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Impact of Technological Innovation Capacity Factors on the Sustainable Development in China's Biopharmaceutical Industry

Kexin Wang *
Faculty of Economics, Peoples' Friendship University of Russia (RUDN University), 6 Miklukho-Maklaya Street, 117198 Moscow, Russia.
ORCID: https://orcid.org/0000-0002-2975-7379
Email: 1042218199@pfur.ru

Yuliana Solovieva
Faculty of Economics, Peoples' Friendship University of Russia (RUDN University), 6 Miklukho-Maklaya Street, 117198 Moscow, Russia
ORCID: https://orcid.org/0000-0002-1437-0008
Email: solovyeva-yuv@rudn.ru

*Corresponding Author Email: 1042218199@pfur.ru

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Abstract
Sustainability has increasingly become a focal point across various research domains, particularly within emerging industries. Among these, the biopharmaceutical sector holds a significant position in the evolving Chinese economic landscape. The substantial potential of this field, and its alignment with sustainability and sustainable entrepreneurship, is closely linked to the sector's capacity for technological innovation and its ability to address development-related challenges. Nonetheless, in developing countries such as China, there remains a notable deficiency in initiatives aimed at cultivating such impact capacities. The sector has largely overlooked opportunities to leverage its influence to advance industrial development. The rapid progression of economic and technological innovation, coupled with uneven developmental patterns, has resulted in heightened uncertainty, increased interdependence, and a growing network of mutual connections. To comprehend this collaborative operational paradigm, it is essential to focus on intentional management approaches and to assess both the extent and nature of interactions among various influencing elements within these complex, large-scale systems. Without a comprehensive analytical framework,

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sustainable industrial development and entrepreneurial innovation within the sector are likely to encounter considerable difficulties. These obstacles may impede progress not only in enterprise-level innovation but also in the broader sustainable advancement of key strategic industries related to biopharmaceuticals. This research aims to construct an impact model grounded in a hierarchical theoretical framework, employing Interpretive Structural Modelling (ISM) in conjunction with the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, to identify and evaluate the foundational challenges that must be addressed in order to realise sustainability-oriented development goals.

Keywords: Sustainable Entrepreneurship, Economic Uncertainty, Technological Innovation Factors, Biopharmaceutical Industry, China.

Introduction

The United Nations' elaboration and expansion of sustainable development principles have clearly delineated the essential objectives that must be pursued. Within this context, China's knowledge-intensive and rapidly expanding emerging strategic industries, notably the biopharmaceutical sector, must prioritise sustainability as a core developmental imperative. Achieving sustainability within an industry is vital for meeting these global objectives (Sachs et al., 2019). Central to this pursuit is technological innovation, which serves as a key driver and accelerator of sustainable economic growth. Such innovations are inherently dynamic and represent a crucial aspect of industrial progress. Schumpeter (1943) notion of "creative destruction" encapsulates the transformative role of innovation, enabling new industries to assume competitive leadership (Dodgson & Gann, 2010; Yoon & Kwon, 2023).

However, despite its importance, the biopharmaceutical sector also confronts multiple challenges and complexities arising from innovation and technological development within enterprise operations and commercial processes. At present, it remains difficult to pinpoint the core determinants that most significantly impact the sustainability of innovation in such a multifaceted environment. These determinants are industry-specific, and their scope and influence vary depending on the industrial context. In China, the biopharmaceutical sector possesses considerable potential to contribute meaningfully to economic development (Ji et al., 2022). It approaches sustainability through a broad and multidimensional lens, focusing on progress across three principal dimensions: economic, social, and environmental (Lalor et al., 2019).

In this regard, technological innovation emerges as a vital dynamic factor capable of identifying and addressing challenges stemming from adverse external environments, particularly within the biopharmaceutical domain, to support sustainability objectives (Singh et al., 2022). Over recent decades, the pharmaceutical industry has evolved into one of the most advanced sectors, largely owing to its sustained innovative efforts aimed at responding to emerging medical needs (Singh et al., 2022). Within this

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transformation, biopharmaceutical innovations have become increasingly important in translating scientific discoveries into new drug solutions, thereby making a substantial contribution to public health system development. These innovations demand high technology utilisation, entail significant risks, require substantial investment, involve lengthy development cycles, and offer high profit margins (Feng et al., 2023).

Government incentives play a particularly important role in stimulating biopharmaceutical innovation, especially in developing nations where healthcare challenges coincide with limited research and development (R&D) capacities (Geng & Shi, 2024). Analysing the processes underpinning innovation development and accurately forecasting new opportunities are essential, particularly when refining research directions and mitigating potential risks (Cao et al., 2023; Duda et al., 2014).

As living standards in China improve, citizens are incurring higher healthcare costs, prompting increased government investment in the healthcare infrastructure (Geng & Shi, 2024; Han, 2009). Concurrently, the proportion of elderly individuals within the population is rising. Despite narrow short-term profit margins, leading domestic pharmaceutical firms continue to pursue aggressive growth strategies aimed at securing long-term advantages (Brueckner et al., 2005; Hsu & Fan, 2022). These strategies involve optimising the entire value chain, including active pharmaceutical ingredient development, R&D, productivity-focused drug development, and generics manufacturing. Nonetheless, several issues persist, including administrative inefficiencies, low public healthcare expenditure, weak intellectual property protection, and inadequate distribution infrastructure. A critical lack of investment continues to constrain the full potential of biopharmaceutical R&D (Xu & Guo, 2019).

Furthermore, prior research highlights enduring problems in the entrepreneurial dynamics of the sector, such as the extended R&D cycles and the inefficiency in converting research findings into practical clinical applications (Wang et al., 2021). Compared to developed nations, biopharmaceutical innovation in developing countries remains relatively limited, primarily due to the modest scale of their markets, which is influenced more by low per capita income and insufficient political support than by population size (Zhang & Nie, 2021). Policy and social decision-making play a critical role in shaping innovation, particularly in collaborative models involving multiple stakeholders (Ollila & Yström, 2024). These relationships can be effectively examined through analytical models such as the Negative Binomial Regression (Papazoglou & Nelles, 2023), the Vector Autoregression (VAR) model (Hsu & Fan, 2022), and the DEMATEL approach (Alinezhad & Khalili, 2019).

Given these considerations, it is essential to assess and differentiate the factors that align with sustainability and to unravel the complex interrelationships among them within the context of China's biopharmaceutical sector. Addressing these analytical gaps, the current study aims to identify critical influencing factors and evaluate their

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interconnections. To achieve this, the Decision-Making Trial and Evaluation Laboratory method is integrated with Interpretive Structural Modelling (DEMATEL-ISM) to systematically categorise the challenges associated with these influential factors.

Literature Review

Based on a comprehensive review of relevant literature and empirical evaluations conducted by multiple experts, the capability for innovation within the biopharmaceutical sector has been categorised into five key indicators: research and development capacity, innovation-driven incentives, supportive infrastructure, governmental policy frameworks, and productive output capability.

Research and Development (R&D) Capability

The interrelationship between R&D capabilities and other influencing factors can be examined through empirical assessments conducted by domain experts. Evidence from such analyses demonstrates a direct correlation between R&D investment and the profitability of biopharmaceutical firms, where limited R&D engagement is typically associated with reduced financial performance (Cao & Yi, 2018). An empirical investigation by Dong and Gou (2010) further revealed that company performance within the biopharmaceutical industry is significantly affected by expenditure on R&D personnel. Additional studies by Pandit et al. (2011) and Ciftci and Cready (2011) highlighted that R&D investments and patent outputs from enterprises, academic institutions, and research bodies collectively contribute to enhanced profitability. Furthermore, it has been shown that financial instruments can be effectively utilised to improve firms' technological innovation capabilities (Tang et al., 2022). Data derived from Italy's extensive enterprise-level databases illustrate that R&D spending has a tangible impact on profitability, particularly in relation to the introduction of new technologies. These findings suggest that the enhancement of R&D capacities may be facilitated through the adoption and internalisation of innovative technologies (Parisi et al., 2006).

Innovation Incentives

A thorough examination of innovation within the biopharmaceutical sector indicates that technological evolution and shifts in the socio-environmental context significantly influence the motivational dynamics of innovators, thereby enhancing their engagement in biopharmaceutical innovation processes (Kinch & Moore, 2016). The development and application of novel materials, technologies, compounds, and ingredients intended for medicinal purposes serve to address rising societal demands in a manner that is both sustainable and cost-effective. Additionally, literature reviews conducted using Scopus and Web of Science databases suggest that innovation exerts a substantially positive influence on corporate performance, policy formulation, economic expansion, and the advancement of sustainable industrial frameworks

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(Dzhunushalieva & Teuber, 2024).

Innovation capacity serves as a crucial benchmark for determining whether a biopharmaceutical organisation possesses the competence to successfully develop new therapeutic products. Synthesising findings from multiple scholars, it becomes evident that innovation capacity is shaped by numerous interconnected factors. For instance, Murovec and Prodan (2009) argue that collaboration with academic and research institutions plays a pivotal role in strengthening a firm's capacity to absorb and apply research-driven innovations. Absorptive capacity, defined as the ability to implement novel outputs arising from technological progress, is a central component in fostering innovation. The mutually reinforcing nature of technological advancement and innovation underscores this interdependence. Organisations with a well-developed absorptive capacity are better equipped to autonomously comprehend, internalise, and apply upstream technological innovations, thereby reinforcing their own innovation potential.

Support Capacity

Support capability represents a critical criterion for assessing the feasibility and effectiveness of innovation activities within biopharmaceutical enterprises. Empirical findings reported by Zhou and Zhang (2015) indicate that, holding other control variables constant, enterprises with greater operational scale tend to allocate more financial and human resources toward innovation-related activities. Similarly, Fu et al. (2018) concluded, based on empirical evidence, that financial assistance provided by the government significantly contributes to the expansion of market capacity, particularly in the context of marine biopharmaceutical enterprises.

Government Policy

The Chinese government adopts a broad strategic vision for industrial advancement, aiming to foster innovation and sustainable development across all sectors (Băzăvan, 2019). A range of targeted fiscal support policies has been implemented to encourage enterprises to optimise their resource distribution by engaging in research and development initiatives (Chang et al., 2002; Howell, 2017; Levy & Terleckyj, 1983). Drawing a comparison with the United States, it is evident that local governments place considerable emphasis on nurturing research-driven clusters, particularly within the life sciences domain. Specific policy frameworks have been introduced to support the biotechnology industry by enhancing its technological innovation capabilities (Moretti & Wilson, 2014). Moreover, studies involving data from developing economies, including China, demonstrate that policy measures such as public health insurance provision and government financial incentives can effectively drive pharmaceutical firms to develop novel medical technologies and improve healthcare standards (Zhang & Nie, 2021).

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In the Chinese context, empirical analysis suggests that state-sponsored financial policies exert a particularly strong influence in promoting innovation. Enhancements to the public health insurance framework and financial aid mechanisms are predicted to significantly encourage innovation activities within the pharmaceutical sector (Zhou & Zhang, 2015). Within the paradigm of innovation economics, existing research further supports the notion that government policy tools and incentives play a vital role in enhancing the output of innovative products (David et al., 2000; Wade, 2017). The consistent and standardised application of these policy tools contributes to the effective functioning of market mechanisms, especially in safeguarding intellectual property rights associated with technological innovations in the biopharmaceutical sector (Buesa et al., 2010). Analyses of China's innovative drug development over the past two decades reveal that regulatory reforms and institutional improvements have reshaped the developmental landscape. Establishing a robust regulatory environment has proven instrumental in accelerating the innovation and deployment of new pharmaceutical products both domestically and internationally (Liu et al., 2022).

Output Capacity

The generation of new patents within the biopharmaceutical sector is widely regarded as a key indicator of technological knowledge creation. Scholars have examined the broader national context alongside innovation activity in enterprises and academic institutions, identifying these elements as critical determinants of patent output. Using European data as a reference, output capability has been utilised as a metric to assess firms' innovation performance (Buesa et al., 2010). Empirical research conducted by Fan and Chen (2018) concluded that the volume of patent production is significantly and positively associated with the level of financial investment and the number of R&D personnel. Additionally, Yang and Chen (2010), along with more recent findings by Sommer (2022), discovered a U-shaped relationship between patent output and the age profile of R&D staff, suggesting that both younger and more experienced personnel contribute substantially to innovation outcomes. Corporate profitability also plays a crucial role in enhancing a firm's capacity for technological innovation. In line with this, Han et al. (2023) affirm that improvements in corporate profitability directly support the expansion of innovation capabilities.

Results

This study employed a questionnaire-based survey approach to gather data from professionals within the Chinese biopharmaceutical sector. The respondents comprised practitioners, researchers, and industry experts affiliated with 15 different institutions and organisations, including hospitals, pharmaceutical companies, and relevant government agencies located in Beijing and Zhengzhou, Henan Province. A total of 133 completed questionnaires were collected, of which 130 were deemed valid.

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Consequently, the final sample size was set at 130 respondents. The survey marked the beginning of the practical phase of sample implementation. Drawing on a review of existing literature, the study aimed to identify and categorise the key factors influencing technological innovation within biopharmaceutical enterprises. Through a combination of literature synthesis and statistical analysis of the survey data, 18 potential influencing factors were identified as relevant within the context of the biopharmaceutical industry.

Delphi Methods

Building on the methodological approach developed by Bianchi and colleagues, which involved expert interviews within industry contexts (Bianchi et al., 2011), the current study adopts and adapts this framework through the use of the Delphi technique. This method typically comprises several stages, including the solicitation of a broad range of expert insights, aggregation of responses, provision of anonymised feedback, and the pursuit of consensus among participants regarding the research subject. The expert panel assembled for this study consisted of professionals and researchers with relevant experience in the biopharmaceutical field. A total of 18 technological innovation influencing factors were identified, and their initial presence within the 133 valid survey responses was summarised in Table 1. These results were used to derive correlation scores reflecting the degree to which each factor impacts innovation in the biopharmaceutical industry. Following the collection and synthesis of expert feedback, a classification structure was established. The final list of 18 influencing factors was organised into five overarching categories: R&D capability, innovation capability, support capacity, government policy, and output capacity, as detailed in Table 2.

Table 1: Basic Information of the Relevant Experts.

Working Area	Numbers of People	Title/Education	Relevant Work Years
Bio-Pharmaceutical Companies' Worker	93	10 Managers, 24 Bachelor's Degree, 59 Employees (Employed by Biopharmaceutical Companies based in Beijing, Zhengzhou)	5-7
Bio-Pharmaceutical Researcher	20	7 Doctors, 13 Master's Degree	9-12
Related Universities Professor	7	6 Ph.D., 1 Undefined	10-15
Government Worker	13	6 Bachelor's Degree, 7 Master's Degree	4-8

Source: Authors Compilation

Drawing from an extensive review of relevant literature and supported by

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empirical evaluations conducted by domain experts, the influencing elements were categorised under five principal indicators: R&D capability, innovation capability, support capacity, government policy, and output capacity. Within this classification framework, a total of 18 secondary indicators (x_i) were identified as having a significant impact. These indicators are summarised and presented in Table 2. Based on the influencing factors outlined in Table 2, a scoring exercise was conducted involving 130 participants, including academics from universities and colleges, as well as experts and senior executives from biopharmaceutical enterprises. Each participant assessed the degree of impact of the identified factors using a four-point scale, where a score of 1 indicated minimal impact and a score of 4 indicated maximum impact. This process generated 130 individual matrices. The average of these scores was then computed and rounded to the nearest integer to construct the composite matrix representing the technological innovation capability of the biopharmaceutical industry, as illustrated in Table 3.

Table 2: Impact Factors Identify.

Primary	Secondary	Symbolic Representation
R&D Capability	Lack of R&D Investment	x_1
	Lack of Investment of R&D Personnel within the Enterprise	x_2
	Lack of Participation of R&D Personnel from Universities, R&D Institutions	x_3
	Age of R&D Personnel	x_4
Innovation Incentives	Lack of Ability to Think Creatively	x_5
	Lack of Innovation Absorption Capacity	x_6
	Lack of Ability to Independently Carry Out Innovative Activities	x_7
	Lack of Ability to Integrate Innovative Elements	x_8
	Low Collaborative Cooperation Ability of Innovation Entities	x_9
Support Capacity	Enterprise Size	x_{10}
	Lack of Marketing Capability	x_{11}
Government Policy	Lack of Medical Insurance Policy	x_{12}
	Lack of Intellectual Property Protection Policy for Bio-Pharma	x_{13}
	Lack of Financial Support Policy	x_{14}
	Lack of Technology Development Loan Policy	x_{15}
	Lack of Drug Regulatory Policy	x_{16}
Output Capacity	Lack of Output of New Drug Patents	x_{17}
	Low Corporate Profitability	x_{18}

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Source: Authors' Compilation.

Table 3: Direct Impact Matrix B.

Factor	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
x_1	0	3	3	1	0	3	0	0	0	0	0	0	0	0	4	0	4	3
x_2	1	0	2	0	0	1	0	0	1	0	0	0	0	2	3	0	2	1
x_3	3	3	0	0	0	2	0	0	1	0	0	0	0	2	3	0	3	1
x_4	1	2	0	0	3	0	1	1	1	0	0	0	0	0	0	0	1	0
x_5	0	0	1	1	0	2	0	1	2	3	0	0	0	4	4	1	2	0
x_6	0	0	1	2	1	0	0	1	0	1	0	0	0	1	1	0	1	1
x_7	0	0	0	0	1	1	0	0	1	1	0	0	0	1	1	0	0	0
x_8	0	0	1	4	1	1	1	0	0	1	0	0	0	4	2	0	1	0
x_9	0	0	0	2	2	1	0	1	0	0	0	0	0	3	1	0	0	0
x_{10}	4	0	2	1	2	2	0	0	2	0	4	0	0	0	3	0	1	4
x_{11}	2	0	1	3	0	0	0	0	3	4	0	1	0	2	0	1	0	3
x_{12}	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	1
x_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
x_{14}	0	1	1	0	2	1	0	0	0	3	0	0	4	0	0	0	1	1
x_{15}	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	3	1
x_{16}	0	0	0	1	0	0	0	1	0	1	1	3	2	1	0	0	0	1
x_{17}	1	0	0	0	1	0	1	0	0	1	0	0	0	1	3	3	0	4
x_{18}	4	3	1	0	3	0	0	0	3	4	3	0	0	4	3	0	3	0

Source: Authors' Compilation.

A hybrid analytical framework combining DEMATEL and ISM methodologies was developed using MATLAB software. This integrated system applies principles of system analysis grounded in graph theory and matrix-based tools to model the causal relationships and intensity of influence among identified factors. The approach facilitates the visual representation of causal linkages and centrality levels, thereby helping to identify key influencing variables and their relative impact within a complex system. Despite its strengths, this method on its own is limited in its ability to distinguish between primary, secondary, and overarching structural relationships among the influencing factors. Moreover, traditional applications of DEMATEL have typically been restricted to small-scale or less complex systems, often without addressing hierarchical arrangement or consistency in expert opinions (Du & Shen, 2023). To address these limitations, the ISM method was incorporated into the analysis, providing logical structure and enabling the construction of a hierarchical model for deeper exploration of the interrelationships among factors.

DEMATEL Centrality-Causality Result

The procedure for deriving the required matrices involves the following steps:

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Step 1: Clearly Identify and Define the Constituent Elements within the System under Study

Step 2: Establish the Direct Impact Matrix

To construct this matrix, expert evaluation is used to assess the influence of each element x_i on every other element x_j. Since a factor does not affect itself, the diagonal values are set to 0. Once all pairwise comparisons are completed, the resulting matrix is recorded as matrix A.

$$A = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & 0 \end{bmatrix}$$

In the formula, the term x_{ij} represents the extent to which factor x_i influences factor x_j. When i equals j, indicating that a factor is being compared with itself, the value of x_{ij} is set to 0.

Steps 3: Normative Direct Impact Matrix

Each row of matrix A is summed, and the highest value among these row totals is identified. Using this maximum value, the elements in matrix A are then normalised to produce the direct impact matrix, referred to as matrix B.

$$B = \frac{x_{ij}}{max \sum_{j=1}^{n} x_{ij}} \quad (1)$$

Step 4: Calculate the Total Relation Impact Matrix

When the normalised direct impact matrix is repeatedly multiplied by itself, the resulting values gradually converge towards zero, such that $\lim_{k\to\infty} B^k = 0$;. Based on this process, the total relation impact matrix, denoted as Q, is derived.

$$Q = (B + B^2 + B^3 \cdots + B^r) = \sum_{r=1}^{\infty} B^r \quad (2)$$

Step 5: Impact Degree, Affected Degree, Centrality, and Causality

The impact degree is calculated by summing the values across each row of matrix Q. This sum reflects the overall influence exerted by the corresponding element and is denoted as M_i.

$$M_i = \sum_{j=1}^{n} x_{ij}, (i = 1,2,3, \dots, n) \quad (3)$$

The degree to which each element is affected is determined by summing the values

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within each column of matrix Q. This value is represented as N_i.

$$N_i = \sum_{j=1}^{n} x_{ij}, (i = 1,2,3, \dots, n) \quad (4)$$

Centrality reflects the significance of a given factor within the constructed system and is represented as G_i.

$$G_i = M_i + N_i \quad (5)$$

The degree of causality for element i is determined by subtracting its affected degree from its impact degree. This is expressed as R_i.

$$R_i = M_i - N_i \quad (6)$$

By applying formulas (1) and (2), the total relation impact matrix is obtained, as presented in Table 4. Using formulas (3) to (6), the corresponding values from Table 3 are processed to calculate the impact degree, affected degree, centrality, and causality for each influencing factor. These results are compiled in Table 5. Based on the data from Table 3, a centrality–causality map is generated in MATLAB, as illustrated in Figure 1. Moreover, the 18 identified factors are classified according to their causality and centrality values. Among these, the most prominent are lack of R&D investment (x_1), enterprise size (x_{10}), and low corporate profitability (x_{18}), with respective scores of 3.481, 3.060, and 2.060. These values indicate a strong interrelationship among the three factors.

Table 4: Total Relation Impact Matrix Q.

Factor	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
x_1	0.053	0.1335	0.1261	0.0506	0.0403	0.1228	0.0084	0.0086	0.0335
x_2	0.0584	0.024	0.0815	0.0121	0.0245	0.0521	0.004	0.0047	0.0474
x_3	0.1265	0.1244	0.0336	0.0184	0.0314	0.0924	0.0059	0.0068	0.0524
x_4	0.0452	0.0745	0.0183	0.0162	0.1119	0.0218	0.0358	0.0387	0.0482
x_5	0.0404	0.0249	0.0609	0.0606	0.0461	0.0948	0.0072	0.0428	0.0894
x_6	0.026	0.0197	0.0476	0.0774	0.0583	0.0177	0.0058	0.0378	0.0194
x_7	0.0106	0.0056	0.0097	0.0101	0.0453	0.0428	0.001	0.0046	0.041
x_8	0.0271	0.0251	0.0516	0.1421	0.0707	0.055	0.0392	0.0096	0.0219
x_9	0.0114	0.0129	0.014	0.0778	0.0874	0.0475	0.0046	0.0394	0.0131
x_{10}	0.1967	0.0578	0.1144	0.0777	0.1188	0.1123	0.0072	0.0145	0.121
x_{11}	0.125	0.0462	0.0725	0.1263	0.0600	0.0426	0.0067	0.0132	0.1397
x_{12}	0.0088	0.0072	0.0059	0.0061	0.0116	0.006	0.0007	0.0031	0.0389
x_{13}	0.0035	0.0026	0.0027	0.0011	0.005	0.0026	0.0012	0.0005	0.0019
x_{14}	0.0374	0.0505	0.0564	0.0171	0.0898	0.0573	0.0032	0.0065	0.0274
x_{15}	0.0198	0.0094	0.0094	0.0058	0.0154	0.0081	0.0039	0.0017	0.012
x_{16}	0.0213	0.0136	0.0139	0.0463	0.0209	0.0121	0.0034	0.0354	0.0202
x_{17}	0.0728	0.0297	0.0265	0.0181	0.0668	0.0243	0.0347	0.0079	0.0329
x_{18}	0.2016	0.1453	0.0968	0.0482	0.1579	0.0665	0.0085	0.0146	0.1532

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Table 4(continued): Total Relation Impact Matrix Q.

Factor	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
x_1	0.0514	0.0225	0.0028	0.016	0.060	0.2115	0.0217	0.2044	0.158
x_2	0.0323	0.0113	0.0015	0.0176	0.0951	0.1408	0.0117	0.1095	0.07
x_3	0.0407	0.0143	0.0021	0.0201	0.1059	0.1644	0.0168	0.1589	0.0885
x_4	0.0249	0.0057	0.0011	0.007	0.0377	0.0457	0.0098	0.0628	0.0229
x_5	0.1441	0.0258	0.0052	0.0315	0.1737	0.1884	0.0461	0.1209	0.0595
x_6	0.0596	0.0137	0.0013	0.0109	0.0626	0.0709	0.0087	0.0659	0.0593
x_7	0.0478	0.0077	0.0006	0.0081	0.0482	0.0514	0.0034	0.0171	0.0153
x_8	0.0696	0.0127	0.0014	0.0245	0.1583	0.1056	0.0099	0.0748	0.0355
x_9	0.0288	0.0055	0.0007	0.0179	0.1212	0.059	0.0056	0.0272	0.0172
x_{10}	0.0833	0.1606	0.0072	0.0193	0.0868	0.2027	0.0218	0.1319	0.2104
x_{11}	0.1805	0.0399	0.0374	0.0226	0.1245	0.0813	0.043	0.0692	0.1584
x_{12}	0.0139	0.0068	0.0035	0.0407	0.0472	0.0119	0.0338	0.0117	0.0405
x_{13}	0.0068	0.0017	0.0004	0.0051	0.0359	0.0067	0.0037	0.0363	0.0078
x_{14}	0.1279	0.0239	0.0018	0.137	0.042	0.0565	0.011	0.0761	0.073
x_{15}	0.0498	0.0125	0.0015	0.0361	0.0186	0.0286	0.0118	0.1133	0.0589
x_{16}	0.0562	0.0449	0.0982	0.0762	0.0601	0.0245	0.0075	0.0232	0.0559
x_{17}	0.0843	0.0306	0.0111	0.0223	0.0805	0.1528	0.1049	0.0568	0.1709
x_{18}	0.2141	0.1352	0.0071	0.0371	0.2156	0.2245	0.029	0.202	0.1111

Source: Authors' Compilation.

Table 5: DEMATEL Comprehensive Impact Results.

DEMATEL	Influence Degree	Affect Degree	Centrality	Causality
x_1	1.321	1.085	2.410	0.239
x_2	0.798	0.806	1.605	-0.008
x_3	1.103	0.841	1.945	0.261
x_4	0.628	0.812	1.440	-0.183
x_5	1.262	1.062	2.324	0.200
x_6	0.662	0.878	1.541	-0.216
x_7	0.370	0.181	0.551	0.188
x_8	0.934	0.290	1.225	0.644
x_9	0.591	0.913	1.504	-0.322
x_{10}	1.744	1.316	3.060	0.428
x_{11}	1.389	0.575	1.964	0.813
x_{12}	0.298	0.184	0.483	0.113
x_{13}	0.125	0.550	0.675	-0.424
x_{14}	0.894	1.573	2.468	-0.679
x_{15}	0.416	1.827	2.243	-1.410
x_{16}	0.633	0.400	1.034	0.233
x_{17}	1.027	1.562	2.589	-0.534
x_{18}	2.068	1.413	3.481	0.655

Source: Authors' Compilation.

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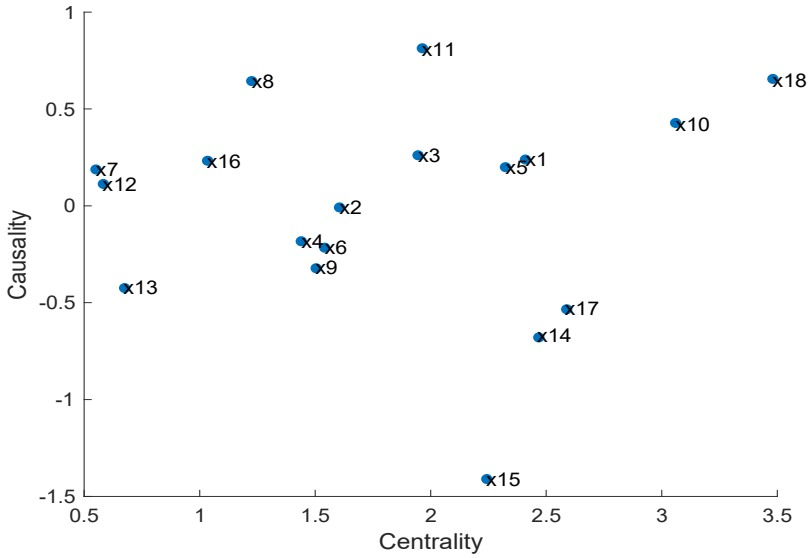

Figure 1: DEMATEL Centrality-Causality Analysis Results.
Source: Authors' Compilation.

ISM Results

$$f_{ij} = \begin{cases} 0, & e_{ij} < \lambda \ (i,j = 1,2,3,\dots,n) \\ 1, & e_{ij} \geq \lambda \ (i,j = 1,2,3,\dots,n) \end{cases} \quad (7)$$

Based on matrix Q, a binary matrix (Table 6) consisting of values 0 and 1 is constructed. A value of 1 signifies a strong correlation between two factors, whereas 0 indicates either no relationship or a weak association.

Table 6: Total Relation Impact Matrix Q.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
x_1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
x_2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
x_4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0
x_6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
x_7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
x_8	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
x_9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
x_{10}	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_{11}	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_{12}	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
x_{13}	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
x_{14}	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
x_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
x_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
x_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
x_{18}	1	0	0	0	1	0	0	0	1	1	0	0	0	1	1	0	0	1

Source: Authors' Compilation.

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By integrating the information from Table 2 and Table 7, an interpretive structural model is developed, which is presented in Figure 2. This leads to the construction of a hierarchical ISM framework that outlines the influencing factors, based on the specific content provided in Table 1. Moreover, Figure 2 illustrates that, based on ISM analysis, the factors influencing the technological innovation capability of biopharmaceutical enterprises are categorised into three hierarchical levels. This model reveals a structured pathway comprising direct, indirect, and deeply embedded interactions among indicators. Thin arrows represent the influence directed towards higher levels, dotted arrows indicate relationships within the same level, while thick arrows reflect cross-level interactions. The strength of influence exerted by factors on innovation capability diminishes progressively from the lower to the upper layers of the hierarchy.

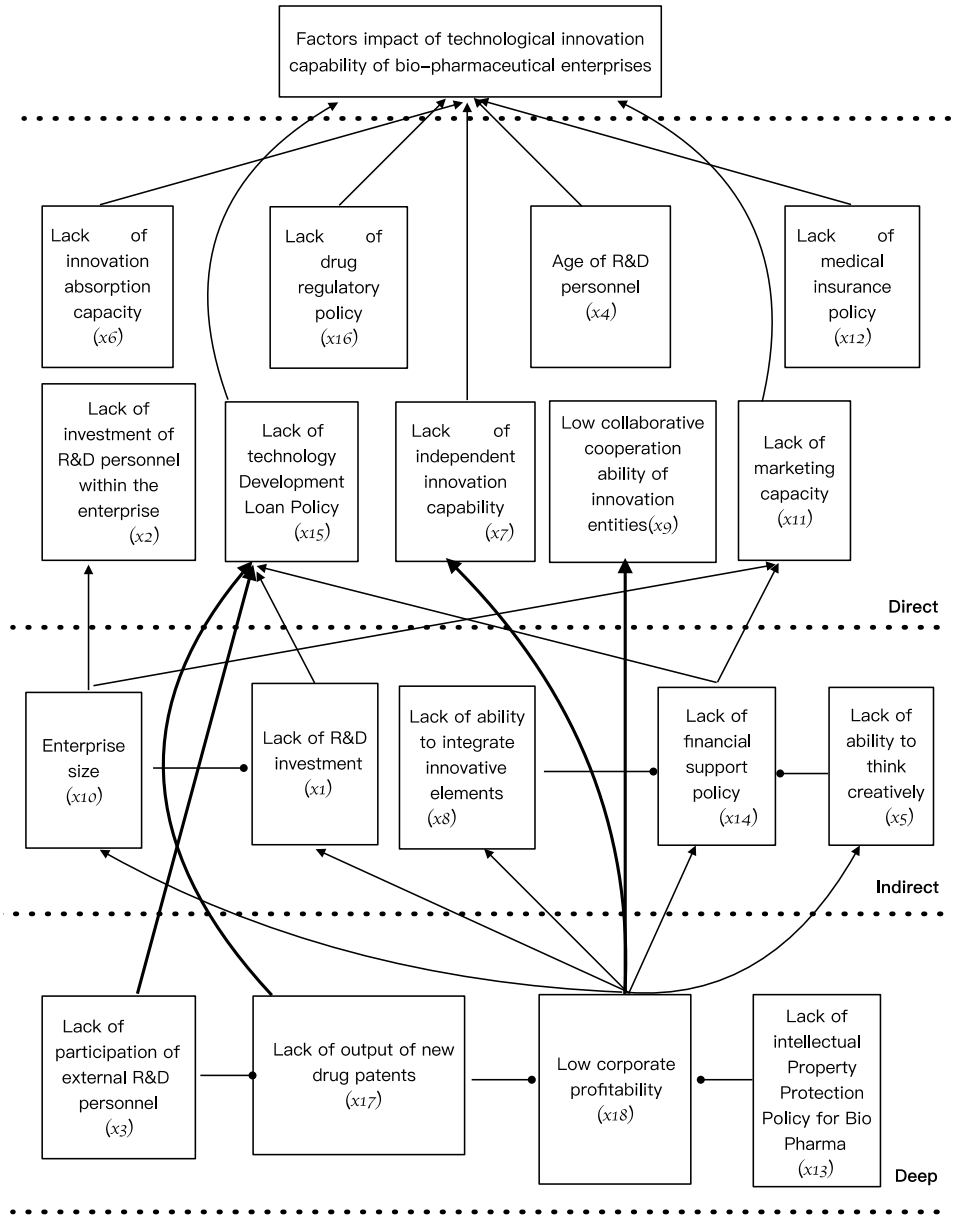

Figure 2: ISM Modelling Factors Impact of Technological Innovation Capability of Bio-Pharmaceutical Enterprises.
Source: Authors' Compilation.

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Table 7: Structural Model of Technological Innovation Capability of Bio-Pharmaceutical Enterprises.

Hierarchy	Factor
First Level	$x_2, x_4, x_6, x_7, x_9, x_{11}, x_{12}, x_{15}, x_{16}$
Second Level	x_1, x_{14}
Third Level	x_5, x_8, x_{10}
Fourth Level	$x_3, x_{13}, x_{17}, x_{18}$

Source: Authors' Compilation.

Conclusion

This study investigates the primary factors influencing the innovative development of the biopharmaceutical industry by constructing a structured hierarchical framework to examine the interrelationships among those variables affecting innovation within biopharmaceutical enterprises. Eighteen innovation-related factors were identified across five key dimensions relevant to Chinese biopharmaceutical firms. By employing the DEMATEL-ISM model, four critical attributes were highlighted: insufficient involvement of external R&D personnel, limited output capacity of new drug patents, low corporate profitability, and inadequate intellectual property protection policies. The hierarchical classification of these influencing factors enables biopharmaceutical companies to implement targeted strategies aligned with their specific challenges, thereby enhancing organisational dynamism and innovation potential. This research offers a detailed interpretation of the layered interactions among influencing elements, providing valuable guidance for enterprises seeking to improve their innovation performance. By focusing on the most relevant factors, firms can more efficiently allocate human, material, and financial resources, increasing the likelihood of successful new drug development. Ultimately, this contributes to sustained innovation and long-term advancement within the biopharmaceutical sector.

Direct Influencing Factors

Among the various capabilities required for technological advancement, several first-level indicators under innovation capability emerge as particularly influential. These include lack of innovation absorption capacity (x_6), insufficient independent innovation ability (x_7), weak collaborative cooperation among innovation entities (x_9), absence of effective drug regulatory policy (x_{16}), inadequate medical insurance policy (x_{12}), lack of technology development loan schemes (x_{15}), limited investment in internal R&D personnel (x_2), the age profile of R&D personnel (x_4), and insufficient marketing capability (x_{11}). These factors collectively represent critical constraints on technological innovation within the biopharmaceutical sector. Innovation in new drug development necessitates not only strong innovation absorption capacity, internal R&D efforts, and marketing expertise, but also effective access to relevant knowledge

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and industry-specific information. Additionally, one of the most significant actions highlighted in the analysis is the need for increased financial support from the government. Expanding loan policies for biopharmaceutical enterprises and improving access to financing channels are essential. As such, easing restrictions on loan policies can have a direct and positive impact on the technological innovation capability of firms within this industry.

Indirect Influencing Factors

At the intermediate level of influence, several factors function indirectly in shaping technological innovation capability. These include enterprise size (x_{10}), insufficient R&D investment (x_1), lack of financial support policies (x_{14}), limited capacity to integrate innovation elements (x_8), and inadequate creative thinking ability (x_5). From a micro-level perspective, firms must first possess the foundational strength required to evolve into established biopharmaceutical enterprises. The ability to integrate innovation components plays a mediating role by enhancing the coordination of various innovative resources. As enterprises improve in this regard, their output of patentable new drugs is likely to increase. In turn, greater innovation output often leads to higher sales volumes and expanded enterprise scale. From a macro-level viewpoint, R&D investment remains crucial, but the role of governmental influence is equally significant. Policy measures such as including pharmaceutical products within public health insurance schemes can substantially reduce the financial burden on consumers. When high-quality drugs become more affordable, consumer trust and product uptake improve, leading to increased sales, larger enterprise scale, and enhanced profitability.

Deep Influencing Factors

The factors exerting the most significant influence across both the first and second levels include lack of participation from external R&D personnel (x_3), limited output of new drug patents (x_{17}), low corporate profitability (x_{18}), and insufficient intellectual property protection policies specific to the biopharmaceutical sector (x_{13}). In China, the advancement of biopharmaceutical R&D remains heavily dependent on universities and research institutions. Therefore, enhancing corporate profitability and strengthening collaboration between enterprises and academic institutions are essential for promoting technological innovation within the sector.

Corporate profitability is closely linked to multiple upper-level factors, making it a central determinant of innovation capability. Output capacity for new drugs serves as the foundational guarantee for continued innovation activities within enterprises. On one hand, firms that prioritise new drug development are typically more capable and better resourced to fund further R&D, while also being more attractive to external investors. On the other hand, such firms are more appealing to skilled R&D professionals, which facilitates the recruitment of top talent. Furthermore, effective protection of intellectual

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property rights remains vital. Currently, this area presents substantial challenges within China. The absence of robust policy support to safeguard innovative outcomes hinders progress. As a result, beyond strengthening innovation itself, there is a pressing need to enhance relevant legal frameworks and policy measures aimed at securing intellectual property rights in the biopharmaceutical field. Despite its contributions, this study does present certain limitations. Potential deviations may exist in the data collection process, and further exploration and validation will be required. The use of expert-based scoring introduces the possibility of bias, as subjective assessments may vary across individuals. Additionally, differences in the interaction between experts and researchers might influence the evaluation and interpretation of factors, thereby affecting the objectivity and independence of responses. This aspect warrants careful consideration in future research.

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