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Innovation Path of Private Enterprise Management Model under the Background of Big Data

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Abstract The creation of innovative private enterprise management models has emerged as a key strategy for boosting businesses' competitiveness in the context of big data's explosive growth. This article examines the particular innovation route in the private enterprise management model based on big data technologies. In order to accurately characterize the management model innovation characteristics of large enterprises as well as small and medium-sized enterprises, the study performs classification analysis on private enterprises of various sizes. Additionally, it constructs an evaluation model to assess the management innovation capabilities of private enterprises and chooses representative indicators. Factor analysis results demonstrate that four key factors-quality, category, promotion, and price-can be extracted from the original multivariate data using dimensionality reduction, offering a scientific foundation for the development of an innovative corporate management model. According to the study, big data-driven management model innovation can greatly increase private companies' operational effectiveness and market flexibility while laying the groundwork for their long-term growth in a highly competitive environment. The goal of this work is to offer theoretical justification and useful recommendations for optimizing private company management models in the big data era.

Index Terms Big Data, Private Enterprises, Management Model, Innovation Path

I. Introduction

Big data technology's quick development is causing significant changes in the worldwide social and economic landscape. Big data has emerged as a key factor in the evolution of corporate management models due to its extensive data volume, quick processing speed, variety of forms, and low value density. In this context, as an important part of the market economy, the innovation of management models of private enterprises is particularly important. Especially in the increasingly competitive market environment, how to optimize resource allocation and improve operational efficiency with the help of big data technology has become a key issue that private enterprises need to solve urgently. This paper takes the background of big data as the starting point to explore the specific path of innovation in the management model of private enterprises, aiming to provide new ideas for the sustainable development of enterprises.

The innovation of private enterprise management model is not only the internal demand of individual development of enterprises, but also an inevitable choice to adapt to changes in the external environment. At present, big data technology is reshaping the decision-making methods and operation models of enterprises, and traditional management concepts can no longer meet the needs of the new era. For private enterprises of different sizes, large enterprises and small and medium-sized enterprises face different challenges, so it is necessary to conduct classified research based on their characteristics. In addition, constructing a scientific evaluation model and selecting representative indicators will help to comprehensively evaluate the management innovation capabilities of private enterprises, thereby providing enterprises with more targeted improvement suggestions. This research method can not only reveal the core elements of management model innovation, but also find a breakthrough for enterprises in a complex and changing market environment.

The research contributions of this paper are mainly reflected in the following aspects: First, by combining big data technology with enterprise management practice, a management model innovation path suitable for private enterprises is proposed; second, based on the results of factor analysis, four core factors of quality, category, promotion and price are extracted, providing a scientific basis for management model innovation; finally, the research results not only enrich the enterprise management theory, but also provide practical guidance for the optimization of management models of private enterprises in the big data era. Solving these problems will help enhance the competitiveness of private enterprises and lay a solid foundation for them to occupy a favorable position in the future market.

II. Related Work

Based on the viewpoint of transaction costs, Wang N investigated how the business environment affects technological innovation in private enterprises and how it works. According to the study, the more market competition there is, the more favorable the economic climate is for igniting private companies' interest in and drive for technical innovation [1]. Pham K T talked about how private enterprise innovation is affected by knowledge management, employee retention, and customer relationship management. The findings demonstrated that decisions to implement innovations are positively correlated with knowledge management, employee retention, and customer relationship management [2]. Hua X examined the impact of CEO's self-status perception on corporate green innovation. A higher self-status perception gives CEOs motivation and ability, thereby prompting them to increase green innovation investment [3]. In terms of enterprise management mode, foreign research is also relatively early. The purpose of Calleja R and others is to introduce and explain the "Corporate Political Model" proposed by Professor Antonio Varero, founder and first dean of the IESE Business School, University of Navarra, Spain in order to discuss the development model of the corporate governance model [4]. Jun and others argue that principal-agent theory is applied in the field of public administration to improve the efficiency goals of public entities. However, most empirical research ignores the role of governance in the public sector in relation to organizational performance. They took South Korean local public enterprises (LPEs) as the research object, and tried to discover the role of the governance system (ie the board of directors) in local public entities with a cycle of 7 years (2007-2013), and tried to discover the role of governance systems (ie boards of directors) in local public entities [5]. According to Guan H, as the information economy has grown, increasing the effectiveness of internal distribution and promotion of organizational knowledge innovation outcomes has emerged as a significant factor influencing the organizational knowledge innovation process. Based on the organization shared mental model, he examined the innovation management performance evaluation model of papermaking companies. Papermaking companies prioritize green manufacturing and technical innovation as solutions to the present pollution issue [6]. All in all, it is more to combine the innovation of enterprise model with the background of the times, and integrate big data and smart city construction into the research of enterprise model innovation.

III. Smart City Construction

III. A. Big Data and Private Enterprise Management

One of the core roles of big data technology in the innovation of private enterprise management models is to provide scientific decision-making support for enterprises through data analysis and modeling. Traditional management models often rely on empirical judgment, while the application of big data enables enterprises to conduct accurate analysis and prediction based on multi-dimensional data [7], [8]. For example, in enterprise management, key management indicators can be extracted through factor analysis to optimize resource allocation and improve operational efficiency. Suppose we have a set of original variables $X_1, X_2, ..., X_n$,which may have multicollinearity problems. After dimensionality reduction through factor analysis, several unrelated common factors $F_1, F_2, ..., F_k$ can be extracted, and their mathematical expressions are:

$$X_i = a_{i1}F_1 + a_{i2}F_2 +, ..., +a_{ik}F_k + \grave{o}_i \tag{1}$$

Among them, a_{ij} represents the factor loading between the $\mathrm{i}-\mathrm{th}$ variable and the $\mathrm{j}-\mathrm{th}$ factor, and ϵi is the residual term. Studies have shown that factor analysis can reduce the original variables to four core factors of quality, category, promotion, and price, thereby significantly simplifying the management model and improving its explanatory power. This big data-based analysis method not only improves the scientific nature of management decisions, but also provides enterprises with stronger market adaptability [9], [10].

III. B. Intelligent Scheduling and Resource Allocation Based on Big Data

In the daily operation of private enterprises, intelligent scheduling and resource allocation are important links in the innovation of management models. Big data algorithms can effectively solve scheduling problems in complex scenarios [11], [12]. Taking enterprise vehicle scheduling as an example, let the state of a vehicle in a certain area be $\mathrm{S_t}$. After performing an action $\mathrm{A_t}$ at time t, the state of the vehicle will be transferred to $\mathrm{S_{t+1}}$. The state transition probability can be expressed by the following formula:

$$\mathrm{P}\left(\mathrm{S_{t+1}}\middle|\mathrm{S_t}, \mathrm{A_t}\right) = \sum_{\mathrm{m=1}}^{\mathrm{M}} \mathrm{P_m} \cdot \mathrm{P}\left(\mathrm{A_t}\middle|\mathrm{m}\right) \tag{2}$$

Among them, P_m represents the probability of a vehicle being assigned an order in area m, and $P(A_t|m)$ represents the conditional probability of performing action A_t in area m. By maximizing the reward function $R(S_t, A_t)$, the optimal scheduling strategy can be obtained:

$$\pi^* = arg\max_{\pi} E\left[\sum_{t=0}^{T}\gamma^t R(S_t, A_t)\right] \tag{3}$$

Among them, γ is a discount factor, which is used to balance short-term benefits with long-term benefits. Through the above algorithm, enterprises can achieve optimal scheduling with limited resources, thereby reducing operating costs and improving efficiency [13].

III. C. Application of Big Data Filtering Algorithms in Information Processing

In enterprise management innovation, big data filtering algorithms are widely used for efficient information screening and processing [14], [15]. The core idea of Bloom filter is to use a bit array and multiple hash functions to quickly determine whether an element belongs to a set. Assuming that the bit array length of Bloom filter is m and the number of hash functions is k, the false positive rate P_e can be approximately calculated by the following formula:

$$P_e = \left(1 - e^{-kn/m}\right)^k \tag{4}$$

where n represents the number of elements to be processed. In order to further reduce the misjudgment rate, this paper adopts the design of a double-layer Bloom filter, and its overall misjudgment rate can be expressed as:

$$P_e' = P_e^2 \tag{5}$$

By introducing a double-layer filtering mechanism, enterprises can quickly filter out valuable information from massive amounts of data while reducing the impact of misjudgments on management decisions. This method has important application value in scenarios such as customer relationship management and supply chain optimization, and significantly improves the level of information management of enterprises.

IV. Innovation of Enterprise Management Model

IV. A. Enterprise Growth Theory

The management innovation of each stage of an enterprise's life cycle can be broken down into four sub-processes based on the growth and evolution of the enterprise: The first is that enterprise management innovation is influenced by changes in the external and internal environment, which results in management innovation's evolutionary motivation. For example, changes in technological innovation, policy environment and demand lead to changes in the industrial pattern and supply and demand, and the size of the organization hinders its further development, thus generating the evolutionary motivation of management innovation [16]. The second phase consists of two key steps. First, it involves enterprises moving beyond traditional practices, driven by evolutionary motivation. This can be achieved either by adopting existing management innovations or through self-directed development to address their shortcomings. Second, it focuses on retaining successful and effective management innovations. The third sub-process highlights the interaction between a company's internal management innovation efforts and external environmental factors. The success of management innovation in driving organizational growth hinges on the interplay between the company's behavioral changes and its surrounding environment. Similarly, as the enterprise evolves, shifts in its internal and external environment can generate new motivations for management innovation. Under the influence of these evolutionary drivers, the enterprise enters a new phase of the evolutionary cycle, as illustrated in Figure 1.

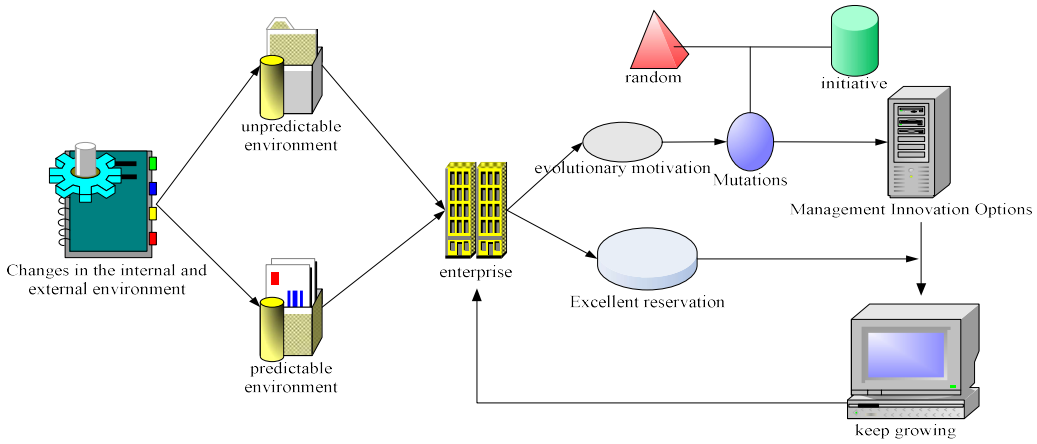

Figure 1: The evolution process of management innovation in the enterprise stage

As illustrated in Figure 2, the enterprise progresses through several distinct phases, each characterized by unique features and corresponding management priorities.

During the incubation period, the enterprise focuses on building its foundational framework. With limited funding and a small-scale organizational structure, accurate positioning is essential for long-term survival. Key management tasks include securing funding, defining market positioning, conducting research and development, and planning promotional activities.

In the survival period, the enterprise remains financially vulnerable, with unstable product sales. Management continues to prioritize fundraising while also emphasizing innovation in research and development processes to enhance competitiveness.

As the enterprise enters the rapid development phase, it experiences significant growth in market share and begins transitioning toward operational standardization. The focus shifts to cost control, continuous product improvement, and advancements in production technology.

In the mature stage, enterprises achieve peak operational efficiency, benefiting from established brand recognition and a strong corporate image. However, growth slows, innovation awareness among employees weakens, and the risk of decline becomes apparent. To counteract stagnation, enterprises must explore new research areas, diversify business channels, and enhance management innovation. Strengthening human resource management and fostering better communication between leadership and employees become crucial at this stage.

Finally, during the recession period, products face obsolescence as newer alternatives emerge, leading to declining revenue and profit margins. Employee turnover increases significantly. To navigate this challenge, enterprises must pursue a second transformation by adopting new technologies, restructuring organizational frameworks, and reforming management systems and supply chain processes [17], [18].

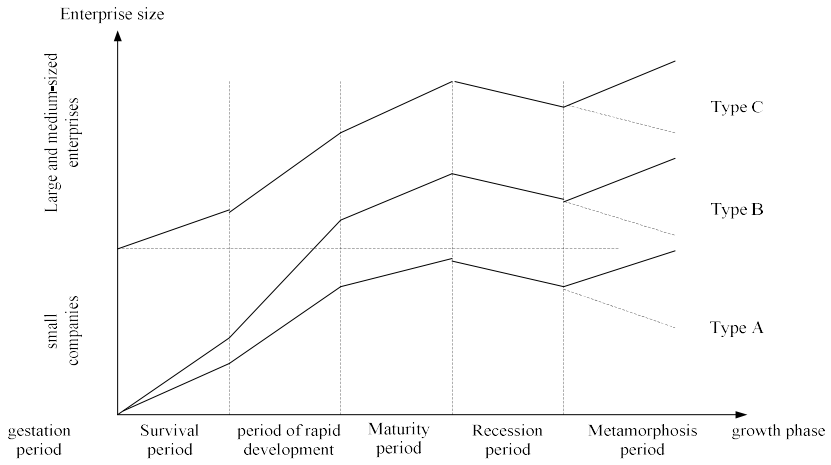

Figure 2: Business life cycle and growth type

IV. B. Management Innovation Concepts and Modules

Management innovation is a very complex system. After the research and practical application of many scholars, it contains many aspects internally, as shown in Figure 3:

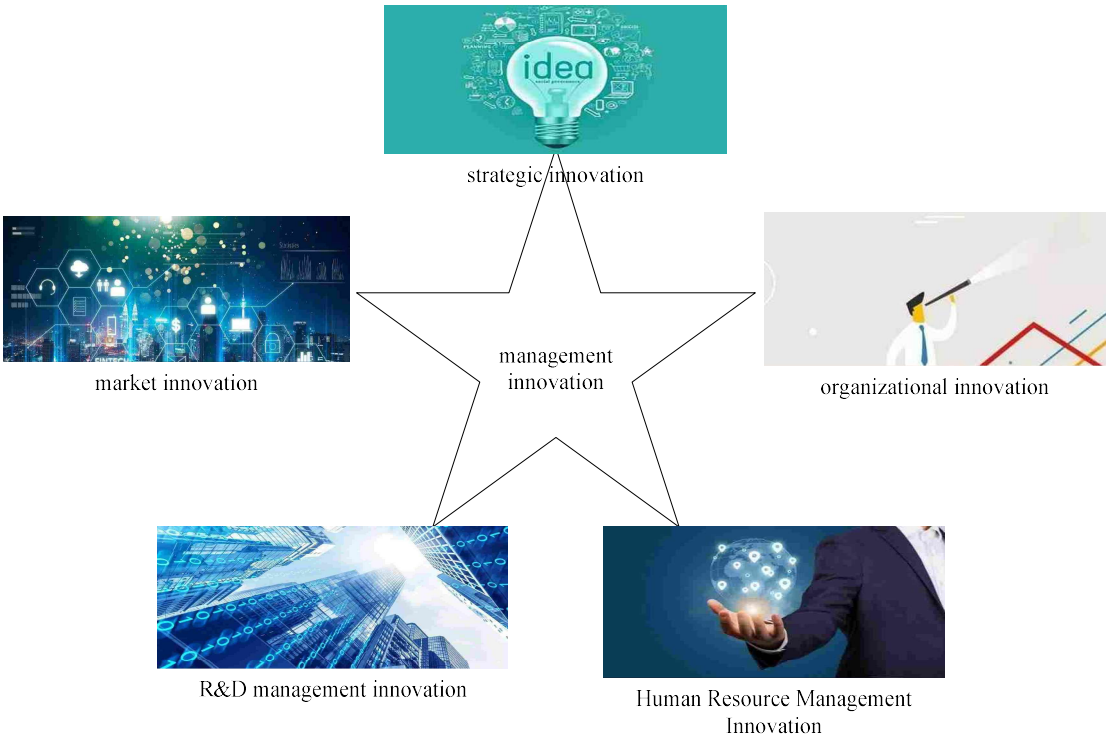

Figure 3: Management innovation system

IV. C. Internal and External Driving Factors of Management Innovation

At present, scholars have not formed a clear definition of the driving factors of management innovation, but have only studied their components.

(1) Internal factors

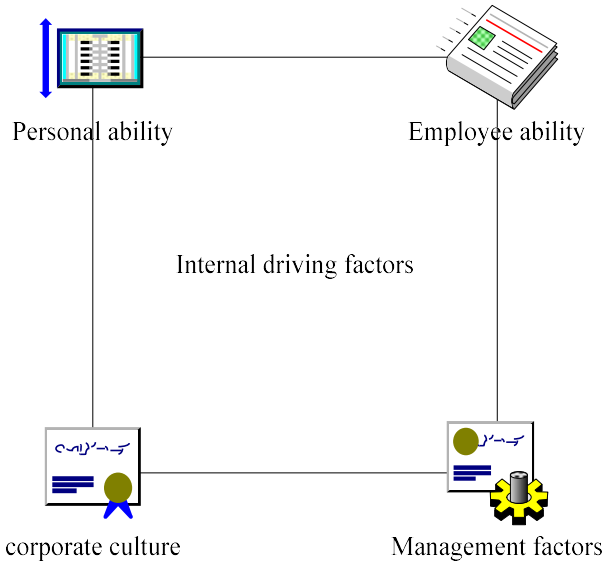

Figure 4: 4 elements of internal drive

As shown in Figure 4, the level of entrepreneurial quality and ability is the key to the success or failure of enterprise management innovation.

The needs and capabilities of enterprise employees can serve as a direct catalyst for management innovation. The stronger an employee's sense of self-transcendence and creativity, the more adept they become at identifying gaps between current realities and desired outcomes. This awareness drives them to harness their innovative potential, engage in creative actions, and contribute to operational advancements. Corporate culture, on the other hand, embodies the collective operating philosophy, control standards, environmental atmosphere, and shared values recognized by all members of the organization. It not only reflects the company's identity but also acts as both a unifying force and a driver of progress. By fostering a culture that encourages innovation and collaboration, it plays a pivotal role in motivating employees, strengthening unity, and facilitating the gradual growth of the enterprise.

The need to change extensive management and adapt to the law of enterprise development is the root cause of management problems that drive Chinese enterprises to carry out management innovation. Enterprises will encounter management problems in different periods, such as deviation of strategic positioning, the scope of operation and management of enterprises exceeds the limit of the quality and ability of entrepreneurs, the contradiction between organizational structure and enterprise scale, the contradiction between organizational form and management method, mature employees are content with the status quo and have a reduced sense of innovation, etc. Some management problems will reduce corporate profits and drive the operation of corporate management innovation [19], [20].

(2) External factors

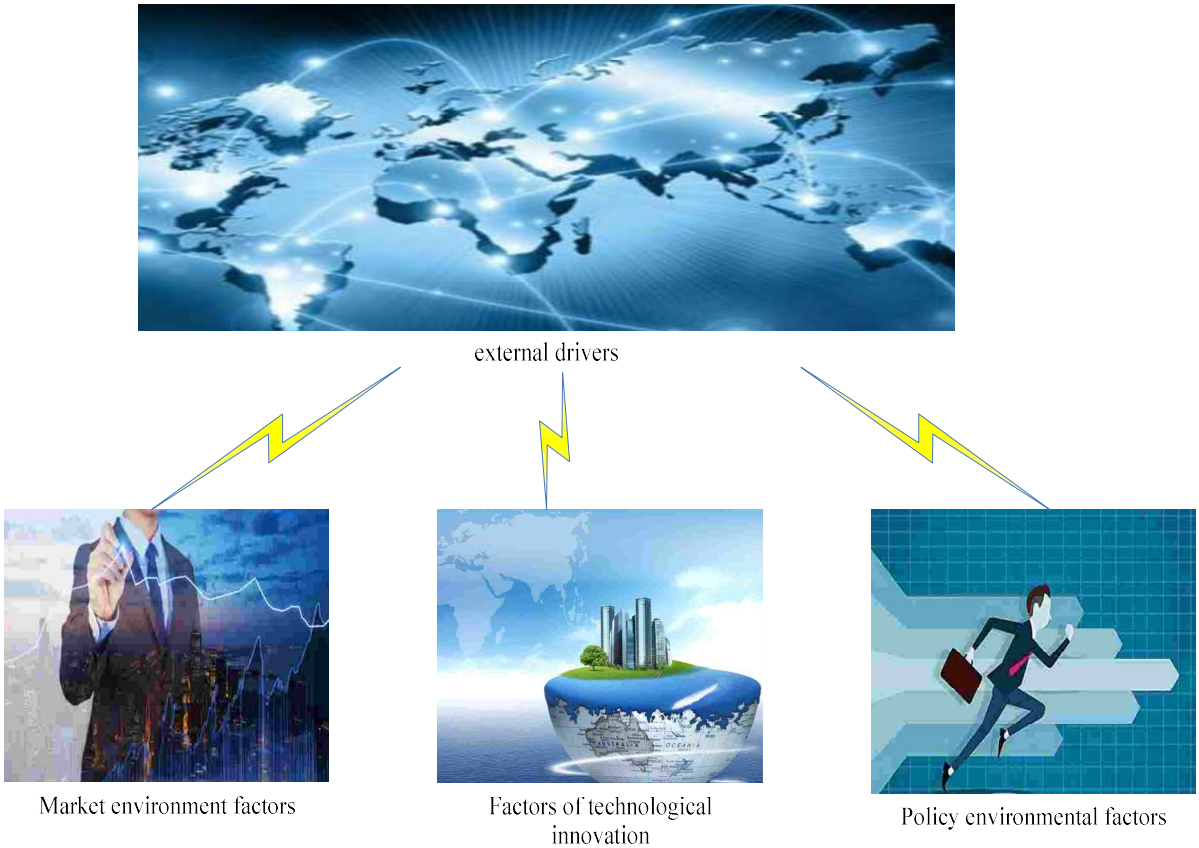

Figure 5: External drivers

Demand and market competitive variables will unavoidably influence the development of enterprise innovation strategies and propel the application of enterprise management innovation, as illustrated in Figure 5. It constantly stimulates enterprises to enhance their market competitiveness through R&D management, cost saving, production process control and other measures, to ensure the survival status of small and medium-sized enterprises, and to achieve business efficiency.

Enterprise management innovation is inevitably influenced by government policies, with policy guidance serving as a direct driver of such innovation. Supportive measures, such as industrial service policies, fiscal and tax subsidies, and incentives for technological talent, can accelerate industrial development. At the same time, these policies may prompt enterprises to adopt corresponding management innovations to align with macro-policy changes. For instance, initiatives like tax incentives or government-subsidized loans can help address issues like broken cash flows, enabling businesses to adapt more effectively. Favorable policy environments not only foster conditions conducive to management innovation but also encourage and motivate enterprises to actively engage in innovative practices.

The rapid advancement of science and technology has compressed the lifecycle of products and technologies, intensifying pressure on enterprises and compelling them to engage in continuous management innovation. Technological progress has significantly fueled the evolution of management practices. For instance, the rise of mechanization paved the way for specialized management techniques, while the advent of information technology catalyzed the development of ERP systems. These innovations have transformed information channels into intricate networks, fundamentally reshaping the entire management paradigm.

V. Innovative Management Model

V. A. Indicator Selection and Analysis

The concept of innovation management capability naturally prompts the question of how this capability evolves over time, which inherently involves a learning process. Simply accumulating experience—whether through success or failure—is insufficient. The critical factor lies in evaluating and reflecting on innovation management practices so that when similar challenges arise in the future, the organization is better prepared to address them with informed insights. While this learning cycle may seem straightforward, it is often neglected by organizations. Consequently, many organizations fall into the trap of repeating past mistakes, failing to learn from their own failures or those of others. For instance, some organizations lack identifiable checkpoints in their innovation processes, skipping post-mortem analyses and neglecting to extract valuable lessons for future initiatives. This oversight often stems from employees being overwhelmed with work, coupled with a fear of facing criticism or reprimands. However, failing to pause and reflect at the appropriate moment can lead to the repetition of errors. The core competencies of management are outlined in Table 1:

Table 1: Core competencies of innovation management

serial number	basic skill
1	identify
2	adjust
3	acquire
4	create
5	select
6	implement
7	carry out
8	study
9	Organizational development

This paper provides a review framework for innovation management, and lists some key indicators for reviewing enterprise innovation management capabilities for five key issues of innovation management. The five key questions are:

(1) Does the organization have an innovation strategy?
(2) Has the organization established effective external linkages?
(3) Does the organization have an effective implementation mechanism?
(4) Does the organization have an organizational climate that supports innovation?
(5) Is the organization a learning organization related to innovation management?

More specific indicators or special factors for evaluating the innovation process mainly include:

(1) New ideas generated by starting the product innovation system;
(2) Failure rate in product development or marketing;
(3) Customer Satisfaction Evaluation—the degree of product matching with customer needs;
(4) Product cost (relative to the industry average);
(5) Quality level (relative to the industry average);

(6) Manufacturing capacity (relative to the industry average);
(7) Detectability;
(8) Recyclability;
(9) The number of man-hours spent on each new product;
(10) The lead time of new technology;
(11) Evaluation of continuous improvement - the number of improvement suggestions per employee, the number of "problem solving" teams, the savings level of each employee, the accumulated savings, etc.

V. B. Extraction of Core Factors and Analysis of Management Innovation Capabilities

In order to intuitively show the distribution of core capabilities of enterprises in management innovation, this figure presents the innovation capability scores of enterprises in four key dimensions: quality, category, promotion and price in the form of a bar chart. These dimensions are extracted and reduced by big data technology, which can fully reflect the management innovation capabilities of enterprises. The results are shown in Figure 6.

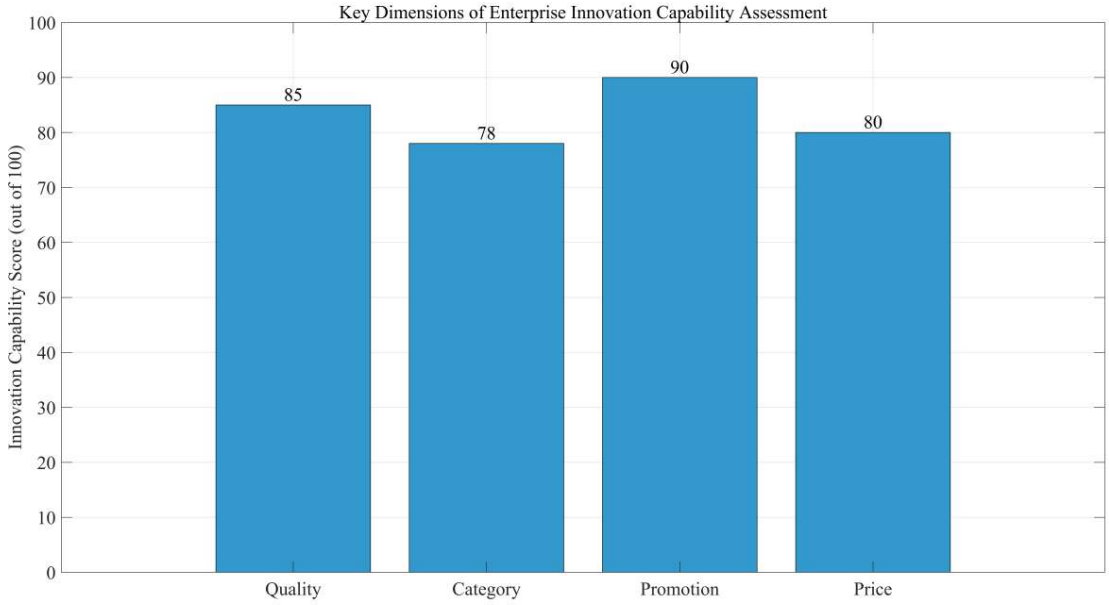

Figure 6: Key dimensions of enterprise innovation capability assessment

As can be seen from Figure 6, the company's innovation ability score in the promotion dimension is the highest (90 points), which shows that the company has outstanding performance in brand building and marketing strategy. Secondly, the score of the quality dimension is 85 points, reflecting that the company has strong competitiveness in the core value of products and services. In contrast, the scores of the category and price dimensions are slightly lower, at 78 and 80 points respectively, which suggests that the company still has room for improvement in product diversity and pricing strategies. Overall, companies need to further optimize resource allocation, especially in improving product variety coverage and cost-effectiveness, in order to enhance market competitiveness.

In order to explore the changing rules of the innovation capability of enterprises in different stages of the life cycle, this figure shows the changing trend of the innovation capability score of enterprises in the five stages of incubation, survival, rapid development, maturity and decline through a line chart. This analysis helps to understand the relationship between enterprise innovation activities and life cycle. The results are shown in Figure 7.

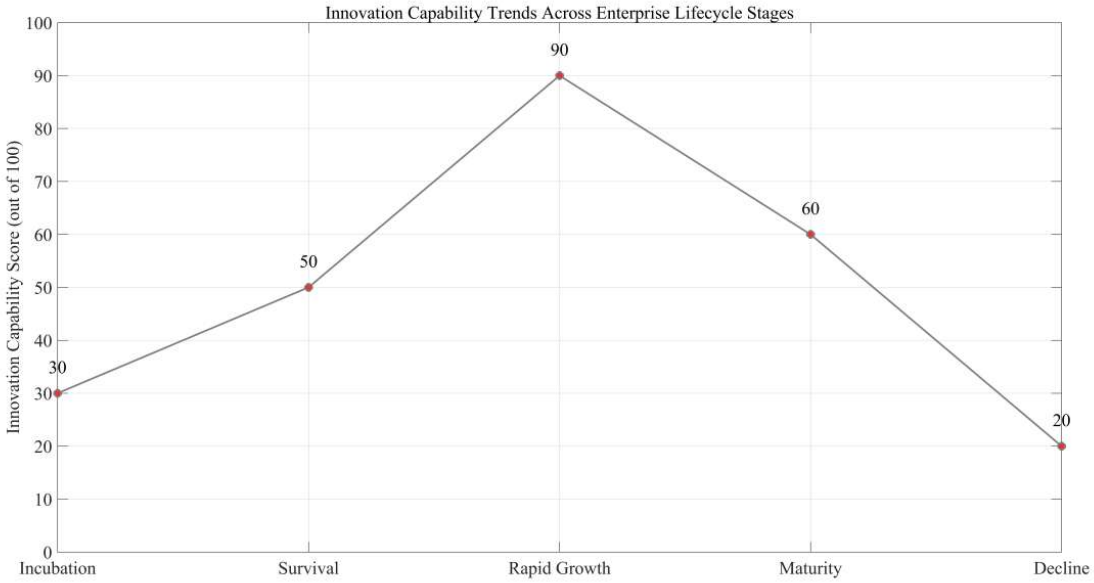

Figure 7: Trends in innovation capabilities at different stages of the enterprise life cycle

It is obvious from the figure that the innovation capability of enterprises in the rapid growth period reaches a peak of 90 points, which is due to the fact that enterprises focus on technological innovation and standardized management in this stage to expand market share. However, in the maturity and decline, the innovation capability scores dropped to 60 points and 20 points respectively, reflecting that enterprises may face stagnant growth and weakened innovation awareness of employees. In addition, the innovation capability score in the incubation is 30 points, indicating that start-ups have relatively weak innovation capabilities under limited resources. Therefore, enterprises should adopt differentiated innovation strategies at different stages of the life cycle, especially in the mature and declining stages, they need to strengthen transformation and technological upgrading.

In order to compare the differences in innovation capabilities among enterprises of different sizes, this table conducts comparative analysis from four dimensions: innovation input, innovation output, customer satisfaction, and market share growth rate. This analysis helps to reveal the changing pattern of innovation capabilities of enterprises during the process of scale expansion. The results are shown in Table 2.

Table 2: Comparative analysis of innovation capabilities of enterprises of different sizes

Business size	Innovation investment(%)	Innovation output (number of patents)	Customer satisfaction	Market share growth rate (%)
Small business	5.2	12	7.8	3.5
Medium business	8.6	25	8.5	6.2
Large business	12.4	45	9.2	8.7

As can be seen from the table, large enterprises have shown significant advantages in both innovation input and output. Their innovation input accounts for as high as 12.4%, far higher than the 5.2% of small enterprises, and the number of patents has reached 45, nearly four times that of small enterprises. In addition, large enterprises also have the highest customer satisfaction and market share growth rates, 9.2 points and 8.7% respectively, indicating that their innovation capabilities are directly converted into market competitive advantages. In contrast, small enterprises are at a disadvantage in all indicators, but their lower innovation investment and flexible operating model still provide them with potential development space. Therefore, small enterprises can achieve breakthroughs through precise positioning and efficient management, while large enterprises need to continue to increase innovation investment to maintain their leading position.

VI. Conclusions

Based on the background of big data, this paper explores the specific path of innovation in the management model of private enterprises and reveals its key role in improving the competitiveness of enterprises. The study shows that big data technology provides strong technical support for the management innovation of private enterprises by providing scientific decision-making support, optimizing resource allocation and improving information processing capabilities. In particular, at different stages of the life cycle, enterprises need to adopt differentiated innovation strategies to cope with changes in the internal and external environment. For example, in the rapid growth period, enterprises should focus on technological innovation and standardized management, while in the mature and declining stages, they need to strengthen transformation and technological upgrading to avoid stagnation. In addition, the four core factors of quality, category, promotion and price extracted through factor analysis provide a scientific basis for the optimization of enterprise management models. Large enterprises have significant advantages in innovation input and output, while small and medium-sized enterprises can achieve breakthroughs through precise positioning and efficient management. Future research can further combine industry characteristics, refine innovation evaluation indicators, and explore the application cases of new management models driven by big data to provide more practical guidance for the sustainable development of private enterprises.

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Conflicts of Interest

The authors declare that there is no conflict of interest with any financial organizations regarding the material reported in this manuscript.

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