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Policy Utility and Empirical Analysis on the Coupling Development of Bio-Pharmaceutical Industry and New Enterprises Based on NB Statistical Model and Bayesian Probability

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ABSTRACT

Recent advances in life sciences and biotechnology have driven a new technological revolution, positioning the biopharmaceutical industry as a global leader. However, China's biomedical technology still lags behind international standards. To capitalize on global biotechnology opportunities and enhance competitiveness, this study employs Bayesian model averaging to account for uncertainty, predict outcomes, and identify key influencing factors. Notably, China's biopharmaceutical industry shows significant agglomeration, but domestic industrial division of labor remains weak, highlighting the need to strengthen and optimize industrial chain coordination.

KEYWORDS

Bayesian model; Biomedical industry; Policy effectiveness; NB statistical model

1. INTRODUCTION

Globally, the pharmaceutical market exceeded USD 1.5 trillion in 2024, with biopharmaceuticals accounting for over 35% and expected to reach 45% by 2030, driven by advances in biotechnology and biomedical engineering.China's pharmaceutical industry, a strategic emerging sector, includes biopharmaceuticals, traditional Chinese medicine, and medical devices, spanning the full value chain from R&D to market. Biotechnology—particularly pharmaceutical biotechnology, which accounts for over 60% of the sector—applies life science principles to prevention, diagnosis, and treatment. The biomedical industry integrates biotechnology and pharmaceuticals, advancing healthcare through innovative biologics, macromolecular drugs, and advanced diagnostics. Rising R&D costs and technological complexity are driving reform, with biotechnology increasingly shaping pharmaceutical development and enhancing innovation and efficiency across the sector [1].

Thomas Bayes developed Bayesian theory, which updates prior knowledge with new evidence to generate revised probabilities. For events A and B, the conditional probability is [2]:

$$P(B|A)=\frac{P(A|B)P(B)}{P(A)} \tag{1}$$

The above formulas are all based on probability statistics. Taking A and B as examples, P(·) is the probability of event occurrence, AB is the occurrence of event, A is A, and B is event B. P(AB) in equation (2) can be calculated by equation (1) [3]:

$$P(A|B)=\frac{P(AB)}{P(B)} \tag{2}$$

Extend Bayes' theorem to the examples to be identified represented by C=(c1, c2, ..., ck) (including m attributes), where X=(X1, X2, ..., Xm) represents a set of feature variables, and Xi is Xi (i 1, 2, ..., m). The posterior probability that I belong to different classes can then be deduced from the above formula:

$$P(c_i|I)=\frac{P(I|c_i)}{p(I)} \tag{3}$$

Technological progress encompasses improvements in production methods, knowledge, and organizational practices at micro, meso, and macro levels. As shown in Figure 1.

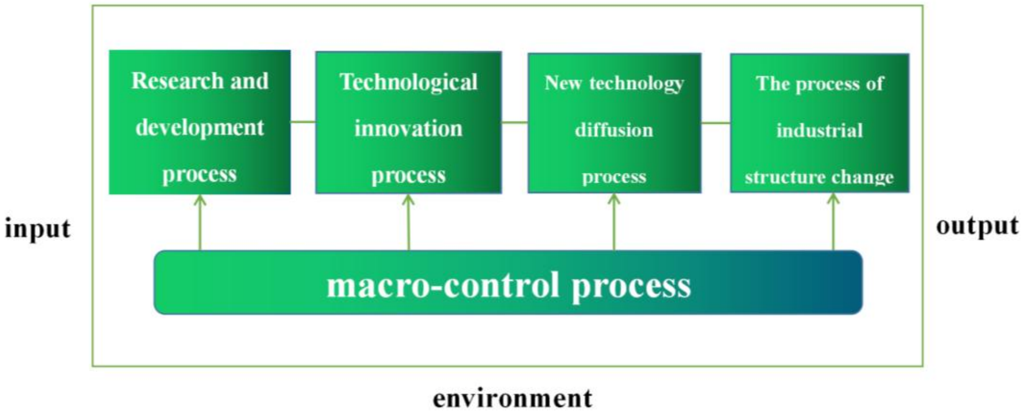

Figure 1. Cycle of technological progress

2. STATE OF THE ART

2.1. Development Trend of Bio-pharmaceutical Industry

The The global biomedical industry is rapidly expanding, driven by advances in genetic engineering and biotechnology, with a market projected to grow from USD 1.55 trillion in 2024 to USD 5.71 trillion by 2034 (CAGR 13.9%). China's biopharma sector, encompassing eight key sub-sectors, reached RMB 565.3 billion in 2022, with R&D expenditure surging to USD 15 billion in 2023. Characterized by high technology, substantial investment, and strong policy support, the industry focuses on gene therapies, recombinant proteins, monoclonal antibodies, and biopharmaceutical innovation [4]. Regional clusters and international licensing deals highlight China's growing global influence [5].

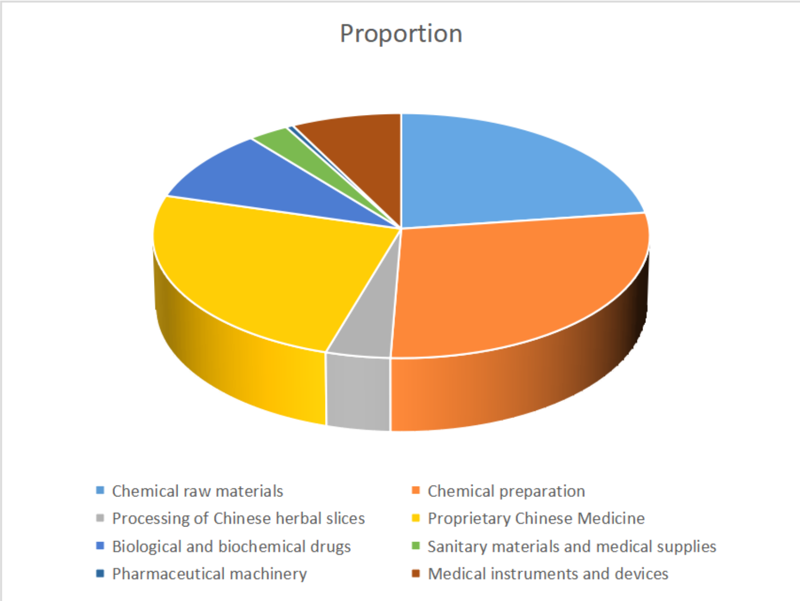

Figure 2. China's bio-pharmaceutical industry structure distribution in 2024.

In 2024, the development speed of China's bio-pharmaceutical industry continues to accelerate, with an average annual growth rate of 14 %. Among them, only the annual growth rate of Chinese patent medicine industry is less than 10 %, and the annual growth rate of pharmaceutical machinery industry and Chinese herbal medicine processing industry is less than 15 % [6]. The annual growth rate of chemical raw materials industry, chemical preparation industry, biochemical pharmaceutical industry and medical equipment and apparatus industry is more than 15 % (see Table 1) [7].

Table 1. Assets of the National Pharmaceutical Industry in 2024

Industry name	Total assets in 2024/100 million yuan	Annual growth rate	Proportion
Pharmaceutical industry	8716.0	14.0%	100%
Chemical raw materials	1992.9	15.0%	22.9%
Chemical preparation	2410.8	16.1%	27.8%
Processing of Chinese Herbal Pieces	350.6	14.5%	4.0%
Chinese patent medicine	2156.2	8.8%	24.8%
Biochemical drugs	841.5	17.6%	9.7%
Pharmaceutical machinery	45.2	10.9%	0.5%
Medical equipment and equipment	661.5	19.0%	7.6%

2.2. Main Problems And Analysis of the Industry

As of 2025, China's pharmaceutical exports have faced significant challenges, with November 2021 export growth dropping from 32.9% to 5.4%. Contributing factors include pre-Olympic environmental restrictions limiting hazardous chemical production, rising raw material, labor, and energy costs, market wait-and-see sentiment due to crude oil price fluctuations, and currency depreciation reducing international purchasing power [8]. Domestic Chinese herbal medicine production remains volatile, with raw material price changes impacting smaller enterprises, though efficiency gains have improved profitability [9]. Globally, developed countries control 80% of the biopharmaceutical market, while Chinese firms show convergence, strong R&D, but limited core competitiveness, high environmental costs, and low industrial concentration; domestic enterprises account for only 1.83% of the market, with 80% foreign capital and 61.86% of total profits [10]. Sustainable growth requires cross-border flows of talent and technology, supportive policies, and structural reforms to enhance competitiveness under pandemic conditions .As shown in Figure 3.

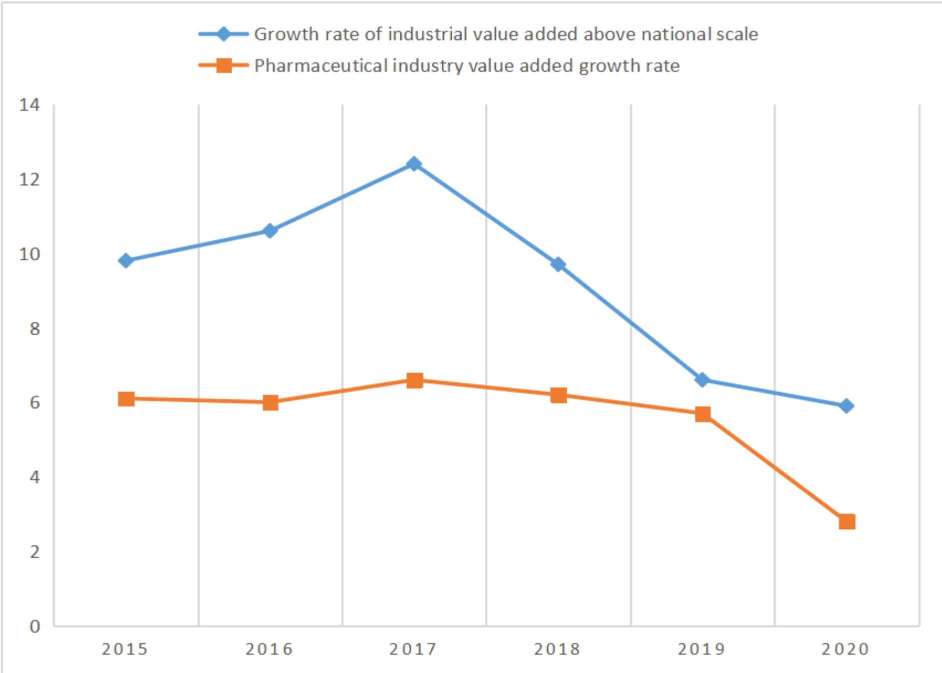

Figure 3. Pharmaceutical industry value added growth rate 2015-2020

2.3. Construction of a Policy Analysis Framework for the Bio-Pharmaceutical Industry

This paper classifies sustainable innovation policy tools in China's bio-pharmaceutical industry into 17 subcategories and constructs an initial analytical framework (Table 2).

Table 2. Biomedical industry policy analysis framework table

Biomedical industry policy analysis framework table		
demand	supply	environment
requirements of public	fund investment	financial support
requirements of business	personnel cultivation	Financial support
requirements of society	technical assistance	reduction and exemption of taxes
Quality and standards	information support	government support
overseas market demand		intellectual property
Third party outsourcing services		sustainable innovation & development

China's bio-pharmaceutical policies use supply-, demand-, and environmental-oriented tools to drive innovation from R&D to market [11]. Demand-side policies expand markets, supply-side policies support R&D through funding and talent, and environmental policies provide financial and regulatory support, collectively shaping a favorable innovation ecosystem (Figure 4) [12].

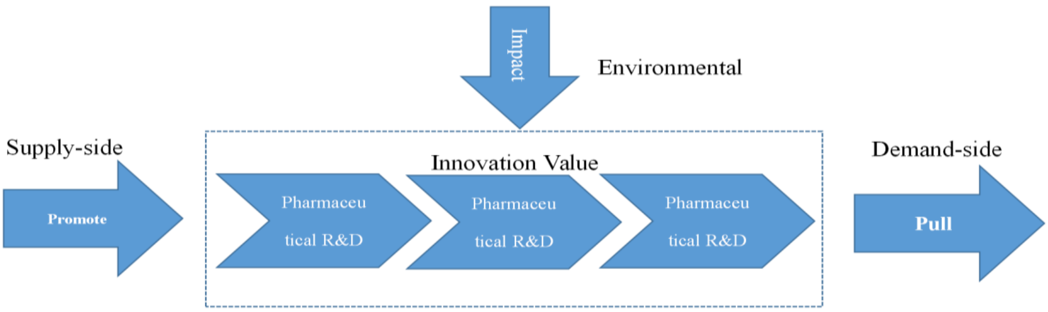

Figure 4. Theoretical model of policy instrument analysis

3. METHODOLOGY

3.1. Commonly Used Bayesian Classification Models

The naive Bayes assumption of conditional independence among features is illustrated in Figure 5.

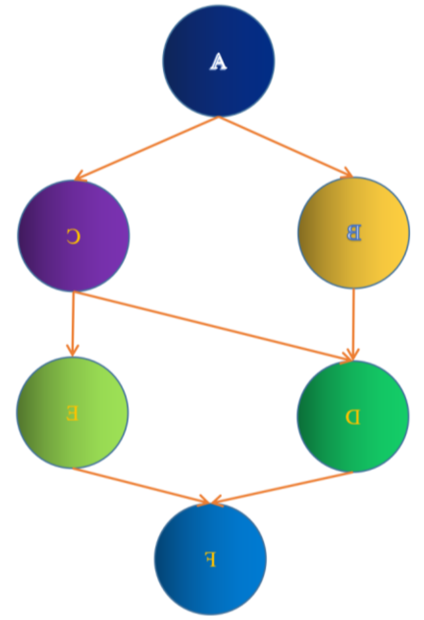

Figure 5. Property Relationship Diagram

Steps are defined as:

(1) Let x={a1, a2, …, an} be an item to be classified, and each ai is a feature attribute of x.

(2) There is a category set C={y1, y2, ..., yn).

The key to its realization is how to calculate each conditional probability in step (2). If each feature attribute is conditionally independent, the following derivation can be obtained according to Bayes' theorem [13]:

$$P(C_i \mid X) = \frac{P(C_i)P(X \mid C_i)}{P(X)} \tag{4}$$

$$P(y_i \mid x) = \frac{P(x \mid y_i)P(y_i)}{P(x)} \tag{5}$$

Since the denominator is the same, we can add all the numerators to the maximum. Since these properties are independent of each other, as follows:

$$P(x \mid y_i)P(y_i) = P(a_1 \mid y_i)P(a_2 \mid y_i) \tag{6}$$

$$P(a_m \mid y_i)P(y_i) = P(y_i)\Pi_{j=1}^{m} P(a_i \mid y_i) \tag{7}$$

3.2. The Overall Design of the Platform

The platform uses a three-tier B/S architecture—presentation, logic, and data layers—where each layer operates independently to handle user interaction, business logic, and database management, ensuring high reusability (Figure 6) [14].

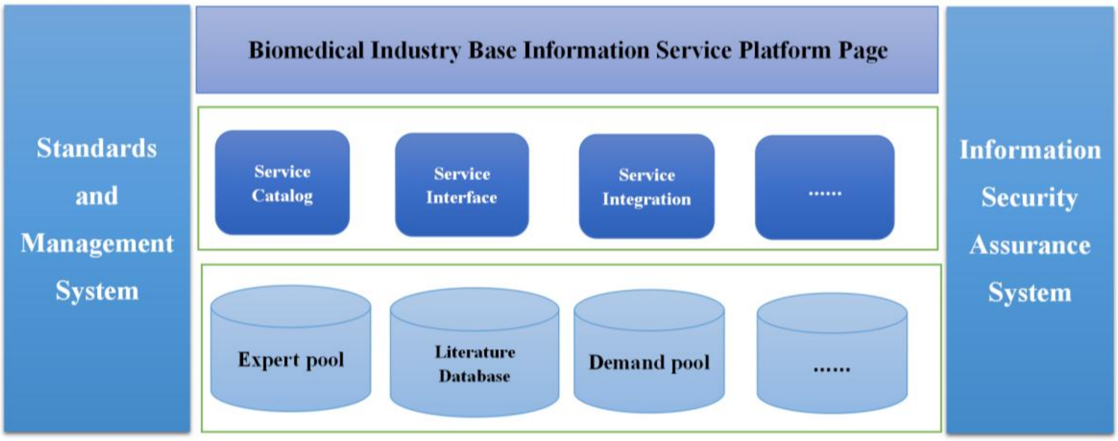

Figure 6. Multi-tier architecture of B/S model

3.3. Principles and Methods

BayesSSE is a server-hosted interactive Bayesian sample estimation tool that updates outputs in real time via user input, combining front-end interfaces, back-end algorithms, and R package computations, with results rendered and returned through the browser (Figure 7) [15].

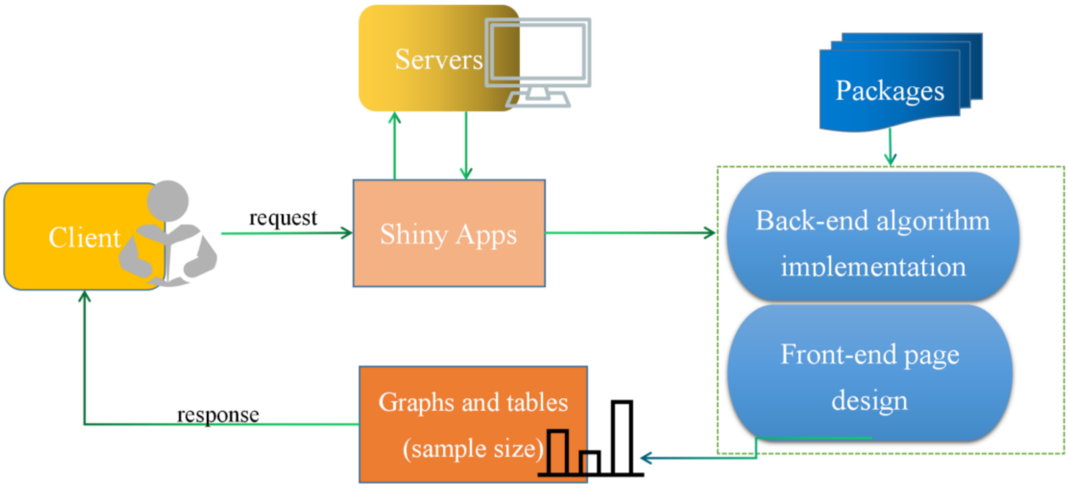

Figure 7. System architecture of BayesSSE

3.4. The Main Working Mode And Operation Mechanism of the Technology Innovation Platform of Bio-Pharmaceutical Enterprises

Bio-pharmaceutical innovation platforms facilitate knowledge exchange among universities, research institutes, companies, and regulators, using centralized warehouses with standardized rules to enhance collaboration and innovation [16]. Strengthening China's biomedical sector requires improving clinical research infrastructure, reforming institutions to incentivize talent and innovation, building multi-center data-sharing platforms, implementing value-based drug pricing, prioritizing domestic drug evaluation, exploring new payment models, and promoting commercial health insurance to expand funding and access [17].

4. RESULT ANALYSIS AND DISCUSSION

4.1. Analysis of the Technological Innovation Capability of My Country's Bio-Pharmaceutical Enterprises

Specific operations are as follows in Table 3.

Table 3. Total variance explained

Element	Initial eigenvalues			Extract sum of squares and load		
	Total	% of variance	accumulation%	Total	% of variance	accumulation%
1	6.81	56.77	56.779	6.814	56.779	56.779
2	2.92	24.35	81.136	2.923	24.356	81.136
3	1.08	8.99	90.133	1.080	8.997	90.133
4	685	5.70	95.842			
5	499	4.15	100.000			
6	2.927E-16	2.440E-15	100.000			
7	1.504E-16	1.253E-15	100.000			
8	4.4.1E-17	3.668E-16	100.000			
9	-4.401E-17	-3.715E-16	100.000			
10	-1.174E-16	-9.784E-16	100.000			

Table 4 shows that the first three factors, explaining 90.13% of the variance, sufficiently capture variable similarities, with communalities indicating strong explanatory power across economic indicators.

Table 4. List of common degree of variables

	initial	extract
C1	1.000	.939
C2	1.000	.933
C3	1.000	.977
C4	1.000	.912
C5	1.000	.836
C6	1.000	.921
C7	1.000	.984
C8	1.000	.887
C9	1.000	.834
C10	1.000	.691
C11	1.000	.996
C12	1.000	.936

After rotating the factor load matrix (Table 5), F1 reflects the innovation environment, F2 represents technological and human resources, and F3 captures patent applications and new products in the bio-pharmaceutical industry cluster.

Table 5. Rotated component matrix

	Element		
	1	2	3
C1		.967	.401
C2		.532	
C3		.433	
C4	.849	.421	
C5	.688		.600
C6	.963		
C7	.754	.727	.544
C8	.940		
C9	.799	.421	
C10	.458	.609	
C11		.924	.315
C12			.965

4.2. Simulation Data Research And Case Analysis

In this paper, the Bender method is used to simulate the life data. First, the covariation matrix of three data scenarios is established:

Scenario 1: The number of independent variables is 20, and there is no real predictor variable, which is B; at the same time, the relationship between the variables is also independent of each other as shown in Table 6.

Table 6. Comparison of the results of three variable selection methods for different residual items in simulated data scenario 1 when the sample size is 50

δ	BMA (50%)		BMA (95%)		Lasso		Stepwise	
	PNSRV	MSRV	PNSRV	MSRV	PNSRV	MSRV	PNSRV	MSRV
0.1	17.00	2.302	67.60	0.562	72.40	0.69	59.20	0.586
0.2	12.80	2.254	64.80	0.53	66.40	0.684	56.00	0.592
0.3	16.40	2.332	68.00	0.506	70.20	0.702	58.60	0.556
0.4	14.20	2.248	67.00	0.518	67.60	0.7	54.60	0.594
0.5	14.00	2.306	66.80	0.598	71.40	0.684	57.20	0.564

Scenario 2: The number of independent variables i=20, where x is the true predictor variable, the actual variable regression coefficient is 1, the variable x2 is the actual variable X, the related variable is independent, other variables and the actual variable are independent of each other, when the variable When the correlation with actual variables is affected, some variable selection methods select the ability of real variables, the ability to exclude irrelevant variables, and select an appropriate model. As shown in Table 7.

Table 7. Comparison of the results of three variable selection methods for different residual items in simulated data scenario 2 when the sample size is 50

δ	BMA (50%)		BMA (95%)		Lasso		Stepwise	
	PSTM	MSRV	PSTM	MSRV	PSTM	MSRV	PSTM	MSRV
0.1	2.318	3.80	0.628	6.40	0.784	5.60	0.614	11.60
0.2	2.444	2.20	0.636	5.60	0.926	5.00	0.64	12.00
0.3	2.274	5.00	0.558	7.80	0.778	7.00	0.574	15.20
0.4	2.064	5.20	0.464	7.40	0.742	7.40	0.524	14.20
0.5	2.362	4.80	0.598	9.40	0.87	5.20	0.638	15.40

4.3. Policy Text Analysis from the Perspective of Policy Instruments

Policy tools, central to policy science, reflect policymakers' values and are designed to achieve complementary functional effects. Commonly categorized as supply-oriented, environmental-oriented, and demand-oriented, these tools can be analyzed at the level of individual policy documents. This study examines 85 valid policy documents, classifying them according to these criteria (see Figure 8) [18].

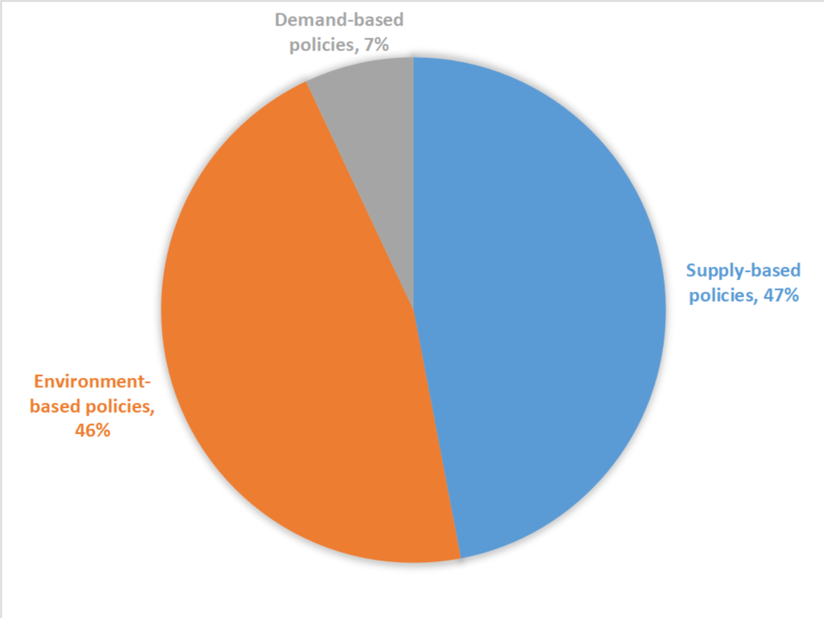

Figure 8. Distribution of basic types of bio-pharmaceutical industrial policy tools

4.4. Formulating and Improving Industrial Policy for Promoting the Development of Bio-pharmaceutical Industry in China

New drug development typically requires 10–12 years and faces challenges including long decision-making chains, insufficient performance evaluation and incentive mechanisms, high upfront investment, and difficulties in team formation and laboratory construction due to the multidisciplinary nature of research [19]. With rising global demand and health awareness, the international bio-pharmaceutical market is expanding but increasingly competitive. China must strategically position itself by exporting competitive products and importing high-end drugs unavailable domestically to balance supply and demand and reduce trade friction.

4.5. Analysis of factors restricting the development of China's biomedical industry

China's bio-pharmaceutical industrial clusters remain weak, with limited interdependence and cooperation. Most industrial parks are "top-down" initiatives led by local governments, relying on preferential policies rather than intrinsic agglomeration [20]. Enterprises often operate independently, lacking leading firms, coordinated division of labor, and effective collaboration. While output and value have increased, innovation remains limited, and few drugs with independent intellectual property have emerged [21]. Policy optimization is urgently needed to strengthen support for new enterprises, enhance R&D investment, improve infrastructure, and address challenges in including high-priced patented drugs in medical insurance catalogs, while also guiding entrepreneurial strategies within the industry [22, 23, 24].

5. CONCLUSION

China's bio-pharmaceutical industry is experiencing significant agglomeration, but empirical research on regional industrial division of labor remains limited[25]. Current studies primarily focus on the industrial chain without sufficient comparative analysis, highlighting the need to strengthen coordination within clusters. As the industry continues its growth phase, policy support is crucial; existing government instruments show structural imbalances that must be addressed[26,27,28]. In particular, demand-oriented policies, including government procurement and inclusion of innovative drugs in official catalogs, should be emphasized to promote clinical application, accelerate commercialization, and enhance the overall efficiency and competitiveness of the bio-pharmaceutical sector [29, 30, 31].

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