as T. As T decreases, economic efficiency rises, resulting in higher total output.

2.2.2 Dynamic accumulation of capital and labor

In the Solow model, capital accumulation is determined by the savings rate s and the capital depreciation rate δ. The capital accumulation equation is given by:

$$\dot{K} = sY - \delta K \tag{2}$$

By substituting the production function into the capital accumulation equation, we obtain the dynamic capital accumulation equation as follows:

$$\dot{K} = sAK^{\alpha}L^{1-\alpha} - \delta K \tag{3}$$

This equation indicates that the growth rate of capital depends on current output and capital depreciation. When capital accumulation reaches the steady-state level, capital no longer grows, i.e., $\dot{K}$ =0. At this point, the steady-state capital level, K^*, can be derived as follows:

$$K^* = \left(\frac{sAL^{1-\alpha}}{\delta}\right)^{\frac{1}{1-\alpha}} \tag{4}$$

2.2.3 The impact of transaction costs on economic growth

Transaction costs T are a critical determinant of economic growth. In the digital economy, optimizing the business environment—such as simplifying cross-border e-commerce procedures and lowering compliance costs—effectively reduces transaction costs. To reflect this in the model, we extend the production function by introducing transaction efficiency T, as follows:

$$Y = AK^{\alpha}L^{1-\alpha}T^{\gamma} \tag{5}$$

Where T represents the improvement in transaction efficiency, and γ is the elasticity of output with respect to transaction efficiency.

Lower transaction costs imply higher T enhancing efficiency and boosting output Y. In the long run, business environment optimization promotes sustained digital economy growth.

2.2.4 Steady-state analysis

After incorporating the transaction cost factor, the expression for the steady-state capital K^* is as follows:

$$K^* = \left(\frac{sAL^{1-\alpha}T^{\gamma}}{\delta}\right)^{\frac{1}{1-\alpha}} \tag{6}$$

Under steady-state conditions, the total output Y^* is given by:

$$Y^* = A\left(\frac{sAL^{1-\alpha}T^{\gamma}}{\delta}\right)^{\frac{\alpha}{1-\alpha}} L^{1-\alpha}T^{\gamma} \tag{7}$$

Simplifying, we obtain:

$$Y^* = A^{\frac{1}{1-\alpha}}\left(\frac{s}{\delta}\right)^{\frac{\alpha}{1-\alpha}} LT^{\gamma} \tag{8}$$

From the steady-state output function, The steady-state output of the digital economy depends on capital, labor, and transaction costs. Capital investment (e.g., digital infrastructure) and labor agglomeration (e.g., services) directly raise output, while reducing transaction costs through business environment optimization further boosts total output.

2.2.5 Mechanisms and hypotheses for promoting urban digital economy development

The above model derivation demonstrates that CBEC pilot areas promote urban digital economy development via three mechanisms. First, digital infrastructure construction increases capital investment, boosting output. Second, service industry agglomeration enhances labor input and efficiency. Third, business environment optimization lowers transaction costs, improving economic performance. These mechanisms are supported by policies such as tax incentives and financial subsidies that foster infrastructure investment and service agglomeration.

Based on this, we propose:

Hypothesis 1: Digital trade policies, represented by CBEC pilot areas, promote urban digital economy development.

Hypothesis 2: CBEC pilot areas promote such development through digital infrastructure construction, service industry agglomeration, and business environment optimization.

3 RESEARCH DESIGN

3.1 Model Design

Between 2010 and 2021, China designated 30 provinces and municipalities across five batches as CBEC pilot areas. The first batch was launched in 2015 and the last in 2021, aligning with the rapid growth of the digital economy and the refinement of CBEC policies. This period provides a suitable window to examine changes in urban digital economic development before and after policy implementation. Accordingly, this study employs a multi-period difference-in-differences (DID) model to assess the policy's impact. By comparing pilot cities (treatment group) with non-pilot cities (control group), we identify the causal effects of the CBEC policy. The model is specified as follows:

$$Dig_{it} = \alpha_0 + \alpha_1 \ Cbec_{it} + \alpha_2 \ Control + \mu_i + v_t + \varepsilon_t \tag{9}$$

Where i represents the city and t represents the year. Dig_{it} is the dependent variable, which denotes the level of urban digital economy development. $Cbec_{it}$ is the key explanatory variable. If city i is identified as a cross-border e-commerce pilot city in year t, then $Cbec_{it}$ will take the value of 1 in year t and thereafter; otherwise, it will be 0. Control represents a set of control variables. ε_t is the random error term, μ_i denotes city fixed effects, v_t represents year fixed effects, and α_0 is the constant term. α_1 represents the direct effect of the establishment of CBEC pilot areas on the development of the urban digital economy, which is the main focus of this study.

3.2 Variable Selection

3.2.1 Dependent variable

The dependent variable is urban digital economy development (Dig). Following Zhao et al. [22], we construct a composite index based on two dimensions: digital internet development and digital inclusive finance. For digital internet development, we adopt Huang et al.'s method using four indicators: broadband users per 100 people (internet penetration rate) [23], share of computer and software service employees (proportion of workforce in digital technology fields), per capita telecommunications business volume (digital service output level), and mobile phone users per 100 people (mobile communication coverage rate). For digital inclusive finance, we use the China Digital Inclusive Finance Index developed by Peking University and Ant Financial [24]. Principal component analysis (PCA) is applied to these five indicators to construct the final index.

3.2.2 Core explanatory variable

The core explanatory variable is the interaction term CBEC, constructed by multiplying a spatial dummy (Treat) and a time dummy (Ryear). Treat equals 1 if the city has been designated as a CBEC pilot area, and 0 otherwise. Ryear equals 1 from the year the city became a pilot, and 0 otherwise. This setting follows the multi-period DID framework to capture policy effects.

3.2.3 Control variables

The establishment of CBEC pilot areas may involve regional and temporal selection biases, potentially introducing endogeneity due to correlation with urban digital economy development. Although policy documents do not specify selection criteria, this study seeks to identify pre-existing factors influencing the designation of CBEC pilot cities. Key selection factors identified from policy reviews are incorporated as control variables in the analysis. Following Jiang et al. [25], we include the following pre-existing factors as control variables: population size (Inpop), human capital (Inaca), economic development level (Ingdp), government intervention (Ingov), urbanization level (Urban), consumer spending level (Incoms), and internet user level (Ininter). A binary panel Logit model is employed to estimate the probability of city selection as a CBEC pilot area. The dependent variable equals one if a city is selected and zero otherwise. Results indicate that selection is primarily driven by the seven factors listed above, validating their use as controls.

3.2.4 Data sources

This study uses panel data from 280 cities (2010-2021). CBEC data comes from Ministry of Commerce lists, patent data from the National Intellectual Property Administration, and socio-economic data from official yearbooks. Cities with major missing values were excluded, and minor gaps were interpolated. As shown in Table 3, the average digital economy index (Dig) is 0.332, with a maximum of 0.801, minimum of 0.065, and a standard deviation of 0.11.

Table 3 Descriptive Statistics of Variables.

Variable	Observations	Mean	Std. Dev	Minimum	Median	Maximum
Dig	3 360	0.332 3	0.110 8	0.065 1	0.352 2	0.801 9
CBEC	3 360	0.092 9	0.290 3	0.000 0	0.000 0	1.000 0
lnpop	3 360	5.914 8	0.663 8	3.400 2	5.946 3	8.136 2
lnaca	3 351	7.692 8	1.312 3	2.484 9	7.610 4	11.234 3
lngdp	3 360	16.610 5	0.925 6	14.177 3	16.503 9	19.884 3
lngov	3 360	14.892 9	0.759 5	12.971 8	14.832 3	18.250 0
lninter	3 360	13.438 6	0.962 7	9.210 3	13.400 0	17.761 7
urban	3 325	0.552 2	0.149 5	0.180 6	0.534 7	1.000 0
lncons	3 360	15.600 9	1.049 0	5.472 3	15.557 2	19.012 9

4 EMPIRICAL ANALYSIS

4.1 Baseline Regression

Table 4 presents baseline regression results. Column (1) shows a significantly positive CBEC coefficient at the 0.1% level without control variables, indicating that CBEC pilot areas promote urban digital economy development. The positive effect remains significant after adding control variables in columns (2) and (3). Column (3) excludes centrally administered municipalities to account for their unique characteristics in pilot designation and digital development, with results still showing significant effects. All models include city and year fixed effects. These findings support Hypothesis H1, confirming the robust positive impact of CBEC pilot policy on urban digital economic development.

Table 4 Baseline Regression Results

	Dig (1)	Dig (2)	Dig (3)
CBEC	0.007 5*** (4.08)	0.006 5*** (3.41)	0.006 3* (2.12)
Controls	No	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	3 360	3 316	3 269
R-squared	0.686 9	0.690 7	0.687 9

Note: ***, **,and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

4.2 Parallel Trends Test

To validate the DID model, a parallel trend test is conducted within a 10-year window. As shown in Figure 1, before the policy, digital economy trends in the treatment and control groups are aligned, with no significant deviation in estimated coefficients. After implementation, the treatment group shows a significant positive shift, confirming the parallel trends assumption. These results demonstrate the policy's positive effect on urban digital economy development and suggest a potential demonstration effect of digital trade policy.

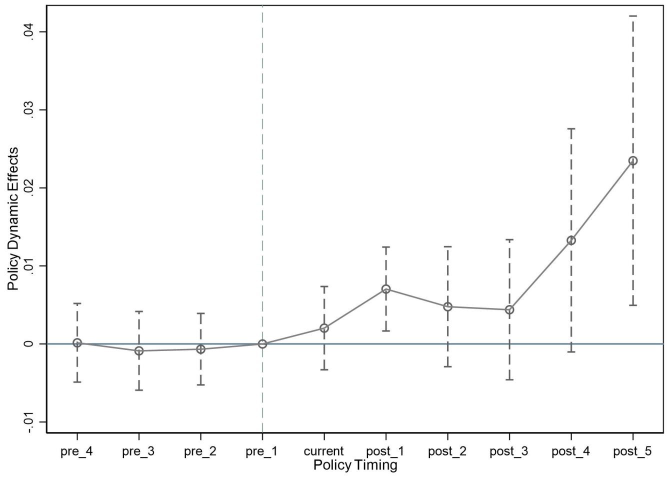


Figure 1 Parallel Trend Test Results

4.3 Robustness Check

4.3.1 Placebo test

Although the DID method addresses endogeneity and passes the parallel trend test, unobserved factors may still bias results. To test robustness, we conduct a placebo test by randomly assigning CBEC pilot locations and repeating the regression 500 times. As shown in Figure 2, the estimated coefficients are normally distributed around zero, indicating no significant influence from unobserved factors. This confirms that the observed positive effect on urban digital economy development is indeed driven by the actual CBEC pilot policy.

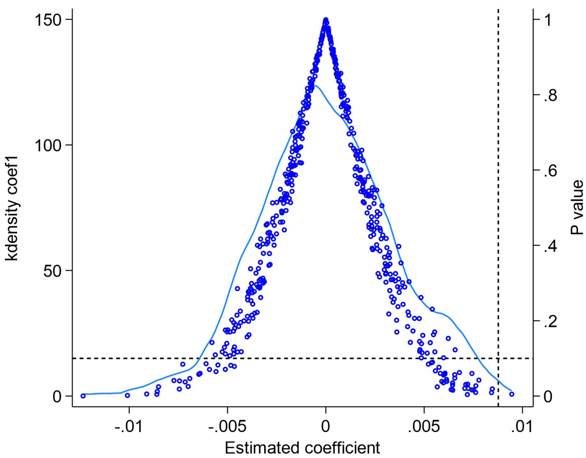


Figure 2 Placebo Test

4.3.2 PSM-DID analysis

This study uses the following probit model to estimate the predicted probability of each sample urban establishing a CBEC pilot area, i.e., the propensity score:

$$probit\left(treat_i = 1\right) = \alpha + \beta X_i + \varepsilon_i \tag{10}$$

$treat_i$ is a dummy variable for the establishment of a CBEC pilot area: if a sample cities established a CBEC pilot area between 2010 and 2021, it is assigned a value of 1; otherwise, 0. X_i represents the matching variables, which include the natural logarithms of regional GDP, general government fiscal expenditure, urbanization rate, total retail sales of consumer goods, and internet user data.

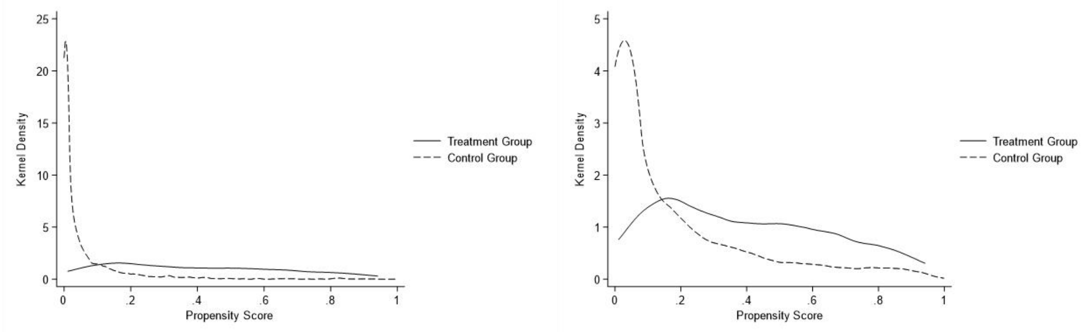
We apply kernel matching with an Epanechnikov kernel and 0.20 bandwidth following Rosenbaum and Rubin to improve robustness [26]. Balance tests confirm the conditional independence assumption: post-matching t-tests (Table 5) show no significant mean differences between groups, with standardized differences greatly reduced. The low R^2 from the Probit model suggests limited predictive power of matching variables, indicating policy assignment can be treated as conditionally random.

A common support test ensures comparability. Lechner highlights that limited overlap reduces estimate reliability [27].

Figure 3 shows that before matching, propensity score distributions show little overlap; after matching, they align closely and the support region expands. Observations outside this region are excluded, ensuring credible estimates of the average treatment effect.

Table 5 Balance Test Results

Variable	Sample	Mean Difference Test			Standardized Difference Test	
		Treatment Group	Control Group	t-test (p-value)	Standardized Bias	Reduction (%)
Regional GDP (logged)	Unmatched	17.909	16.485	28.63(0.000)	167.2	77.8
	Matched	17.909	17.593	4.04(0.000)	37.1	
Government General Fiscal Expenditure (logged)	Unmatched	16.005	14.786	30.30(0.000)	66.6	76.9
	Matched	16.005	15.723	3.89(0.000)	38.4	
Urbanization Rate (%)	Unmatched	0.722	0.535	22.35(0.000)	142.1	85.9
	Matched	0.722	0.696	2.17(0.030)	20.1	
Total Retail Sales of Consumer Goods(logged)	Unmatched	17.005	15.472	27.13(0.000)	166.9	78.1
	Matched	17.005	16.669	4.12(0.000)	36.6	
Internet User Data(logged)	Unmatched	14.785	13.307	28.55(0.000)	190.9	78.6
	Matched	14.785	14.468	4.65(0.000)	40.9	
Pseudo R^2		Unmatched			0.405	
		Matched			0.026	



(a) Before Matching (b) After Matching

Figure 3 Results of the Co-Support Test

As shown in Table 6, the policy exerts a positive and statistically significant impact. The average treatment effect estimated by kernel matching is 0.0304, suggesting that during the sample period, the establishment of CBEC pilot areas promoted digital economic growth in the treated cities. This result aligns with the baseline regression, further reinforcing its robustness.

Table 6 Average Treatment Effects of Digital Trade Policy

	Kernel Matching
	urban digital economic development
Average Treatment Effect	0.030 4*** (0.009 6)
Treatment Group Sample	305
Control Group Sample	3 011
Total Sample	3 316

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5 FURTHER ANALYSIS

5.1 Mechanism Test

Building on prior qualitative analysis, this section empirically examines how digital infrastructure, service industry agglomeration, and business environment optimization mediate the effects of CBEC policies. We employ Sobel tests to identify the significance and strength of these transmission mechanisms, as specified in the following model.

$$M_{it} = \beta_0 + \beta_3 cbec_{it} + \gamma X_{it} + \lambda_i + \mu_i + \varepsilon_{it} \quad (11)$$

$$\gamma_{it} = \beta_0 + \beta_1 cbec_{it} + \beta_4 M_{it} + \gamma X_{it} + \lambda_i + \mu_i + \varepsilon_{it} \quad (12)$$

In (11) and (12) M_{it} represents the mediator variable, which is replaced by the Digital Infrastructure Index (Diginf), the Service Industry Agglomeration Index (Spec), and the Chinese Urban Business Credit Environment Index (Envir), while other variables remain consistent with those used earlier.

5.1.1 Digital infrastructure construction

Digital infrastructure is crucial for China's growth, public services, regional equity, and security. Following Wang et al. [28], we construct a two-dimensional Digital Infrastructure Index (Diginf) using six indicators. Table 7 shows that CBEC pilot areas significantly enhance digital infrastructure. The interaction term is positively significant, and the Sobel test confirms a strong mediating effect at the 1% level. CBEC policies thus promote both physical infrastructure and digital ecosystems such as cloud computing, big data, and cybersecurity.

Table 7 Mechanism Test: Digital Infrastructure Construction

	(1)
Variable	Dig
Diginf	0.393 6*** (6.93)
CBEC	0.074 6*** (10.95)
Sobel Z	6.62***
Controls	Yes
City	Yes
Year	Yes
N	3 360
R-squared	0.0708

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5.1.2 Service industry agglomeration

Productive services are central to global industrial competition and crucial for manufacturing-driven growth. Based on the 2019 classification by China's National Bureau of Statistics and Gu [29], this study includes six sectors: ① Transportation, storage, and postal services; ② Wholesale and retail; ③ Leasing and business services; ④ Information transmission, software, and IT services; ⑤ Finance; ⑥ Scientific research and technical services. The first three are low-to-mid-end services, and the latter three are high-end. The service industry agglomeration index (Spec) is calculated following Han and Yang as the sum of sub-industry agglomeration indices [30], with the calculation formula as follows:

$$Spec_{it} = \frac{\sum_{j=1}^{J} S_{ijt} / \sum_{i=1}^{N} \sum_{j=1}^{J} S_{ijt}}{S_{it} / \sum_{i=1}^{N} S_{it}} \quad (13)$$

S_{ijt} represents the number of employees in industry j of city i in year t, S_{it} represents the total number of employees across all industries in city i in year t, and N represents the number of cities.

The impact of CBEC pilot areas on service industry agglomeration is significant (0.1% level), with the Sobel test confirming mediation is presented in Table 8. Both high-end and low-/mid-end services respond positively, though the latter are more affected due to strong demand, low entry barriers, and cost-reducing incentives in sectors like logistics and warehousing. In contrast, high-end services such as finance and R&D require more capital and talent, leading to slower, less policy-sensitive agglomeration.

Table 8 Mechanism Test: Service Industry Agglomeration

	(2)
Variable	Dig
Spec	0.032 5*** (4.81)
CBEC	0.085 8*** (8.40)
Sobel Z	4.548***

Controls	Yes
City	Yes
Year	Yes
N	2 800
R-squared	0.0419

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

Table 9 Mechanism Test: Service Industry Agglomeration

	(2)
Variable	Dig
Spec_low	0.030 7*** (5.35)
CBEC	0.085 2*** (8.38)
Sobel Z	4.957***
Controls	Yes
City	Yes
Year	Yes
N	2 800
R-squared	0.0437

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

Table 10 Mechanism Test: Service Industry Agglomeration

	(2)
Variable	Dig
Spec_high	0.015 4** (2.73)
CBEC	0.093 0*** (9.22)
Sobel Z	2.641***
Controls	Yes
City	Yes
Year	Yes
N	2 800
R-squared	0.0365

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5.1.3 Business environment optimization

The business environment spans economic, legal, and social dimensions and plays a critical role in industrial upgrading and digital transformation. Using the China Urban Business Credit Environment Index [31]. this study finds that CBEC pilot areas significantly enhance urban business conditions (Table 11), with results robust at the 0.1% level. The Sobel test confirms a significant mediating effect. Improvements stem from streamlined e-commerce processes, simplified customs and tariffs, and enhanced regulatory transparency, jointly fostering a stable, efficient, and predictable environment for digital economy growth.

Table 11 Mechanism Test: Business Environment Optimization

	(3)
Variable	Dig
Envir	0.200 5*** (5.33)
CBEC	0.079 4*** (11.77)
Sobel Z	5.159***
Controls	Yes
City	Yes
Year	Yes
N	3 350
R-squared	0.065 4

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

In conclusion, the three mediating variables—digital infrastructure development, service industry agglomeration, and business environment optimization—mediate the relationship between digital trade policies and urban digital economic development. Therefore, Hypothesis 2 is validated.

5.2 Heterogeneity Analysis

5.2.1 Regional heterogeneity

Given China's regional disparities, the impact of CBEC pilot areas on digital economy development is likely heterogeneous.

This study examines this from three dimensions: geographic location, city size, and urban agglomeration. Based on national classifications, 280 cities are categorized into 51 coastal and 229 inland cities. As shown in Table 12 (columns 1-2), CBEC pilot areas significantly promote digital economic growth in coastal cities (significant at the 0.1% level), while effects in inland cities are insignificant. Coastal regions benefit from advanced infrastructure, greater openness, maritime advantages, and early policy adoption, enhancing implementation outcomes. In contrast, inland areas face logistical and institutional constraints that reduce policy effectiveness.

Further, based on data from the National Bureau of Statistics, this study divides cities into four regions: Eastern, Central, Western, and Northeastern. Table 12(columns 3-6) indicates that significant policy effects are observed in the Eastern region. Effects in the Central and Western regions are statistically insignificant, while those in the Northeast are limited. This heterogeneity reflects the East's advantages in economic concentration, infrastructure, and policy readiness. In contrast, weaker foundations and sparse pilot coverage in other regions—especially the Northeast, with only 14 pilots by 2022—may delay or dilute policy impacts, highlighting spatial and temporal disparities in implementation.

Table 12 Regional Heterogeneity

	Coastal cities (1)	Inland cities (2)	Eastern region (3)	Central region (4)	Western region (5)	Northeastern region (6)
Coast×CBEC	0.013 6*** (3.40)					
Inland×CBEC		0.000 5 (0.15)				
East×CBEC			0.014 6*** (4.61)			
Mid×CBEC				-0.006 4 (-1.48)		
West×CBEC					-0.011 0* (2.15)	
Northeast×CBEC						0.020 2 (1.85)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	3 316	3 316	3 316	3 316	3 316	3 316
R-squared	0.691 8	0.689 5	0.693 1	0.689 8	0.690 4	0.690 8

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5.2.2 City scale heterogeneity

To examine policy effects across city sizes, this study divides cities into megacities and medium-to-large cities based on population size. Table 13 shows that CBEC pilot areas significantly promote digital economy development in megacities (0.1% level), while effects in medium-to-large cities are insignificant or negative. This heterogeneity stems from infrastructure gaps, weaker industrial ecosystems, and lower policy absorption in smaller cities. Megacities, with mature digital infrastructure and stronger markets, attract cross-border e-commerce firms and amplify policy effects. Conversely, smaller cities face limited market capacity and the "siphon effect" of megacities, reducing their ability to benefit from CBEC policies and possibly weakening local industries.

Table 13 City Scale Heterogeneity

	Megacities (Population > 5 million) (1)	Large Cities (Population 1–5 million) (2)
Large×Cbec	0.009 5** (2.65)	
Medium×Cbec		-0.000 6 (-0.17)
Controls	Yes	Yes
City	Yes	Yes
Year	Yes	Yes
N	3 316	3 316
R-squared	0.691 3	0.689 5

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

5.2.3 Urban agglomeration heterogeneity

Based on the Beijing-Tianjin-Hebei Coordinated Development Plan and other national development plans, we divide cities into three major urban agglomerations: Beijing-Tianjin-Hebei (JJJ), Yangtze River Delta (YRD), and Pearl River Delta (PRD). Table 14 shows CBEC pilot areas significantly promote digital economy development in YRD and PRD, with stronger effects in YRD. YRD benefits from mature industrial base, advanced infrastructure, and high openness, while PRD leverages strong export networks and digital services. In contrast, JJJ shows no significant policy effect, possibly due to structural imbalances, slow industrial transformation, and weak innovation-to-application conversion that hinder full utilization of CBEC policy advantages.

Table 14 Urban Agglomeration Heterogeneity

	JJJ (1)	YRD (2)	PRD (3)
JJJ×CBEC	0.011 2 (0.76)		
Yangtz×CBEC		0.011 1** (2.74)	
Pearl×CBEC			0.018 2* (1.99)
Controls	Yes	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	3 316	3 316	3 316
R-squared	0.689 7	0.690 4	0.690 6

Note: ***, **, and*indicate significant at the 0.1%, 1% and 5% levels, respectively, with standard errors in parentheses.

6 CONCLUSION AND DISCUSSION

This study investigates how digital trade policies influence the development of urban digital economies. Existing literature suggests such policies reduce transaction costs, foster technology spillovers, and improve resource allocation efficiency [32]. Qi et al. find that cross-border e-commerce policies enhance regional digital services through infrastructure investment [33]. Chou et al. highlight digital technology diffusion's role in boosting productivity [34], while Casalini and González emphasize that liberalized cross-border data flows facilitate industrial clustering [35]. However, most studies focus on national-level mechanisms and lack empirical assessment of regional heterogeneity and transmission pathways.

Drawing on policy text analysis and a difference-in-differences (DID) model, this study finds that CBEC pilot areas significantly promote urban digital economy development through three key mechanisms: digital infrastructure, service industry agglomeration, and business environment optimization. These results align with Ruan et al. [36], who show stronger policy impacts in coastal and megacities with robust digital and institutional capacities. The findings also support Zhou [37], emphasizing the importance of policy coordination. A limitation is the focus on short-term effects; further research is needed to explore long-term institutional dynamics and sustainability.

Based on these conclusions, China's experience offers valuable policy lessons for other countries:

(1) Investment in Digital Infrastructure

Governments should prioritize upgrading broadband, 5G, data centers, and cloud platforms to bridge the digital divide. Strengthening digital governance and cybersecurity can enhance transaction reliability and create a more inclusive environment for SMEs.

(2) Talent and Technological Innovation

Developing human capital in AI, big data, and blockchain is essential for sustainable growth. Supporting research collaboration and offering innovation incentives—such as funding or tax relief—can boost the CBEC sector's global competitiveness.

(3) Improving the Business Environment

Policymakers should streamline regulations, enhance transparency, and reduce compliance costs. Local authorities should tailor measures to local conditions—for instance, promoting innovation in advanced cities and improving infrastructure in underdeveloped regions—to support balanced digital economic development.

COMPETING INTERESTS

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

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DECISION OPTIMIZATION MODEL FOR ELECTRONIC PRODUCT PRODUCTION BASED ON BINOMIAL DISTRIBUTION

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Abstract: This paper aims to solve the key balance between quality control and cost optimization in the multi-stage electronics manufacturing process. By combining statistical hypothesis testing with mixed integer linear programming (MILP), we propose a novel decision-making framework that can dynamically adapt to different defect rate, inspection cost, and risk scenarios. Firstly, a one-sided hypothesis testing method was proposed to calculate the minimum sampling size in order to solve the problem of supplier defect rate verification. Secondly, for the multi-stage production decision-making problem, a mixed integer linear programming model is constructed, and the total cost is optimized by the combination of enumeration strategies. This study provides a theoretical basis for enterprises to formulate flexible production strategies, promotes the development of production decision science by combining statistical quality control with operational optimization, and provides a data-driven tool for manufacturers to cope with the dynamic supply chain environment. This approach can be extended to the context of sustainable manufacturing, especially for recycling-oriented production systems with material uncertainty.
Keywords: Quality control; Mixed integer programming; Hypothesis testing; Sampling testing; Production decisions

1 INTRODUCTION

In view of the contradiction between quality risk and detection cost in the production of electronic products, the existing research lacks a multi-process collaborative optimization framework, and the contradiction between the fluctuation rate of spare parts defective rate and the high cost of full inspection in the manufacturing process of electronic products is becoming increasingly prominent, and the existing research has shortcomings in cross-process collaborative decision-making and uncertainty quantification. In this paper, aiming at the typical scenario of 10% nominal defective rate, a dynamic optimization model is constructed through binomial distribution hypothesis testing, aiming to solve the cost-benefit imbalance problem in the chain decision-making of "detection, dismantling, swapping", and provide enterprises with a scientific decision-making framework that takes into account quality risk control and cost savings of more than 15%.

In recent years, research has paid more attention to multi-objective collaboration (e.g., cost, environment, social responsibility), integration of data and mechanism, and real-time dynamic decision-making. In 2021, Chungchi Hsieh et al. [1] discussed the production decision problem of alternating raw materials and recycled materials in a single production process, and studied the batch decision strategy under the constraint of the maximum allowable setting time by constructing a cost optimization model. In 2023, Wu Amin et al. [2] proposed a dual-stream information bottleneck (TIB) method on multiple object detection datasets, which is suitable for industrial defect detection and medical image analysis. The Anomaly CLIP team [3] developed an object-independent text prompt learning method to generalize the CLIP model to cross-domain anomaly detection tasks through global and local loss optimization, covering industrial defects and medical imaging. Li Wei et al. [4] established a two-stage game model for cross-border remanufacturing supply chain, which provides a theoretical basis for policymakers to adjust the tax structure. In 2025, Lingxin Wang et al. [5] proposed a hierarchical scheduling model to integrate demand fluctuations, resource constraints, and social responsibility goals, and optimize production planning through three-level decision-making (demand feasibility, resource allocation, and dynamic adjustment).

In the field of electronic product manufacturing, the fluctuation of the quality of spare parts directly affects the qualified rate of finished products, and comprehensive testing will greatly increase the production cost. How to balance quality risk and economic benefits under limited testing resources has become the core issue of enterprise operation in our paper. Most of the existing studies focus on single-process optimization, and lack a multi-stage collaborative decision-making framework. In this paper, a whole-process decision-making model covering sampling detection, assembly optimization, and dismantling strategy is established by combining statistical methods and operations research theories, so as to provide a dynamic optimization scheme for multi-stage complex production systems which is different from the previous research.

2 PREREQUISITES

2.1 Approximately Normal Distribution Formula for Binomial Distribution

The binomial distribution is a discrete probability distribution that describes the results of a Bernoulli experiment with a probability of success p n times[6]. Normal distribution is a continuous probability distribution that is widely used in statistics and natural sciences. Under some conditions, the binomial distribution can be approximated by a normal distribution. First, let's define the binomial distribution and the normal distribution.

Binomial distribution: Let X be the number of successes in n Bernoulli experiments, and the probability of each success is p. then X obeys the binomial distribution of the parameters n and p, which is denoted as $X \sim B(n,p)$.

Normal distribution[7]: Let X be a random variable, if for any real numbers a and b $(a < b)$, P$(a \leq X \leq b)$ is a constant, and is a continuous function about (a, b), then X is said to obey a normal distribution, denoted as $X \sim N(\mu, \sigma^2)$, where μ is the mean and σ^2 is the variance.

The conditions and precautions for an approximately normal distribution of binomial distributions are given below.

Conditions for an approximately normal distribution of binomial distributions:

(1) When n is large enough, n≥30 is usually required.

(2) The probability of success p is close enough to 0.5, i.e. 0.2≤p≤0.8.

Under such conditions, the binomial distribution can be approximated with a normal distribution, i.e

X~B(n,p) can be approximated as X~N(μ, σ^2).

where μ = E(X) = np and σ^2 = Var(X) = np(1-p)

Notes:

(1) The probability calculation of the binomial distribution can be converted into the probability calculation of the standard normal distribution.

(2) It should be noted that the calculation result of the binomial distribution is discrete, while the calculation result of the normal distribution is continuous, so when making the approximate calculation, a correction is required, usually rounding the result to the nearest integer.

In summary, the binomial distribution can be transformed into a normal distribution by normalizing the variables, and the probability table of the normal distribution can be used to approximate the calculation. This approximation is valid when n is large enough and the probability of success p is close to 0.5.

2.2 Mixed Integer Linear Programming Model

Mixed Integer Linear Programming (MILP) is a mathematical optimization model that combines continuous and integer variables, and is suitable for problems that include both discrete and continuous decisions[8]. First, learn the Linear Programming (LP) model. LP means that the objective function is linear, all constraints are linear, and finally, the decision variable can take any real number.

Table 1 Food Variables

Food	Cost per serving	Vitamin A	Calories
Corn	$ 0.18	107	72
2% Milk	$0.23	500	121
Wheat Bread	$0.05	0	65

Table 1 shows that there are 3 kinds of food sold in the supermarket, corn, milk and bread, and the price, vitamin A and calorie information are shown in the table above. Now the question is how many servings of corn, milk, bread to buy so that the total price is the lowest, and the total intake of vitamin A is not less than 500 but not more than 50,000, and the total calorie intake is not less than 2,000 but not more than 2,250.

The objective functions and constraints are as follows:

Objective Function:

$$\min \ 0.18x_{corn} + 0.23x_{milk} + 0.05x_{bread} \tag{1}$$

Constraints:

$$\begin{cases} 107x_{corn} + 500x_{milk} \leq 50000 \\ 107x_{corn} + 500x_{milk} \geq 500 \\ 72x_{corn} + 121x_{milk} + 65x_{bread} \leq 2250 \\ 72x_{corn} + 121x_{milk} + 65x_{bread} \geq 2000 \\ x_{corn}, x_{milk}, x_{bread} \geq 0 \end{cases} \tag{2}$$

If there are some decision variables in the linear programming problem, such as the above x_{corn} requirement must be an integer, then the programming problem becomes a mixed integer linear programming problem.

2.3 Hypothesis Testing

Definition Hypothesis testing is a statistical inference method used to determine whether the differences between samples and samples and populations are caused by sampling errors or essential differences. The basic principle is to make some kind of assumption about the characteristics of the population, and then make inferences about whether this hypothesis should be rejected or accepted through statistical reasoning from sampling studies.

First assume that a certain hypothesis is true in the whole and calculate what results it will lead to. If it leads to an

unreasonable phenomenon, the original assumption is rejected. If it does not lead to an unreasonable phenomenon, the original hypothesis cannot be rejected and the original hypothesis can be accepted.
It is also different from the general method of counterproof. The so-called irrational phenomenon is based on the principle of small probability. That is, an event with a small probability is almost impossible to occur in an experiment, and if it happens, it is unreasonable. As for what is considered a "small probability"? Events with a probability of no more than 0.05 can usually be called "small probability events", or 0.1 or 0.01 depending on the specific situation α. The hypothesis that was originally set up becomes the null hypothesis and is recorded as H_0. The hypothesis contrary to the H_0 is called the alternative hypothesis, which is the hypothesis that should be accepted when the null hypothesis is rejected, and is denoted as H_1.
Hypothetical form H_0--- Null hypothesis, H_1---alternative hypothesis
Two-sided test: $H_0: \mu = \mu_0$, $H_1: \mu \neq \mu_0$
One-sided test: $H_0: \mu \geq \mu_0$, $H_1: \mu < \mu_0$ or $H_0: \mu \leq \mu_0$, $H_1: \mu > \mu_0$
Hypothesis testing is to test the null hypothesis (H_0) according to the sample observations, and the H_0 is accepted and the H_1 is rejected. If you reject H_0, accept H_1.

2.4 Notations

The symbols used in the paper are listed in Table 2.

Table 2 Description of the Symbol

symbol	illustrate
p_1, p_2, p_f	Spare parts 1, spare parts 2 and finished product defect rate.
c_1, c_2	Purchase unit price for Parts 1 and Parts 2.
t_1, t_2, t_f	Unit cost of inspecting parts 1, 2 and finished products.
c_a	The assembly cost per finished product.
c_d	The cost of dismantling a non-conforming finished product.
c_r	A loss arising from the return of a non-conforming finished product.
s	The market price of qualified finished products.
x_1, x_2	A binary variable that indicates whether parts 1 and 2 are tested.
x_f	A binary variable that indicates whether or not the finished product is tested.
x_d	A binary variable that indicates whether or not the non-conforming finished product is disassembled.
N	The total number of finished products produced.

3 HYPOTHESIS TESTING-DRIVEN SAMPLING DESIGN

Enterprises need to design a sampling test program to determine whether the defective rate of a batch of spare parts exceeds the nominal value. The goal is to reduce the number of sampling tests as much as possible while maintaining a certain level of confidence. Here we use a linear programming solver to solve the model, so we need to specify the decision variables, objective functions and constraints.

3.1 Hypothesis Testing Methods

Null hypothesis H_0: The defective rate p of the spare part does not exceed the nominal value p_0, i.e., $p \leq p_0$.
Alternative assumption H_1: The defective rate of the spare part p exceeds the nominal value p_0, i.e., $p > p_0$.
We want to find a sample size n and a cut-off value c such that:
If the number of defective products in the sample is $x \leq c$, the null hypothesis H_0 will be accepted and the batch of spare parts will be considered qualified.
If the number of defective products in the sample is $x > c$, the null hypothesis H_0 is rejected and the batch of spare parts is considered unqualified.

3.2 Constraints

We need to meet the following two constraints:
Producer risk constraint α: When the null hypothesis H_0 is true, the probability of rejecting the H_0 does not exceed α.

$$P(\text{"Reject"}H_0|H_0 \text{ "True"}) \leq \alpha \; P(\mathrm{x} > \mathrm{c}|p \leq p_0) \leq \alpha \tag{3}$$

Consumer risk β: When the alternative hypothesis H_1 true, the probability of accepting the H_0 does not exceed β.

$$P((\text{"Accept"}H_0|H_1 \text{ "True"}) \leq \beta \tag{4}$$

$$P(\mathrm{x} \leq \mathrm{c}|p > p_0) \leq \beta \tag{5}$$

3.3 Solution Method

Due to the large sample size, we use a normal distribution to approximate the binomial distribution.
First, identify the deny domain. Based on the producer risk α, we can determine the cut-off value c for the rejection domain:

$$P（x>c \mid p\le p_0） \approx P(Z > \frac{c-np_0}{\sqrt{np_0(1-p_0)}})\le\alpha \quad (6)$$

If you find the Z-value corresponding to the α from the standard normal distribution table, denoted as Z_α, then there are:

$$\frac{c-np_0}{\sqrt{np_0(1-p_0)}} \ge Z_\alpha \quad (7)$$

$$c \ge np_0 + Z_\alpha\sqrt{np_0(1-p_0)} \quad (8)$$

Therefore, the sample size is determined.
Based on the consumer risk β, we can determine the sample size n:

$$P（x\le c \mid p>p_0） \approx P(Z \le \frac{c-np}{\sqrt{np(1-p)}})\le\beta \quad (9)$$

If you find the Z-value corresponding to "β" from the standard normal distribution table, denoted as Z_β, then there are:

$$\frac{c-np}{\sqrt{np(1-p)}} \le - Z_\beta \quad (10)$$

Substituting the c obtained in (1) and replacing p with p_1 yields:

$$\frac{np_0+Z_\alpha\sqrt{np_0(1-p_0)}-np_1}{\sqrt{np_1(1-p_1)}} \le - Z_\beta \quad (11)$$

After simplification, the inequality about n is obtained, and n can be solved.

3.4 Acceptance Plan

The solution of the acceptance scheme is similar to that of the rejection scheme, except that the alternative assumption is changed to the following: the defective rate p of the spare parts is less than or equal to the nominal value $p_0$minus a set value p', that is, $p\le p_0$- p'.
Through the above steps, we can calculate the minimum sample size n and the cut-off value c based on the pre-set producer risk α and consumer risk β, as well as the nominal value p_0 and the expected defective rate p_1, so as to design a sampling test scheme with as few tests as possible.

4 PRODUCTION DECISION MODEL BASED ON COST-BENEFIT ANALYSIS

Enterprises need to assemble two kinds of spare parts (denoted as A and B) to produce a certain product, and their quality characteristics must meet:
(1) If any spare parts are unqualified, the finished product must be unqualified.
(2) There is still a risk of defective products after the assembly of double qualified spare parts.
(3) Nonconforming products can be dismantled and recycled spare parts (dismantling fees need to be paid).
Here, we continue to use the Linear Programming Solver (PuLP) to solve the model to obtain the optimal value of the decision variables, that is, which parts, semi-finished products and finished products are detected and disassembled, so it is necessary to clarify the decision variables, the upper limit of the confidence interval of the defective rate, the objective function and the constraints[9]. Table 3 shows the data needed for decision-making.

Table 3 The Situation Encountered by the Enterprise in Production

circumstance		1	2	3	4	5	6
Spare part A	Defective rate	10%	20%	10%	20%	10%	5%
	Unit price of purchase	4	4	4	4	4	4
	Cost of detection	2	2	2	1	8	2
Spare part B	Defective rate	10%	20%	10%	20%	20%	5%
	Unit price of purchase	18	18	18	18	18	18
	Cost of detection	3	3	3	1	1	3
finished product	Defective rate	10%	20%	10%	20%	10%	5%
	Assembly costs	6	6	6	6	6	6
	Cost of detection	3	3	3	2	2	3
	The market price	56	56	56	56	56	56
Non-conforming finished products	Swap loss	6	6	30	30	10	10
	Dismantling costs	5	5	5	5	5	40

4.1 Objective Functions

Our goal is to maximize corporate profits. Whereas the total profit is equal to the total revenue minus the total cost [10]. Among them, the total revenue and total cost are calculated as follows:
Total Revenue: Equal to the number of qualified finished goods sold multiplied by the market selling price. Namely

$$\text{Revenue} = s\cdot N\cdot(1-p_f)\cdot(1-p_1x_1)\cdot(1-p_2x_2)\cdot x_f \quad (12)$$

The total cost consists of the following components.
Spare parts purchase cost: $N(c_1 + c_2)$
Spare parts testing cost: $N(p_1t_1x_1 + p_2t_2x_2)$
Finished product assembly cost: Nc_a
Finished product testing cost: Nx_ft_f
The cost of handling unqualified finished products includes the following two parts.
In case of disassembly: $N(p_f + (1 - p_f)p_1x_1 + (1 - p_f)(1 - x_1)p_2x_2)\cdot x_dc_d$
If you don't disassemble: $N(p_f + (1 - p_f)p_1x_1 + (1 - p_f)(1 - x_1)p_2x_2)\cdot(1 - x_d)c_r$
Therefore, the objective function can be written as:

$$\text{Maximize Profit} = s\cdot N\cdot(1 - p_f)\cdot(1 - p_1x_1)\cdot(1 - p_2x_2)\cdot x_f - N(c_1 + c_2) - N(p_1t_1x_1 + p_2t_2x_2) - Nc_a - Nx_ft_f - N(p_f + (1 - p_f)p_1x_1 + (1 - p_f)(1 - x_1)p_2x_2)\cdot(x_dc_d + (1 - x_d)c_r)$$

where the decision variable is a binary variable: x_1, x_2, x_f, $x_d \in \{0,1\}$

4.2 Solution

For each case in Table 3, we can substitute the known p_1, p_2, p_f, c_1, c_2, t_1, t_2, t_f, c_a, c_d, c_r, s into the objective function and enumerate the combinations of all decision variables (2^4=16 in total) to calculate the profit under each strategy. Finally, the strategy with the greatest profit is selected as the optimal decision. Table 4 shows the final decision plan and the corresponding profit.

Table 4 The Final Decision Plan and the Corresponding Profit

situation	Spare parts A detection	Spare parts B detection	Finished product testing	Dismantling of non-conforming products	profit
1	No	No	Yes	Yes	34600
2	Yes	No	Yes	Yes	14600
3	No	No	Yes	No	36000
4	Yes	No	Yes	No	24400
5	No	Yes	Yes	Yes	31800
6	No	No	Yes	No	36000

4.3 Analysis of the Basis for Decision-Making

Spare parts detection: The detection of spare parts depends on the inspection cost, purchase unit price and defective rate. If the inspection cost is low relative to the purchase unit price, and the defective rate is high, the inspection can effectively reduce the cost and improve the profit.
Finished product testing: Since the market price of finished products is much higher than the production cost, and the return and replacement losses are large, it is usually necessary to test the finished products, which can effectively avoid the flow of substandard products into the market.
Dismantling of non-conforming products: The decision to dismantle non-conforming products depends on the cost of dismantling and the loss of return and exchange. If the cost of dismantling is lower than the return loss, then dismantling can recover part of the loss.
The quality correlation of spare parts is not taken into account. The reuse rate of parts after dismantling is not modeled. In the future, machine learning can be introduced to dynamically optimize detection thresholds

5 CONCLUSION

The hybrid decision model proposed in this paper effectively solves the problem of quality-cost trade-off in multi-process production. By introducing hypothesis testing, integer programming and risk analysis, the dynamic optimization of the strategy is realized. In the future, the research can be extended to multi-objective optimization and reinforcement learning frameworks to further improve the complexity and adaptability of product inspection models.

COMPETING INTERESTS

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

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ANALYSIS OF DECISION-MAKING CHALLENGES IN PRODUCTION PROCESSES

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Abstract: This study focuses on challenges in electronic product manufacturing like quality control, cost optimization and multi-stage decisions. It uses a comprehensive math modeling and optimization approach. Advanced techniques such as sampling inspection, decision analysis, dynamic programming and Bayesian inference are integrated to build decision tree and multi-stage dynamic programming models, implemented via Python. For sampling, a hypothesis testing-based scheme is developed. At 95% and 90% confidence levels, minimum sample sizes of 138 and 108 components are set respectively, with error margin within 5%, balancing accuracy and cost. Also, decision tree modeling optimizes key processes like inspection, disassembly and return management. By simulating 16 decision combinations under different conditions and analyzing costs, the optimal cost-effective strategy is found. Overall, it offers enterprises tools and insights for better production decisions.
Keywords: Sampling and detection; Decision tree; Dynamic planning; Production optimization

1 INTRODUCTION

With the rapid development of global manufacturing industry, quality control and cost optimization in the production process have become crucial issues. Especially in the field of electronic product manufacturing, the defective rate of spare parts, testing cost and the optimization of multi-stage decision-making directly affect the production efficiency and market competitiveness of enterprises. Scholars at home and abroad have extensively studied this work. Foreign scholars such as Montgomery (2017) proposed the statistical process control (SPC) method in the field of quality control[1], emphasizing the importance of sampling detection in production, while domestic scholars such as Zhu Yu (2024) discussed the application of reliability evaluation in production decision based on Bayesian statistical mode[2] -type. In addition, Chen Quanheng (2024) studied the[3] control measures of sampling quality in the testing of agricultural products, which provided theoretical support for the sampling testing in the production process. Although existing studies have made some achievements in quality control and cost optimization, there are still shortcomings in multi-stage decision optimization, especially the application of combining dynamic planning and decision tree model[4]. This paper puts forward a set of comprehensive and systematic mathematical modeling and optimization methods for the problems of quality control, cost optimization and multi-stage decision[5] in the production process of electronic products. By using advanced methods such as sampling detection, decision tree model, dynamic programming and Bayesian inference[6], this paper constructs a multi-stage dynamic planning model and solves the model with the help of Python programming language. The results show that the method proposed in this paper can effectively balance the detection cost and reliability requirements, significantly reduce the production cost of enterprises, improve the product quality, and provide a scientific production decision tool for enterprises. (The data comes from question B of the 2024 China College Student Modeling Competition)

2 THE SAMPLING SCHEME

2.1 Establishment and Solution of the Sampling and Detection Model

In order to conduct sampling detection this paper adopts the hypothesis test[7], especially the single proportional test, assuming that the defective rate of spare parts p 10%, the test results conform to the binomial distribution. Construct the following assumptions: original hypothesis H0: spare parts defective rate p 10% (meet the supplier's nominal value). Optional hypothesis H_1: defective rate of spare parts p> 10% (defective rate higher than nominal value).
Estimate the required test sample size based on the principle of a binomial distribution, or by using a normal distribution as an approximate method[8]. In this context, because the detection of defective rate is essentially a counting problem of success (defective) and failure (non-defective) in discrete and finite trials, it is very suitable to solve with the binomial distribution.

$$x \sim Bin(n, p) \tag{1}$$

Where: X is the number of defective products detected; n is the size of the sample; and p is the rate of defective products.
Because the sample size n is large enough, the normal distribution is approximately a binomial distribution:

$$p \sim N(p, \frac{p(1-p)}{n}) \tag{2}$$

Where: p-is the estimate of the defective rate in the sample.

$$n = (\frac{Z_{\frac{\partial}{2}} \cdot \sqrt{p(1-p)}}{E})^2 \tag{3}$$

$Z = \frac{\partial}{2}$ is the critical value for the standard normal distribution at the confidence level. And p is the hypothetical defective product rate. E is the allowed error, which is the difference between the estimate we accept and the true value. solve:95% Reliance ($a = 0.05$):

$$n = (\frac{1.96 \cdot \sqrt{0.1(1-0.1)}}{0.05})^2 \approx 138 \tag{4}$$

$$n = (\frac{1.645 \cdot \sqrt{0.1(1-0.1)}}{0.1})^2 \approx 108 \tag{5}$$

Sampling scheme at 90% reliability: test at least 108 spare parts

2.2 Establishment and Solving of the Decision Tree Model

First, the decision variable is defined as follows: D_{p1}: whether to test the spare parts 1,1 is testing, and 0 is not detected. D_{p2}: whether to test the spare parts 2,1 is testing, and 0 is not testing. Dk: whether to test the finished product, 1 is the test, 0 is not tested. D_d: whether to dismantle the unqualified products, 1 is dismantling, and 0 is not. Establish correlation functions to calculate costs under various decisions[9]:

Testing cost:

$$C_e = D_{p1} \cdot C_{p1} + D_{p2} \cdot C_{p2} + D_k \cdot C_k \tag{6}$$

C_{P1} 、 C_{P2} 、 C_k Test cost of spare parts 1,2 and finished products, respectively.

Disassembly cost:

$$C_d = D_d \cdot C_{di} \tag{7}$$

C_d 、 C_{di} Disassembly cost and disassembly cost, respectively.

Return and exchange loss:

$$C_r = (1 - D_k) \cdot P_k \cdot C_{re} \tag{8}$$

Cr 、 Pk 、 Cre、 They are the total loss of return and exchange, defective product rate and exchange loss.

Objective function:

$$\min(C_d + C_e + C_r) \tag{9}$$

In order to develop the optimal strategy, this paper requires the expected cost of three functions, and selects the result with the minimum cost.

In order to obtain the expected cost of each strategy in detail, the decision tree model [10] was used to randomly combine the choices of each stage, yielding 16 strategies (1,1,1,1,1), strategies (1,1,1,0), and strategies (1,1,0,1).

Table 1 It Shows the Data for the Different Situations

circumstances	Parts 1 rate	Parts 1 unit price	Parts 1 Cost of detection	Parts 2 rate	Parts 2 unit price	Parts 2 Cost of detection	end product rate	end product Assembly cost	end product cost	selling price	Unqualified finished products losses	Unqualified finished products costs
1	10%	4	2	10%	18	3	10%	6	3	56	6	5
2	20%	4	2	20%	18	3	20%	6	3	56	6	5
3	10%	4	2	10%	18	3	10%	6	3	56	30	5
4	20%	4	1	20%	18	1	20%	6	2	56	30	5
5	10%	4	8	20%	18	1	10%	6	2	56	10	5
6	5%	4	2	5%	18	3	5%	6	3	56	10	40

As can be seen from the Table 1 above, strategy 15 (0,0,0,1) achieves the least cost, which is the optimal strategy. Other different cases, and so on. We will visualize the obtained data by following:

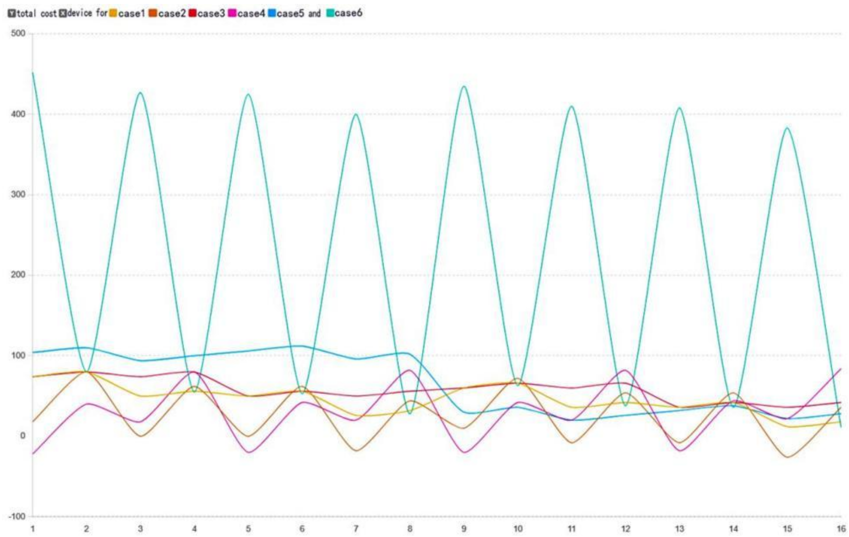

Figure 1 Data visualization

The figure 1 shows the change trend of multiple indicators over time or sequence number, the vertical axis indicates the value range, and the horizontal axis indicates the time or sequence number. Figure 1 (green line) shows obvious periodic fluctuations, with a large fluctuation range, the highest is close to 500, significantly higher than other indicators. In contrast, the fluctuations from cases 1 to 5 are relatively flat, with values maintained roughly between 0 and 100, with relatively small changes. In particular, cases 3 and 4 (purple and orange lines) cross at multiple times, showing a more synchronous trend. Overall, situation 6 has significant volatility, while the change of other indicators is relatively stable, showing a certain correlation.

The analysis and comparison of the 6 cases can obtain the results as shown in Table 2:

Table 2 Disassembly Methods for Various Cases

circumstances	Parts 1	Parts 2	end product	Whether to disassemble
Case 1	deny	deny	deny	yes
Case 2	deny	deny	deny	yes
Case 3	deny	deny	yes	yes
Case 4	deny	yes	yes	yes
Case 5	deny	yes	deny	yes
Case 6	deny	deny	deny	deny

3 IPSPECTION AND ANALYSIS OF THE MODELS

3.1 Sensitivity Analysis

3.1.1 Determine the key parameters

Misgrade rate: including spare parts 1, spare parts 2, defective rate of semi-finished products and finished products.

Testing cost: test cost per spare part and finished product.

Disassembly cost: Disassembling cost for the unqualified finished products.

Exchange loss: the exchange loss of the unqualified finished products.

3.1.2 Set the benchmark scheme

(1) The rate of spare parts is 10%, the rate of spare parts is 20%, and the rate of finished products is 10%.

(2) The testing cost of spare parts 1 and 2 is 2 yuan and 3 yuan respectively, and the testing cost of finished products is 3 yuan.

(3) The replacement loss is 10 yuan, and the disassembly cost is 5 yuan.

3.1.3 Univariate sensitivity analysis

When conducting the cost analysis, we first need to focus on the impact of spare parts and finished products on the total cost. To estimate this effect, we took the following steps: First, we fixed all other relevant parameters to ensure the accuracy of the analysis. Then, we will gradually increase the defective rate of spare parts 1, spare parts 2 and finished products from 5% to 20%. After each increase of defective rate, we will record the change of total cost and the specific value of finished defective rate. To make these data more intuitive and understandable, we usually use the form of tables or charts to show the specific impact of changes in defective product rates on the total cost.

Next, keep the defective rate and other parameters unchanged, and focus on adjusting the testing cost of spare parts and finished products. for instance,we gradually increased the testing cost of spare parts 1 from 1 yuan to 3 yuan, and recorded the changes of the total cost and defective rate after each adjustment. In this way, we can analyze whether the rising testing cost will have a significant impact on the total cost, so as to judge the reasonable control range of the testing cost.

Finally, this paper also needs to consider the impact of transposing losses on the total costs. We will gradually increase the exchange loss from 10 yuan to the same 30 yuan, and observe the change of defective rate and total cost of finished products. By recording these data, we can analyze the sensitivity of transpose loss to cost at different defective rates. This analysis result can provide an important reference basis for the decision-making of enterprises, and help enterprises to optimize the testing and exchange strategies, so as to reduce the total cost as far as possible while ensuring the product quality.

3.1.4Draw the sensitivity curve

For each parameter change, the parameter values are plotted against the total cost or defective rate. For example, the sensitivity curve of defective rate to total cost, showing the magnitude of the change in total cost for defective rate from 5% to 20%. This helps to visually show which parameter is the most sensitive to the system.

The following figure 2 shows the results of the sensitivity analysis of the different defective product rates on the total cost:

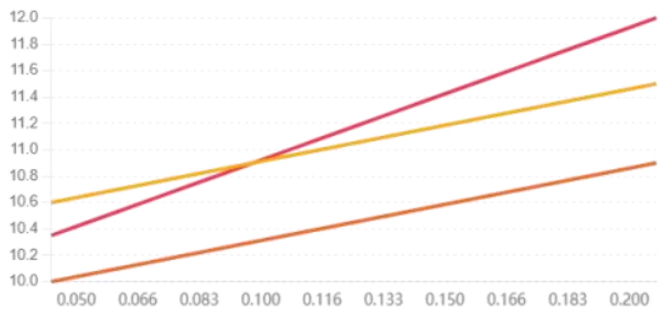

Figure 2 Sensitivity Curve

The impact of the change in the defective rate of parts 1 on the total cost: when the defective rate of parts 1 increases from 0. 05 to 0. 20, the total cost gradually increases. This indicates that the increase in the defective rate of spare parts 1 significantly increases the overall production cost, mainly due to the additional loss of defective products during the assembly process.

The effect of the change of defective rate of spare parts on the total cost: the change of defective rate of spare parts is similar to the total cost IMPACT As the defective rate increases, the total cost also increases.

The impact of change in finished defective rate on total cost: the impact of change in finished defective rate on total cost is also very significant. This is because the rate of finished products directly affects the loss of replacement and disassembly costs, resulting in the total cost rise.

The sensitivity analysis[11] results show that the change of defective rate has a great impact on the total cost, so enterprises need to focus on the control of defective rate in the decision-making process, and reducing the defective rate can effectively reduce the total cost

3.2 Stability Test

The stability test is used to evaluate whether the output of the model (such as total cost and defective rate) will change significantly under a small disturbance to determine the robustness of the model[12]. Next, we observe the stability of the model output by randomly perturbing the model parameters (defective rate, detection cost, etc.) and conducting multiple simulations[13].

3.2.1 Random fluctuations of defect rate, test costs and transposing loss

(1) The defective product rate was varied randomly within a range of ± 2%.

(2) Test costs varied randomly within ± 10%.

(3) The transposing loss also fluctuates randomly within a certain range.

3.2.2 Model stability analysis: low variance and narrow confidence intervals of total cost under disturbances

By analyzing these simulation results, the variance of total cost and defective rate as well as confidence intervals were calculated. If the variance is small, the model is stable under these disturbances; if the variance is large, the model output is very sensitive to parameter changes, and the results of the possible stability analysis are as follows: Mean of total cost: 10. 9yuan,Standard deviation of the total cost: 0. 37yuan,95%confidence interval (10. 19, 11. 62) yuan.

Through 100 simulations, the results show that the total cost of the model output varies less in the case of disturbance parameters, with a standard deviation of 0. 37 yuan. This means that the model has good stability under small random perturbations and has narrow confidence intervals for the total cost (95% confidence interval of 10. 19 yuan to 11. 62 yuan).

The results show that despite the changes of key parameters (such as defective rate, detection cost, and exchange loss), the output of the model is still relatively stable, indicating that the model has some robustness in practical application.

4 CONCLUSION

This paper presents a set of mathematical modeling, cost optimization and quality optimization methods based on sampling detection, decision tree model and dynamic planning. By designing a sampling test scheme based on hypothesis testing, the study determined the minimum test sample size at the 95% and 90% reliability levels, effectively balancing the detection cost and reliability requirements. At the same time, the decision tree model is used to optimize the key links in the production process, and 16 decision combinations are simulated, and finally the optimal strategy with the lowest cost is selected. For example, the spare parts and finished products but the unqualified products under specific circumstances. In addition, through the sensitivity analysis and stability test, the study found that the defective product rate has a significant impact on the total cost, and the model showed good stability under small parameter perturbations, with high robustness. The research in this paper provides enterprises with scientific production and testing programs for enterprises, helps them find a balance between defective rate control and cost optimization, and improves the production efficiency and market competitiven

COMPETING INTERESTS

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

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DISCUSSION ON THE SCHOOL-ENTERPRISE COOPERATION MODE OF HIGH-LEVEL INTEGRATION OF INTERNET OF THINGS BASED ON THE INTEGRATION OF POSITION, COURSE, COMPETITION AND CERTIFICATE

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Abstract: In the process of professional development, by deepening cooperation between schools and enterprises, clarifying talent cultivation goals, optimizing the professional curriculum system, enhancing course resources, and implementing teaching method reforms, a school-enterprise cooperation model has been established, characterized by 'position-based courses, certification-integrated courses, and competition-driven courses.' This model integrates position, course, competition, and certification, systematically deepening school-enterprise cooperation. It defines the curriculum system from the perspective of the technical chain, integrates the standards of vocational skill level certificates from the perspective of the talent chain, and conducts 'dual-teacher courses' from the perspective of the innovation chain. This article, based on the principle of 'position-based courses, certification-integrated courses, and competition-driven courses,' aims to create an integrated theoretical and practical teaching and training environment, establish methods such as 'triple-teacher training' and 'dual-teacher teaching and evaluation,' thereby enhancing the strength of the teacher team and the quality of student training.
Keywords: Post; Course; Competition and certificate; Integration of course and certificate; Dual-teacher course; Teaching method reform

1 INTRODUCTION

This paper solves the three pain points by deepening the practice of school-enterprise cooperation, clarifying the goal of talent training, professional curriculum system, optimizing curriculum resources and carrying out teaching method reform.

First, how to address the shift in the positioning of secondary vocational education. As the focus of secondary vocational education has shifted from being solely employment-oriented to a balance between employment and further education, students 'multiple choices and diverse growth have become the norm[1]. Data shows that the college entrance rate for Shanghai's secondary vocational students has consistently been close to 100% over the years. Therefore, it is urgent to promptly introduce integrated programs while adjusting the professional talent training plans to align with higher vocational education[2].

Second, how to align with the trends in industrial development. The thriving digital economy continuously generates new application scenarios, and the industry's requirements for professional skills are becoming more sophisticated, multifaceted, and practical[3]. For positions such as testing, implementation, marketing, and after-sales service, which primarily involve graduates from secondary and higher vocational schools, specific application scenarios are essential for their professional success. This necessitates deepening the connection between job roles and courses, and integrating course certification, to cultivate technical and skilled talents who are recognized by enterprises, have a solid theoretical foundation, and possess strong technical skills, as well as professionals with interdisciplinary expertise[4].

The third point is how to innovate the model of course construction. Enterprises that align with the majors of secondary and higher education typically require versatile talents who can master a wide range of professional skills. From the perspective of school talent cultivation, aligning with enterprise standards and enhancing skill training has become the preferred approach for course teaching and practical training.

2 SCHOOL-ENTERPRISE COOPERATION MODE OF MIDDLE AND HIGH SCHOOL INTEGRATION BASED ON THE INTEGRATION OF POSTS, COURSES, COMPETITIONS AND CERTIFICATES

2.1 Refinement of the School-Enterprise Cooperation Mode

In terms of the technical chain, the analysis and decomposition of job-course alignment and school-enterprise cooperation are conducted to clarify the professional capabilities required for five positions in the IoT system integration, IoT technical services, and electronic product application technical services: IoT installation and commissioning technician, sensor network installation and commissioning technician, sensor product tester, sensor product installation and maintenance technician, and intelligent terminal installation and commissioning technician. This approach aims to build a curriculum system that can effectively cultivate students' skills in electrical engineering, electronics, sensors, IoT, and intelligent terminals. In the talent chain dimension, the integration of courses and certification focuses on three types of vocational skill level certificates: sensor network application development, IoT installation and commissioning, and intelligent hardware installation and commissioning[5]. Collaborating with standard-setting enterprises, we develop corresponding integrated courses, with a particular emphasis on developing sensor network application development into a high-quality course. Based on the logic of skill development, these integrated courses are progressively arranged in independent practical teaching segments over the semester. Through the integration of theoretical and practical learning, students can meet the requirements for vocational skill level and standard assessment[6].

In the innovation chain dimension, the competition and course advancement are integrated. Based on the technical regulations of the IoT technology application and maintenance event from the Shanghai 'Starlight Plan' Vocational College Skills Competition, and incorporating the teaching methods refined during the competition training and intensive training, the teaching and evaluation models have been improved to enhance students 'advanced skills and innovative thinking[7]. With a focus on' dual-teacher courses, 'schools and enterprises collaborate to offer blended online and offline courses, enterprise practice courses, and other educational reforms. This approach combines' participation in teaching 'with' participation in evaluation,' increasing the involvement of enterprise mentors in both classroom instruction and practical training[8].

2.2 Specific Practices

2.2.1 Establishing a business based on production, facing regional economic development planning majors

The Internet of Things (IoT) serves as the infrastructure of the digital economy era, playing a crucial role in promoting the deep integration of the digital and real economies, facilitating industrial transformation and upgrading, and fostering high-quality economic development. The '14th Five-Year Plan' of the country explicitly identifies IoT as one of the seven key industries in the digital economy. The 20th National Congress of the Communist Party of China first included IoT in its report, highlighting the state's strong commitment to the development of the IoT industry.

In Shanghai, the Internet of Things (IoT) industry is a crucial part of the '2+ (3+6) + (4+5)' modern industrial system, specifically in the electronics and information sector. The 14th Five-Year Plan for Shanghai outlines the need to accelerate the large-scale application of smart sensors and expedite the development of the Shanghai Smart Sensor Industry Park. It also outlines plans for the development of the IoT industry and related applications in areas such as smart elderly care, new city construction, and modern agriculture. Special plans released by new cities like Jiading and Songjiang also propose requirements and measures for the development of sensor and IoT industries.

The research on enterprises reveals that over 300 companies in Shanghai have the qualifications to integrate intelligent sensor technology systems. Over 60% of the demand for composite talents with an application electronics technology major and a higher vocational education level or below is expected over the next five years, primarily in roles such as testing of smart electronic products, on-site implementation, marketing, and after-sales service. Students with at least one year of internship experience during their studies have a job opportunity rate exceeding 80%.

To meet the needs of regional economic development, including the construction of Shanghai's modern industrial system, the development of electronic information industry clusters, and the establishment of new city industrial parks, this article outlines how to cultivate technical talents with comprehensive skills through systematic and coherent skill training and knowledge enhancement. These talents will be proficient in designing and manufacturing smart electronic products, developing sensor network applications, and maintaining and applying intelligent hardware systems.

2.2.2 Set courses based on job requirements and based on the analysis of vocational ability

The sensor and IoT industry is characterized by a wide range of technologies, diverse skills, and broad applications. It demands technical and skilled professionals with a broad foundation, versatility, and a focus on development. When designing the curriculum, it is essential to focus on developing students' lifelong learning abilities while also emphasizing the enhancement of specialized skills and cultivating foundational competencies relevant to their future roles. Therefore, schools design their curricula based on occupational fields, breaking down professional competencies into specific components, integrating the characteristics of integrated secondary and higher vocational education, and implementing an integrated design approach.

Identify job positions. Based on enterprise research, identify the positions (groups) where secondary and higher vocational students are concentrated. In conjunction with the specific employment needs of school-enterprise cooperation units (Table 1), determine that the professional fields corresponding to these positions are Internet of Things (IoT) system integration, IoT technical services, and electronic product application technical services. Specifically, IoT system integration includes the position of IoT installation and commissioning technician. IoT technical services include the positions of sensor network installation and commissioning technician, sensor product tester, and sensor product installation and maintenance technician. Electronic product application technical services include the position of intelligent terminal installation and commissioning technician.

Table 1 Professional Corresponding Occupational Fields, Occupations (Positions)

order number	Jobs in the enterprise	occupational area	Occupation (job)
1	Integrator of smart sensor systems	IoT system integration	IoT installation and commissioning officer

2	Intelligent sensor system operation and maintenance personnel	Internet of Things technology services	Sensor network installation and commissioning officer Sensor product tester Sensor product installation and maintenance personnel
3	Intelligent sensor technical support personnel	Electronic product application technology service	Smart terminal installation and debugging operator
4	Pre-sales staff for smart sensor products	/	
5	Smart sensor product salesperson		
6	Sensor network application software developer		

Modularization. Given that students 'abilities typically follow a normal distribution, a small number of underperforming students may not be able to handle positions with specific technical requirements, while a few outstanding students can excel in roles with higher technical demands. When designing the curriculum structure around professional roles, the program has integrated pre-sales, sales, and development positions, which are not explicitly included in the talent cultivation goals. Courses such as IoT application, electronic product automation, application development, and product marketing (Table 2) are offered as restricted electives to develop students' specialized vocational skills.

Table 2 Professional Module Courses

order number	Jobs in the enterprise	Course modules	course title
1	Integrator of smart sensor systems	Internet of Things applications	Internet of Things cabling Internet of Things operating system IoT cloud platform application
2	Intelligent sensor system operation and maintenance personnel		
3	Intelligent sensor technical support personnel	Electronics automation	Electronic product automation assembly Electronic automation testing
4	Pre-sales staff for smart sensor products	product marketing	Customer demand management Electronics marketing
5	Smart sensor product salesperson		
6	Sensor network application software developer	Application development	APP program development C language programming

Optimizing course content through school-enterprise collaboration, developing digital and practical training resources, and integrating enterprise equipment, cases, and processes into the curriculum. For instance, in the collaboration with New Land, the school and enterprise jointly developed practical training resources that include real-world cases from New Land's smart stores, smart municipal services, and smart factories. The co-built training labs include the NEWLAB IoT key technology lab, the IoT typical industry application lab, and the IoT comprehensive application lab. The introduced industrial-grade equipment and platforms include IoT gateways, application development terminals, laser beam modules, various sensors and sensing modules, the full-stack intelligent application system for IoT, and accompanying training manuals. By recreating real-world enterprise development environments, projects, and processes, these resources aim to enhance students' practical skills.

2.2.3 Use certificates to integrate courses and develop courses with skill level certificates

In collaboration with enterprises that have established vocational skill level standards, we aim to jointly develop integrated courses and related resources. Taking the 'Vocational Skill Level Standard for Sensor Network Application Development' as an example, this article outlines how school-enterprise cooperation can be conducted to develop two independently set practical courses, 'Sensor Network Application Development (Beginner)' and 'Sensor Network Application Development (Intermediate)', based on the vocational skill requirements outlined in the standard. To align with the vocational skill level requirements, a comprehensive set of course resources, including lesson plans, courseware, micro-lessons, theoretical question banks, and operational question banks, are developed. These courses are offered in the fifth and seventh semesters of integrated secondary and higher vocational programs, covering both secondary and higher vocational stages. Additionally, single-chip microcomputer and embedded systems courses are introduced at the beginning to facilitate a step-by-step development of students' vocational skills. Table 3 sets the teaching content according to the vocational skill level standard.

Table 3 Teaching Content According to the Vocational Skill Level Standard

Vocational skill level/course name	Occupational skill requirements	Practical course teaching content
Sensor network application development （ elementary ）	Engaged in inspection and testing, installation and debugging, prototype testing and other work, can build and communicate the equipment bus according to the wiring diagram, complete data	Simulation, digital, switch data acquisition, wired networking communication, short distance wireless communication, low power consumption narrowband networking

	acquisition and other work.	communication.
Sensor network application development （ middle rank ）	Engaged in coding implementation, function verification, system debugging and other work, able to complete data acquisition, wired communication, wireless communication and other work according to the data manual, development guide, etc.	Sensor technology, wireless sensor network technology, RFID technology, NB-IOT technology, LoRa technology, Internet of Things gateway application technology and Internet of things application development technology.

2.2.4 Promote teaching by competition and refine innovative teaching methods for vocational skills competitions

Drawing on the evaluation criteria from the Shanghai 'Starlight Plan' Vocational College Skills Competition for IoT Technology Application and Maintenance, and in line with enterprise requirements, a 'dual-teacher course' has been established. Teachers are brought into schools to lead the competition training, working alongside enterprise engineers and core teachers, who are Huawei from leading enterprises in the electronic information industry. They refine the competition evaluation standards and innovate teaching methods based on long-term enterprise practice. Enterprises are also involved in teaching by offering practical courses, with 540 class hours of enterprise teachers being stationed at schools each academic year. These courses utilize the practical training rooms and resources co-built through school-enterprise cooperation. Enterprises are also involved in the evaluation process, using an online teaching platform to strengthen enterprise evaluations in integrated theory and practice courses, selecting outstanding students to participate in the competition. Through these three approaches, a 'triple-teacher training' competition training method and a 'dual-teacher teaching and evaluation' practical teaching method have been developed.

3 ACHIEVEMENTS AND EFFECTS

3.1 Promoting Integrated Practice

This civilization sets the goal of talent cultivation: This major is committed to moral and technical development, aiming for students to achieve all-round development in morality, intelligence, physical fitness, aesthetics, and labor. It primarily targets enterprises and institutions in the computer, communication, and other electronic equipment manufacturing sectors, cultivating individuals with high cultural standards and humanistic qualities, who possess solid professional knowledge and skills, and have excellent professional ethics and an innovative spirit. These individuals are capable of engaging in work related to IoT system integration, IoT technical services, and electronic product application services, and are equipped with foundational knowledge for career development, as well as high-quality technical and skilled talents.

3.2 Building Integrated Courses

The course 'Application Development of Sensor Networks' is divided into two parts: 'Application of Sensor Technology' for the secondary vocational stage and 'Application Development of Sensor Networks' for the higher vocational stage, corresponding to the primary and intermediate levels of the Vocational Skills Certificate for Sensor Network Application Development. The course consists of a theoretical component and a practical training component. The course 'Sensor Technology' has been successfully designated as a municipal-level high-quality online open course by higher vocational colleges. The 32-hour primary practical training course for 'Application Development of Sensor Networks' was developed through collective preparation by school-based professional teachers and IoT industry engineers, resulting in 16 lesson plans, 8 courseware, 8 micro-lessons, and 3 question banks, among other teaching resources.

3.3 Cultivating Excellent Talents

Through methods such as 'triple-teacher training' and 'dual-teacher teaching evaluation,' the quality of professional talent cultivation has been significantly improved, and an excellent teaching team has been established. In recent years, 12 textbooks have been edited or co-edited by professional teachers, and 21 papers have been published in important domestic and international journals. They have undertaken 7 municipal-level projects and industry-university-research collaborations, and 2 municipal-level course construction projects. Two teachers have joined master studios, one teacher is a member of the teaching and research group of the municipal secondary vocational school's Internet of Things (IoT) specialty center, and two teachers have participated in international cooperation projects. They have also provided 13 enterprise technical services to society, totaling over 1.79 million yuan. Professional students have won several gold, silver, and bronze awards in the Shanghai regional competition of the China International College Students Innovation and Entrepreneurship Competition; they have won the national second prize in the National College Students Electronic Design Competition. In the 2024 National Vocational Colleges Skills Competition, the selection contest for the secondary vocational group, they won the municipal first prize in' Electronic Product Design and Application' and the national silver prize.

4 EXPERIENCE SUMMARY

The key to the service economy is the integration of industry and education. A consortium of professional and IoT industry associations, IoT enterprises, AI companies, and other electronic information enterprises has been formed to deepen cooperation with leading electronic information companies. This consortium aims to meet the needs of regional economic and industrial development in the area where the main campus is located, accurately define talent cultivation goals, and lay a solid foundation for the establishment and development of these programs.

The core of deepening the integration of enterprises into schools is to introduce key equipment, typical processes, and critical technologies from the current industrial chain into schools through teaching environments, platforms, and resources. It also involves actively engaging enterprises in vocational education, providing students with real-world industry equipment, projects, experiences, and opportunities on campus, ensuring that students acquire the practical skills required by enterprises.

The construction of ideological and political education in courses is the direction. As a sector that embodies the uniqueness of 'hard technology' and the critical importance of addressing 'bottlenecks,' the sensor and IoT industry requires schools to systematically develop case studies and resource libraries that can be integrated into projects, tasks, and teaching. This approach subtly guides students to embrace core socialist values, fostering a sense of patriotism and craftsmanship through their course learning and practical experiences, and nurturing their aspirations to serve the country with their skills.

5 PROMOTION AND APPLICATION

Scope of application: This paper is applicable to the relevant secondary and higher vocational majors related to the Internet of Things, such as the Internet of things technology application and electronic technology application in secondary vocational schools, and the Internet of things application technology and applied electronic technology in higher vocational schools.

Application scenario: The "position-based course, certification-based course, and competition-promoted course" in this paper can be systematically replicated to build a complete professional school-enterprise cooperation model; it can also be applied in different aspects, such as clarifying the professional orientation, building the course system, developing integrated courses, and exploring teaching method reform.

Precautions: The foundation of the school-enterprise cooperation model, which integrates job requirements into courses, certification into courses, and competitions into courses, is to clearly define the industry's requirements for professional skills. This requires thorough research to map out the industrial chain, technology chain, and job clusters, and to identify the specific job needs. The scope of this research is similar to the' Professional Talent Demand Analysis and Forecast Research Report' at the start of a new major, making it particularly suitable for concurrent development when a new major is launched.

6 CONCLUSION AND PROSPECTS

The "integration of positions, courses, competitions, and certification" perspective on the school-enterprise cooperation model is not a simple addition. Instead, it starts with industry needs, focuses on capability development, and ensures comprehensive evaluation. Through deep collaboration between schools and enterprises, it reconstructs the entire talent cultivation process. This model marks a fundamental shift in vocational education from being supply-driven to demand-driven, serving as the "golden key" to cultivating high-quality technical and skilled talents for future industrial development. To achieve this model, it requires the government, schools, enterprises, and industries to break down barriers, innovate boldly, and jointly build a new ecosystem of industry-education integration.

Specifically, the school-enterprise cooperation model based on 'job-course-competition-certificate integration' is an inevitable choice for building a high-quality vocational education system. The future development directions include: First, greater intelligence: AI and big data technologies will be deeply integrated into personalized learning path planning, skill deficiency diagnosis, virtual simulation training, and precise employment recommendations. Second, a more ecological approach: it is necessary to form an educational ecosystem where government, schools, enterprises, industry organizations, and research institutions collaborate and co-prosper. At the same time, it will be more international: by introducing advanced international occupational standards, course resources, and competition systems, it aims to cultivate technical and skilled talents with an international perspective. Finally, it will be more lifelong: providing flexible and open lifelong learning and skill enhancement channels for different groups, including students, enterprise employees, and social individuals, based on the integration of 'job-course-competition-certificate'.

COMPETING INTERESTS

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

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DIGITAL TRANSFORMATION, NEW QUALITY PRODUCTIVE FORCE AND GREEN TECHNOLOGY INNOVATION

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Abstract: Using panel data of Shanghai and Shenzhen A-share listed companies from 2012 to 2023 to systematically examine the transmission mechanism among digital transformation, new quality productive force and green technology innovation. Empirical analysis shows: First, accelerating the digital transformation process and improving the level of new quality productive force can significantly enhance the level of green technology innovation; Second, digital transformation contributes to the improvement of new quality productive force; Third, new quality productive force shows a significant mediating effect between digital transformation and green technology innovation. The research results can provide theoretical guidance for enterprises to enhance their green innovation capabilities through digital transformation and new quality productive force, thereby improving their core competitive advantages.
Keywords: New quality productive force; Technological innovation; Green; Digital transformation

1 INTRODUCTION

In view of the continuing deterioration of the ecosystem, increasing environmental pollution and the tightening of resource constraints in China, the Party Central Committee has repeatedly mentioned the importance and urgency of promoting the construction of a green economy. The Fifth Plenary Session of the 16th CPC Central Committee put forward the idea of building a "resource-conserving and environment-friendly society", focusing on the economical use of resources and the protection of natural ecosystems. The new development concept advocated by the Fifth Plenary Session of the 18th CPC Central Committee highlights the element of "green" and actively advocates the harmonious coexistence of man and nature. The report of the 20th Party Congress clearly states that respecting nature, adapting to nature and protecting nature are the fundamental requirements for the comprehensive construction of a modern socialist country, and stresses that a good ecological environment is the most popular form of people's well-being.

Concurrently, digital transformation is profoundly altering the business models and competitive landscapes of enterprises. In view of the aforementioned points, it is important to consider how digital transformation can play a significant role in the innovation of green technology, which is vital for sustainable economic development. Furthermore, the study will explore how this innovation can stimulate the enthusiasm of Chinese enterprises for green technological innovation, and consequently improve the level of green technological innovation in China. The primary objective of this research is to address these issues.

The existing literature presents a multi-theoretical perspective on the driving mechanism of green technology innovation, with the double-edged sword effect of environmental regulation as the core point of contention. The promotion theory posits that reasonable environmental regulations can stimulate the improvement of green technology innovation in enterprises [1-3], while the inhibition theory reveals the crowding-out effect of environmental factors on R&D resources, thereby hindering the development of technology and processes in the production process and thus affecting the green technology innovation of enterprises [4]. More complex is the existence of nonlinear relationships, as Wang Zhenyu et al. [5] argue that there is a "U" -shaped relationship between environmental regulations and corporate green innovation.

Most of the existing studies on the relationship between digital transformation and green technology innovation suggest that there is a significant synergy effect, and the mechanism of action shows multi-dimensional characteristics. From the perspective of factor input, the digitalization process of enterprises forms the resource advantage of green technology innovation by increasing the input of digital resources[6] and the input of R&D elements [7]; From the perspective of organizational change, the upgrading of human capital structure and the construction of a collaborative network among industry, academia and research[8] jointly drive the evolution of the green innovation ecosystem. The moderating effect analysis further reveals that the ecological benefits of digital transformation are significantly enhanced when enterprises possess the following capabilities: human capital capabilities, technology integration capabilities, and technology absorption capabilities [9] , etc.

A comprehensive review of extant literature reveals a predominant consensus among scholars that digital transformation is positively associated with green technological innovation, with a predominant focus on human capital and resource allocation. However, the theoretical value of new quality productive force as the core engine of high-quality development has not yet been fully deconstructed. In particular, there remain significant research gaps concerning the mediating transmission mechanism in the "digital-green" co-evolution. Therefore, this paper places digital transformation, new quality productive force and green technology innovation in a unified research framework and examines the mechanism of their interaction in depth, which is of great practical significance for promoting the improvement of the level of green technology innovation in enterprises. The possible marginal contribution of this paper lies in: First, expanding the research on digital transformation and green technology innovation on the basis of existing theoretical literature. Second, from the perspective of indirect effects, exploring whether there is an influence channel of "digital transformation - new quality productive force - green technology innovation" to provide a new perspective for studying the impact of digital transformation on green technology innovation.

2 THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

2.1 The Impact of Digital Transformation on Green Technology Innovation

Digital transformation can be defined as a strategic process in which enterprises integrate digital technology clusters to systematically and digitally restructure their operational architecture, thereby achieving intelligent transformation of production systems and data-driven optimization of management processes[10]. Enterprise green technology innovation refers to the continuous innovation process in the operational system by which enterprises systematically reduce environmental negative externalities and improve resource utilization efficiency through technological innovation, process improvement and product reconfiguration.

Based on the theoretical framework of the dynamic resource base view, the digital transformation of enterprises reconfigures the endowment of innovation resources through the embedding of digital elements, forming the potential of digital resources for green technological innovation. Digital transformation brings new material production factors to enterprises, such as infrastructure and smart networks, helping them to transform their resource capability system and mechanism creation model and acquire green innovation resources more efficiently. Artificial intelligence also plays a unique role in green technology innovation. It can be used to optimize complex production systems to maximize energy efficiency and minimize waste emissions. For example, in the quality control stage of industrial production, AI algorithms can detect product defects quickly and accurately, avoiding resource waste and additional energy consumption due to quality issues. At the same time, AI can also be used to predict equipment failures, schedule maintenance in advance, and reduce excessive energy consumption and possible environmental pollution caused by sudden equipment failures.

Corporate digital transformation for green technology innovation can be achieved by reducing information asymmetry. Digital transformation can promote high transparency and openness of data, thereby facilitating extensive exchange and deep sharing of information both within and outside the enterprise. By building a unified and efficient information interaction platform, enterprises can obtain the latest information on environmentally friendly materials, advanced technologies and specialized equipment from upstream and downstream of the industrial chain in real time, and build a rich information resource pool needed for green technology innovation. This information resource can provide precise innovation guidance for the enterprise's internal R&D team, enabling them to closely align with market demands and industry development trends in the selection, design and implementation of innovation projects, significantly improve the practicality and market conversion rate of innovation results, and accelerate the process of green technology innovation results moving from the laboratory to market application. As a result, the following assumption is proposed:

Hypothesis 1: Digital transformation promotes the improvement of green technology innovation capabilities of enterprises.

2.2 The Impact of New Quality Productive Force on Green Technology Innovation

New quality productive force is a new starting point for high-quality economic growth and a productive force for transforming the traditional growth model and aiming for high-quality development. Compared with traditional productivity, new quality productive force takes innovation-driven development as its core logic, highly gathers innovative elements, involves new industries and new fields, new technologies and new models, and represents a leap and upgrade of productivity [11].

New quality productive force can provide technical support for enterprises' green technological innovation. The mechanism of action is reflected in three aspects: Firstly, the integration of advanced materials application and intelligent technologies drives the improvement of resource element utilization efficiency and accelerates the formation of green competitive advantages; Secondly, through technologies such as digital twins, shorten the development cycle of clean technologies and enhance the market responsiveness of environmentally friendly products; Finally, build a closed-loop system of "R&D - production - recycling" to realize the ecological reconfiguration of the innovation value chain.

New quality productive force empowers enterprises' green technology innovation through the upgrading of human capital structure. High-tech talents can bring advanced expertise and technology to the R&D, production and operation of the enterprise, and the increase in the proportion of high-tech talents in the enterprise can further innovate through the aggregation and sharing of resources such as technology to enhance the overall resource control ability of the enterprise, thereby achieving the upgrading of the enterprise's green technology. As a result, the following assumption is proposed:

Hypothesis 2: New quality productive force promotes the improvement of green technology innovation capabilities of enterprises.

2.3 The Impact of Digital Transformation on New Quality Productive Force

Digital transformation, with the use of data elements as the means, the application of digital technologies as the core, the development of digital business as the focus, and the integration into the digital ecosystem as the path [12], provides dual support for the evolution of new quality productive force-intelligent technology foundation and human capital upgrade. As a result, the following assumption is proposed:
Hypothesis 3: Digital transformation has a positive impact on new quality productive force.

2.4 The Mediating Role of New Quality Productive Force

The new quality productive force consists of three core dimensions: the new type of labourer, the new type of subject of labour, and the new type of means of labour, and a symbiotic mechanism of elements is formed among these dimensions through a digital collaborative network [13]. The digital transformation of enterprises has a positive effect on improving the level of green technology innovation of enterprises by generating new types of workers, new types of means of labor and new types of objects of labor.
Firstly, the digital transformation of enterprises is driven by digital technology, and the application of digital technology relies on highly skilled and high-quality talents, which forces human capital to transform towards "digital" capabilities and gives rise to new types of labourers, and these new types of labourers often, due to their dual capabilities in digital technology and ecological design, can promote the improvement of enterprises' green technology capabilities; Secondly, the digital transformation of enterprises can upgrade the means of labour through big data, and this higher technological content of the means of labor can promote efficiency improvement, thereby promoting green technology innovation of enterprises; Finally, digital transformation of enterprises can generate demand for new energy and new materials and give rise to new types of labor objects, which can quickly integrate different resources, facilitate more convenient and rapid information collection in various industries, accelerate technology exchange and cooperation, and provide a material basis for promoting green technology innovation. Therefore, the following assumption is proposed:
Hypothesis 4: New quality productive force plays a mediating role in the relationship between digital transformation and green technological innovation. That is, digital transformation can influence green technology innovation in manufacturing enterprises through the path of new quality productive force.

3 Theoretical Analysis and Research Hypotheses

3.1 Sample Selection and Data Collection

This study takes the data of A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2012 to 2023 as the research sample. To ensure the validity of the study, A three-stage data sorting process was carried out: Firstly, the data values of financial enterprises are excluded; Secondly, special treatment and delisting warning companies (ST/PT labels) are excluded; Finally, abnormal samples with a financial indicator missing rate of more than 30% and negative net assets are excluded. In addition, to avoid the interference of extreme values, this paper truncates the continuous variables by 1% above and below. The basic financial data is derived from the cross-validation of the CSMAR Economic and Financial Research database and the Wind Information Financial terminal. The innovation indicators are obtained through the CNRDS Innovation Research database, and the unstructured text information is collected from the official information disclosure platforms of the Shanghai Stock Exchange and the Shenzhen Stock Exchange.

3.2 Variable Measurement

3.2.1 Digital transformation (DT)
This paper draws on the practice of Wu Fei et al.[14], extracting key words related to digital transformation from corporate annual reports and constructing proxy variables for digital transformation through word frequency statistics. Due to the extremely right-skewed nature of the word frequency statistics, the summed word frequencies were summed and logarithmised.

3.2.2 New quality productive force (Nqd)
This paper draws on the practice of Song Jia et al. [15] and uses the entropy method to calculate the weights of each indicator to construct an indicator system of enterprise new quality productive force, as shown in Table 1.

3.2.3 Green technology innovation (Green)
Referring to the practice of Wang Xin et al.[16], green invention and green utility model patents are selected to measure the level of green technology innovation. The specific approach is to first sum up the quantities and add one, and then take the natural logarithm.
In addition, referring to existing studies[14], the age of the enterprise, the size of the enterprise, the debt-to-asset ratio, etc. are selected as control variables.

Table 1 New Quality Productive Force Index System of Enterprises

Factors	Sub-factor	Indicators	Indicator explanation
Labourer	Live labor	Research and development personnel salary proportion	(R&D expenses - salary and compensation)/Revenue
		Proportion of R&D personnel	R&D personnel/Total staff
Subject of labour	Materialized labor	Proportion of highly educated personnel	Number of people with a bachelor's degree or above/Number of employees
		Proportion of fixed assets	(R&D expenses - Payroll)/Operating income
		Proportion of manufacturing expenses	(Cash outflow from operating activities + Depreciation of fixed assets + Amortization of intangible assets + Provision for impairment - Cash paid for purchasing goods and services - cash paid to employees and on behalf of employees)/Cash outflow from operating activities + Depreciation of fixed assets + Amortization of intangible assets + Impairment allowance)
Means of labour	Hard tech	R&D depreciation and amortization ratio	(R&D expenses - depreciation and amortization)/Operating income
		R&D lease expenses ratio	(R&D expense - Lease fee)/Operating income
		Proportion of direct investment in R&D	(R&D expense - Direct input)/Operating income
		Proportion of intangible assets	Intangible assets/Total assets
	Soft tech	Total asset turnover rate	Operating income/Average total assets
		Reciprocal of equity multiplier	Owner's equity/Total assets

3.2 Regression Model

In this paper, a multiple hierarchical regression model is established to empirically test the relationship between digital transformation, new quality productive force and green technology innovation in the following steps:

The first step is to take the control variable as the independent variable and analyze its relationship with green technology innovation, and construct the model as follows:

$$Green_{it} = \alpha_0 + \sum \alpha_1 control_{it} + \varepsilon_{it} \tag{1}$$

where $Green_{it}$ is green technology innovation; $controls_{it}$ is the control variable; i is enterprise; t is year; ε_{it} is error.

Step 2: Examine the relationship between digital transformation and green technology innovation. Introducing digital transformation on the basis of Equation (1), the model is constructed as follows:

$$Green_{it} = \alpha_0 + \alpha_1 DT_{it} + \sum \alpha_2 control_{it} + \varepsilon_{it} \tag{2}$$

Step 3: Examine the relationship between digital transformation and new quality productive force. With new quality productive force as the dependent variable, the model is constructed as follows:

$$DT_{it} = \alpha_0 + \alpha_1 Nqd_{it} + \sum \alpha_2 control_{it} + \varepsilon_{it} \tag{3}$$

Step 4: Examine the relationship between new quality productive force and green technology innovation. Introducing new quality productive force on the basis of equation (1), the model is constructed as:

$$Green_{it} = \alpha_0 + \alpha_1 Nqd_{it} + \sum \alpha_2 control_{it} + \varepsilon_{it} \tag{4}$$

Step 5: To verify the mediating role of new quality productive force in the relationship between digital transformation and green technology innovation, new quality productive force is introduced based on equation (4), and the mediating role of new quality productive force is judged by combining model (3) and model (4). the model is constructed as follows:

$$Green_{it} = \alpha_0 + \alpha_1 DT_{it} + \alpha_2 Nqd_{it} + \sum \alpha_2 control_{it} + \varepsilon_{it} \tag{5}$$

4 DATA PROCESSING AND RESULT ANALYSIS

4.1 Descriptive Statistics

Table 2 shows the descriptive statistics of the variables. The standard deviation of digital transformation is less than that of green technology innovation, indicating that the DT score of A-share listed companies is more concentrated than that of green. The standard deviation of the mediating variable Nqd is greater than that of other variables, indicating that the new quality productive force level of A-share listed companies varies greatly.

Table 2 Descriptive Statistics of The Variables

Variables	Observations	Mean value	Standard deviation	Maximum	Minimum
Green	34579	0.367	0.782	6.518	0.000

DT	34579	1.431	1.397	5.063	0.000
Nqd	34579	5.093	2.503	14.464	0.685
Firm_age	34579	2.980	0.324	3.562	1.967
Size	34579	22.44	1.294	26.890	19.657
Lev	34579	0.424	0.205	0.902	0.065
Cashflow	34579	0.047	0.069	0.246	-0.167
ROA	34579	0.039	0.065	0.256	-0.272
Bm	34579	1.060	1.174	7.224	0.093

4.2 Correlation Analysis

The results of the correlations among the variables are shown in Table 3. The correlation coefficient between DT and Green is significantly positive, preliminarily confirming that digital transformation has a positive transmission effect on green technology innovation, and H1 holds. Similarly, Hypothesis 2 and 3 are preliminarily verified. In addition, an analysis of the average VIF value and the maximum VIF value of each variable reveals that both are less than 10, thus confirming the absence of multicollinearity.

Table 3 Correlation of Variables

Variable	Green	DT	Nqd	Firm_age	Size	Lev	Cashflow	ROA
Green	1							
DT	0.241***	1						
Nqd	0.179***	0.222	1					
Firm_age	0.071	0.222***	0.345	1				
Size	0.303***	0.229***	0.342	0.168	1			
Lev	0.013	0.297***	0.281***	0.286	0.464***	1		
Cashflow	0.038***	0.054	0.026	0.056	0.161	0.074	1	
ROA	0.176	0.186	0.076***	0.286**	0.057	0.176***	0.034	1
Bm	0.016	0.265***	0.086	0.246	0.081***	0.038	0.236***	0.347

Note: *, **, ***represent significant correlation at the 10%, 5%, and 1% levels, respectively. The same below.

4.3 Analysis of Regression Results

4.3.1 Direct effects analysis

Based on the analysis of correlations, this paper extends the testing of hypotheses through the implementation of multivariate hierarchical regression. Model 1 in Table 4 incorporates solely control variables, while Model 2 incorporates DT variables based on Model 1. It is evident that the digital transformation of enterprises can enhance their green technology innovation capacity, thereby validating hypothesis 1.

The dependent variable of Model 3 is New quality productive force, with control and digital transformation variables included in the model. The findings of the test demonstrate a significant positive relationship between digital transformation and New quality productive force. Consequently, hypothesis 2 is substantiated. In this study, Model 4 is employed to analyse the relationship between the mediator variable Nqd and green technology innovation. The findings indicate that Nqd can contribute to the upgrading of green technology levels, thereby validating hypothesis 3.

4.3.2 Mediating effect analysis

As demonstrated in the preceding analysis, both digital transformation and new quality productive force exert a substantial positive influence on green technological innovation. Model 4 in Table 4 incorporates the DT variable as model 5. Upon observing models 5 and 2 and 4, it becomes evident that the regression coefficients of DT and Nqd are diminished to a certain extent, yet remain significant at the 1 per cent level.

To further verify the mediating effect of new quality productive force, on this basis, BOOTSTRAP was used to verify the indirect effect of new quality productive force between digital transformation and green technology innovation. The mediating effect of new quality productive force was 0.275, and the confidence intervals were [0.189, 0.251], excluding 0. Therefore, Hypothesis 4 was validated.

Table 4 Regression Models and Significance Tests

Variables		Dependent variable				
		Green	Green	Nqd	Green	Green
		Model 1	Model 2	Model 3	Model 4	Model 5
Control variables	Firm_age	-0.161***	-0.129***	0.498	0.318**	0.289**
	Size	0.291**	0.232	0.194**	0.067	0.054
	Lev	-0.218	-0.162**	-0.089	0.163**	0.148**
	Cashflow	2.619	2.289**	2.019**	3.716	3.683
	ROA	-2.692	-2.281	0.891*	2.761***	2.543**
	Bm	-0.152	-0.117*	-0.177	0.051**	0.039
Independent variables	DT	—	0.329***	0.428***	—	0.297***
Mediating variables	Nqd	—	—	—	0.519***	0.425***
R^2		0.287	0.487	0.672	0.631	0.628

F value	5.892***	26.413***	31.789***	37.719***	35.816***
Adjusted R^2	0.217	0.429	0.618	0.592	0.572

4.4 Robustness Analysis

To test the reliability of the above regression results, referring to the practice of Yuan Weihai et al.[17], the total factor productivity of enterprises is used to measure the level of new quality productive force of enterprises, and the results of empirical analyses in this paper remain robust according to the models 1-4 shown in Table 5. Referring to the practice of Yuan Chun et al.[18], digital transformation is measured by the sum of the frequency of digitally related words of enterprises divided by the length of MD&A segments of annual reports, and the results are still robust (the regression coefficients of the variables of Models 1-3 are 0.167, 0.253, and 0.293 in that order, and in Model 4, the results of the DT regression are 0.213, and the results of the Nqd regression are 0.237, and they are significant at the level of 1 per cent). Referring to the practice of Ren et al.[19], the ratio of green patents granted by listed companies to all patents granted in that year is re-measured as green technological innovation, and the results are still robust. (The regression coefficients of the variables in Models 1-3 are 0.253, 0.286, and 0.381 in that order, and the DT regression result in Model 4 is 0.229, and the Nqd regression result is 0.262, and it is significant at the 1% level).
Considering the possible differences in aspects such as government policy support among regions[17], the relevant data of enterprises in municipalities directly under the Central Government were excluded and the test was conducted again. The test results are shown in Model 5-8 of Table 5. The research hypothesis of this paper still holds.

Table 5 Robust Analysis

Variables		Dependent variable							
		Green	Nqd	Green	Green	Green	Green	Nqd	Green
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Control variables	Firm_age	-0.189	0.378	0.809**	0.249**	-0.161	0.430	0.374**	0.245**
	Size	0.368	0.196**	0.047	0.024	0.292	0.158**	0.377	0.034
	Lev	0.046**	-0.160	0.259**	0.163**	-0.498**	-0.029	0.266**	0.136**
	Cashflow	1.783**	2.416**	3.736	3.896	3.892**	3.514**	3.378	3.253
	ROA	-1.820	0.067*	2.891**	2.589**	-2.631	0.638*	2.268	2.243**
	Bm	0.062*	-0.165	0.189**	0.076	-0.186*	0.873	-0.035**	0.062
Independent variables	DT	0.271***	0.378***	—	0.243***	0.386***	0.416***	—	0.326***
Mediating variables	Nqd	—	—	0.568***	0.496***	—	—	0.635***	0.523***
R^2		0.381	0.654	0.684	0.628	0.647	0.682	0.635	0.754
F value		18.89**	39.749**	47.989**	38.530**	42.749**	57.39**	45.34**	45.893**
Adjusted R^2		0.317	0.598	0.628	0.592	0.613	0.637	0.592	0.683

5 RESEARCH CONCLUSIONS AND DEFICIENCIES

This study utilises the dynamic panel data of A-share listed companies in Shanghai and Shenzhen from 2012 to 2023 in order to empirically examine the relationship between digital transformation, new quality productive force and green technology innovation. The findings of this study demonstrate that the acceleration of digital transformation and the augmentation of new quality productive force can substantially enhance green technological innovation. The outcomes of the mediation mechanism test reveal that digital transformation can indirectly promote the enhancement of green technological innovation capacity through the promotion of new quality productive force, and this conclusion remains consistent after conducting multiple robustness tests.

Although this paper examines the impact of digital transformation on green technology innovation from the perspective of new quality productive force, there are still many deficiencies Firstly, with regard to the measurement of variables, although the study draws on previous research, there is still the possibility that the quantification is not sufficiently precise. For example, the specific measurement of the three aspects of new quality productive force is inevitably missing in a small aspect due to a paucity of previous research. Secondly, due to the limitation of space, the empirical part of this paper does not analyse the specific mechanism of new quality productive force on green technology innovation in more detail.

In response to these deficiencies, the future research direction is as follows: Firstly, with the continuous enhancement of future data mining technology and the deepening of research on new quality productive force, subsequent research on new quality productive force and digital transformation can be quantified using a multi-dimensional evaluation system instead of being confined to a single evaluation indicator. Secondly, future research on the impact mechanism of digital transformation on green technology innovation can be further explored. For example, explore the role of digital technology and dynamic capabilities in the process of the impact of digital transformation on green technology innovation.

COMPETING INTERESTS

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