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A Multi-Objective Optimization Framework for Evaluating Technological Innovation Performance in Regional Public Hospitals

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Abstract: Evaluating technological innovation performance in regional public hospitals requires balancing multiple policy objectives, including operational efficiency, distributive equity, and innovation value creation. Conventional evaluation methods often rely on fixed indicator weights, which inadequately capture trade-offs among competing objectives and limit their usefulness for strategic resource allocation. To address this limitation, this study develops a multi-objective decision optimization framework that reformulates innovation performance evaluation as a constrained decision-making problem under fiscal, institutional, and policy conditions. A multi-objective linear programming model is constructed to jointly optimize efficiency, fairness, and innovation value. Using three-year panel data from regional public hospitals, the framework is validated through comparative evaluation, sensitivity analysis, and statistical testing. The results show that the optimized weighting structure improves institutional performance balance, reduces inter-regional disparities in innovation capacity, and strengthens the contribution of research investment to technological output and knowledge transformation. Human capital composition, research funding intensity, and technology commercialization capability are identified as key variables shaping the innovation performance frontier. Scenario analysis further shows that institutional performance varies under different policy preferences, highlighting the need for adaptive weighting mechanisms. The findings provide a practical and interpretable framework for evidence-based innovation performance evaluation and public hospital governance.

Keywords: Multi-objective optimization; Innovation performance; Public hospitals; Indicator weighting; Resource allocation; Healthcare governance

1 Introduction

Under the "Healthy China 2030" initiative and the broader Big Health strategy, China's healthcare system is shifting from rapid expansion toward a stage of quality-oriented development. Public hospitals, as the core providers of medical services, are no longer limited to delivering clinical care and public health services; they are increasingly expected to serve as key nodes in regional science and technology (S&T) innovation and health governance systems. In particular, regional public hospitals occupy a pivotal position between national medical centers, provincial institutions, and primary healthcare providers. Their capacity for innovation and their ability to translate research outputs into practice have a direct impact on both the efficiency and the equity of regional healthcare development. In this context, the assessment of innovation performance in regional public hospitals can be viewed as a structured decision problem involving multiple, and often competing, objectives.

The evaluation system, when examined from a decision perspective, functions as more than a measurement tool. It shapes the allocation of innovation resources, influences institutional priorities, and determines how research activities are directed and rewarded. Recent policy efforts have led to the gradual formation of a relatively stable evaluation framework for S&T innovation in tertiary public hospitals [1]. Existing studies have contributed to the construction of indicator systems, the assessment of research capacity, and the analysis of transformation mechanisms for research outcomes [2–5]. Nevertheless, at the level of regional public hospitals, several structural issues remain.

First, current practices continue to emphasize efficiency and the scale of academic output. Indicators such as publication counts and project numbers are easy to quantify and therefore tend to dominate evaluation frameworks. This tendency can distort innovation behavior, encouraging short-term output expansion at the expense of sustained capability building and practical application. Second, substantial disparities exist in the resource base across regions. In the absence of mechanisms that account for balance, evaluation systems may reinforce existing inequalities through cumulative advantages in funding, talent, and institutional capacity. Third, indicators related to the transformation and application of research outcomes are often marginal, providing limited incentives for technology transfer, clinical adoption, and the conversion of intellectual property into practical use. As a result, the broader value of innovation is not fully reflected in regional healthcare systems [6, 7]. More broadly, hospital performance evaluation has been shown to involve multiple dimensions and indicator categories, which further supports the need for a structured evaluation framework [8].

These issues stem from the inherently multi-objective nature of innovation performance evaluation in public hospitals. In practice, innovation performance cannot be sufficiently characterized by a single objective, because efficiency, fairness, and value creation are often inconsistent and may even conflict with one another. Traditional healthcare performance evaluation methods, such as data envelopment analysis (DEA), have been widely applied to measure efficiency and productivity [9], yet they typically focus on benchmarking input–output relationships and are less capable of explicitly addressing equity and innovation value considerations within the same framework [10–12]. Moreover, conventional indicator weighting approaches frequently rely on expert scoring or subjective assignment, such as the analytic hierarchy process (AHP), which may lack transparency and be sensitive to judgment bias when the evaluation environment is complex and resource-constrained [13]. In multi-criteria decision-making (MCDM) settings, such conflicts among objectives are well recognized, and the core challenge lies in how to construct a decision mechanism that explicitly represents trade-offs and balances multiple evaluation dimensions [14].

In this context, multi-objective optimization provides a structured approach to integrate competing objectives into a unified decision framework. Multi-objective optimization theory emphasizes that decision solutions should not aim at maximizing a single dimension, but rather at achieving compromise solutions under constraints, which has been widely discussed in decision science and operational research [15, 16]. Compared with fixed-weight evaluation systems, an optimization-based framework can treat the evaluation indicator weights as decision variables and reconstruct them under fiscal and policy constraints. In addition, optimization models allow the evaluation system to function as an adaptive decision-support tool, making it possible to adjust evaluation orientation according to governance priorities. To ensure the robustness of such models, sensitivity analysis is also important, as it can evaluate how changes in objective preferences or parameter settings may influence optimized results [17, 18].

This study addresses the innovation performance evaluation of regional public hospitals by developing a multi-objective optimization framework. The model incorporates three coordinated objectives—efficiency, fairness, and innovation value—and reconstructs the indicator weight structure under fiscal and policy constraints. Empirical analysis is conducted using panel data from regional public hospitals to examine how the optimized structure affects performance distribution and system behavior. The main contributions are as follows:

(1) An optimization framework is proposed to coordinate competing objectives within innovation performance evaluation;

(2) A multi-objective linear programming model is established to support transparent adjustment of indicator weights under constraints;

(3) Empirical evidence is provided to identify key driving factors and to clarify how structural adjustment influences innovation performance in practice.

2 Theoretical Framework and Model Construction

2.1 Multi-Objective Conflict Analysis in Innovation Performance Evaluation

The evaluation of S&T innovation in regional public hospitals differs fundamentally from the assessment of academic performance in research-oriented institutions. Rather than focusing on a single dimension of output, it involves a set of interrelated objectives, including research productivity, improvement of service capacity, transformation and application of research outcomes, and contributions to regional health governance. When these objectives are considered under limited resource conditions, they form a decision environment characterized by internal tensions, which provides the basis for introducing a multi-objective optimization framework.

First, a structural tension arises between improving research efficiency and maintaining balanced support for innovation activities. Regional public hospitals typically operate with constrained research resources. Efforts to improve input–output efficiency tend to favor concentration of resources in established disciplines or high-performing teams. At the same time, these institutions are expected to cultivate broader innovation capacity and support talent development across departments. Maintaining participation opportunities while pursuing efficiency therefore introduces a clear trade-off between concentration and balance.

Second, there is an inherent trade-off between output scale and innovation quality. Indicators such as publication counts and project numbers are readily measurable and often dominate evaluation practices. However, an emphasis on scale expansion may encourage repetitive or incremental work, reducing the space available for more original and high-quality research. In this sense, quantity-oriented targets and quality-oriented objectives do not necessarily align, and the evaluation system must accommodate this tension.

Third, a further tension exists between academic output and the transformation of research outcomes. The ultimate role of S&T innovation in public hospitals lies in its contribution to clinical practice and public health. In practice, however, evaluation systems tend to prioritize publications and awards, which can lead to a separation between academic production and practical application. As a result, innovation activities are not always effectively integrated into regional healthcare systems.

Taken together, these observations indicate that the evaluation of S&T innovation performance in regional public hospitals is not a matter of optimizing individual indicators in isolation. Instead, it involves coordinating multiple, and often competing, objectives within a constrained decision setting. Approaches based on fixed weighting structures are not well suited to capturing these interactions, nor do they provide a mechanism for adjusting the relative importance of different objectives. This context makes it necessary to adopt multi-objective optimization methods in order to support a more structured and balanced adjustment of the evaluation framework.

2.2 Construction of the Multi-Objective Optimization Model

To optimize the structure of the S&T innovation performance evaluation indicator system for regional public hospitals, this study formalizes the adjustment of indicator weights as a multi-objective decision-making problem. The model takes the indicator weight vector as the decision variable and, under budget and policy constraints, optimizes the objective functions to achieve coordinated improvement in efficiency, fairness, and innovation value.

2.2.1 Decision variables and indicator system definition

Let the S&T innovation performance evaluation system of regional public hospitals include standardized indicators, forming the decision vector $X = (x_1, x_2, \ldots, x_n)$, where x_i denotes the standardized value of performance indicator i (e.g., proportion of research funding, proportion of staff with a master's degree or higher, achievement transformation rate, etc.).

To eliminate differences in measurement units, all indicators are standardized before modeling. In this framework, the indicator weight vector is used as the decision variable $W = (\omega_1, \omega_2, \ldots, \omega_n)$, where ω_i represents represents the weight of performance indicator i in the overall evaluation and satisfies $\omega_i \geq 0$ and $\sum_{i=1}^{n} \omega_i = 1$.

Under this setting, the comprehensive performance score of a hospital can be expressed as shown in the following equation:

$$S = \sum_{i=1}^{n} \omega_i x_i$$

This expression indicates that adjusting the weights can directly influence the performance evaluation orientation and achieve structural reconstruction of the indicator system.

2.2.2 Objective function design

To capture the multidimensional attributes of S&T innovation performance in regional public hospitals, this study constructs three types of objective functions: efficiency, fairness, and innovation value.

Objective 1: maximization of efficiency

The efficiency objective aims to improve the overall performance level of research input and service output. Let the set of efficiency-related indicators be E; then, the efficiency objective function can be expressed as shown in the following equation:

$$F_1(W) = \sum_{i \in E} \omega_i x_i$$

This objective reflects the overall level of research resource input, research output efficiency, and innovation-supporting service capability.

Objective 2: maximization of fairness

The fairness objective measures the balance of the indicator weight structure, preventing over-concentration of weights that could lead to a unidirectional evaluation orientation. This study uses the coefficient of variation (CV) to characterize the dispersion of the weight distribution, as shown in the following equation:

$$CV(W) = \frac{\sigma(W)}{\mu(W)}$$

where, $\sigma(W)$ is the standard deviation of the weights, and $\mu(W)$ is the mean of the weights.

Since the mean weight satisfies $\mu(W) = \frac{1}{n}$, a larger CV indicates that the weights are more concentrated and the structure is less balanced. To reflect the goal of improving fairness, the CV should be minimized; equivalently, the fairness objective can be formulated as the maximization of its reciprocal, as shown in the following equation:

$$F_2(W) = \frac{1}{CV(W) + \varepsilon}$$

where, ε is a small positive constant introduced to avoid division by zero. A larger value of this objective function indicates a more balanced weight structure, thereby enhancing support for multidimensional indicators at the performance evaluation level.

Objective 3: maximization of innovation value

The innovation value objective emphasizes the transformation of technological achievements and the enhancement of social health value. Let the set of innovation-related indicators be I. The innovation objective function can be expressed as shown in the following equation:

$$F_3(W) = \sum_{i \in I} \omega_i x_i$$

Innovation indicators may include achievement transformation rate, number of patents converted, new technology adoption rate, number of appropriate technologies implemented, and social satisfaction, reflecting the contribution of innovation activities to regional healthcare service capability and health governance performance.

2.2.3 Constraint settings

To ensure the feasibility of the optimization results and their alignment with policy requirements, the following constraints are established.

(a) Fiscal Budget Constraint

The constraint can be expressed as shown in the following equation:

$$\sum_{i=1}^{n} c_i x_i \leq B$$

where, c_i represents the resource cost required for the performance indicator i, and B denotes the total budget constraint.

(b) Policy Minimum Threshold Constraint

Key performance evaluation indicators must satisfy the minimum standards required by national or regional policies: $x_i \geq L_i$, where L_i is the the minimum threshold specified by policy.

(c) Total Resource Allocation (Weight Sum) Constraint

The constraint can be expressed as $\sum_{i=1}^{n} \omega_i = 1$. This constraint ensures the rationality and interpretability of the weight structure.

2.2.4 Multi-Objective Model Formulation

By integrating the above objective functions and constraints, the multi-objective optimization model can be formulated as $\max(W_1, W_2, W_3)$. The model is subject to the corresponding budget constraint, policy threshold constraint, and weight feasibility constraints.

In practical implementation, the weighted-sum method is adopted to transform the multi-objective problem into a single-objective optimization problem, as shown in the following equation:

$$\max W = \alpha W_1 + \beta W_2 + \gamma W_3 \downarrow$$

where, $\alpha + \beta + \gamma = 1$. The weighting parameters can be determined through expert judgment methods or sensitivity analysis.

2.2.5 Model solution method

After constructing the objective functions and constraint conditions, this study transforms the indicator weight optimization problem for S&T innovation performance evaluation in regional public hospitals into a multi-objective linear programming problem. Taking efficiency, fairness, and innovation value as the core optimization objectives, the model seeks the optimal combination of indicator weights or allocation proportions under given budget constraints, policy baseline constraints, and total resource allocation constraints. The solution procedure is as follows:

Step 1: Standardize the original indicators to obtain x_i;

Step 2: Classify indicators according to their attributes into the efficiency indicator set E, the fairness-constrained indicator set L_i, and the innovation value indicator set I;

Step 3: Construct the multi-objective functions and constraint conditions;

Step 4: Apply the weighted-sum method to convert the multi-objective problem into a single-objective linear programming model;

Step 5: Use a linear programming solver to obtain the optimal weight vector;

Step 6: Calculate the comprehensive performance scores and structural differences before and after optimization, and conduct statistical tests.

During the solution process, all performance evaluation indicators are first standardized to ensure comparability across different dimensions. Then, based on the objective functions and constraints defined in the model, a multi-objective optimization framework is established. In practical computation, a weighted transformation mechanism is introduced to integrate multiple objective functions into a single comprehensive objective function, thereby achieving coordinated balance among different performance dimensions. The weighting parameters can be determined according to expert judgment or sensitivity analysis results, which improves the scientific validity and stability of the model outcomes.

Through this approach, it is possible to achieve the combined goals of improving performance efficiency, enhancing balance in resource allocation, and optimizing innovation and social value, while satisfying fiscal resource constraints and policy requirements. The proposed multi-objective linear programming model is characterized by a clear structure, strong practical operability, and broad applicability, providing a methodological foundation for subsequent empirical analysis and comparative evaluation of optimization results.

3 Empirical Analysis

3.1 Data Sources and Sample Description

This study uses public hospitals in a selected region as the research objects. The data sources include hospitals' annual performance reports, statistical data from research management departments, financial statements, and publicly available data released by health administrative authorities. To improve the stability and comparability of the analysis results, this study selects continuous data from the most recent three years as the research sample. Missing values and outliers are checked and supplemented through consistency verification to ensure that the statistical definitions of the indicators are consistent.

The sample covers different types of public hospitals within the region, including general hospitals, specialized hospitals, and integrated traditional Chinese and Western medicine hospitals, thereby enhancing the representativeness of the sample. These hospitals undertake responsibilities such as basic medical services, public health services, and the implementation of hierarchical diagnosis and treatment within the regional healthcare system. Their S&T innovation performance not only reflects research output levels but also directly affects the promotion of appropriate technologies and the improvement of clinical service capacity.

During data processing, range standardization (min–max normalization) is first applied to eliminate dimensional differences among indicators. Then, according to the model construction framework, the indicators are classified into three categories: efficiency-oriented indicators, fairness-oriented indicators, and innovation value-oriented indicators. These categorized indicators are further used for multi-objective linear programming optimization and the evaluation of optimization effects.

3.2 Analysis of Multi-Objective Optimization Results

3.2.1 Comparison of indicator structures before and after optimization

Based on the results of the multi-objective optimization model, this study compares the performance evaluation indicator weight structures before and after optimization. The results show that the optimized weights exhibit significant structural adjustments: efficiency-related indicators remain central, but the proportion of fairness and innovation value-related indicators has clearly increased. This indicates that the performance evaluation orientation has shifted from the traditional "academic quantity priority" toward a comprehensive "efficiency–fairness–value synergy" approach.

As shown in Figure 1, before optimization, the weights were primarily concentrated on traditional efficiency indicators such as operational efficiency and service output. After optimization, a noticeable redistribution occurs: fairness indicators (resource balance, regional differences) receive higher weight, reflecting the model's balance between efficiency goals and regional coordination; innovation value indicators (research investment, results transformation) gain significantly in weight, particularly the results transformation indicator, which shifts from a marginal to a structurally key role. This change demonstrates that the performance evaluation system increasingly emphasizes the actual contribution of technological innovation to clinical application and regional health services.

The weight adjustments show a "key driver variable reinforcement" characteristic. Combined with regression analysis results, the proportion of medical staff with a master's degree or above and the annual research funding proportion have a significant positive effect on technological innovation performance. Accordingly, their corresponding weights are strengthened in the optimized structure, focusing resource allocation on high-contribution factors and enhancing the interpretability and policy relevance of the indicator system.

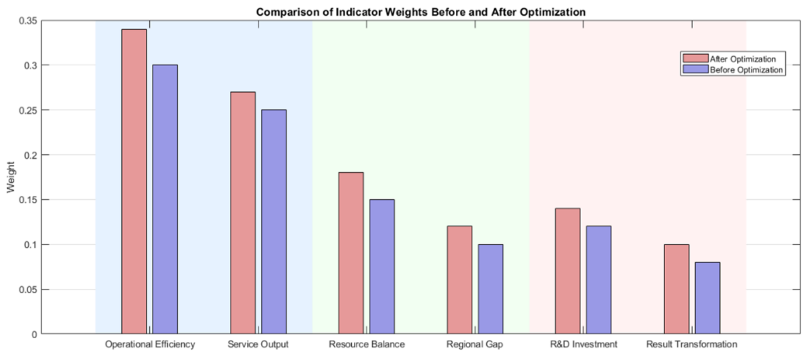

Figure 1. Comparison of indicator weights before and after optimization

From the perspective of the three indicator categories, efficiency indicators remain central after optimization but no longer dominate the overall structure alone. Fairness indicators increase in proportion, helping to reduce regional disparities. Innovation indicators also gain weight, reflecting greater emphasis on research results transformation and social service value. Overall, the weight structure shifts from a quantity-biased orientation toward a coordinated framework emphasizing efficiency, quality, and value, achieving structural optimization of the evaluation system.

3.2.2 Analysis of changes in overall performance levels

To examine the practical effect of the multi-objective optimization model, this study compares the overall technological innovation performance of regional public hospitals before and after optimization, evaluating four aspects: distribution characteristics, overall trend, grade structure, and improvement magnitude.

The original evaluation results show that the comprehensive scores of sample hospitals ranged from 0.31 to 0.83, exhibiting significant differentiation, with large gaps between high and low performers, indicating uneven regional performance development. Before optimization, the distribution followed a pattern consisting of a few excellent performers, a majority of medium performers, and a few weak performers, and the system's structural stability was limited, as illustrated in Figure 2.

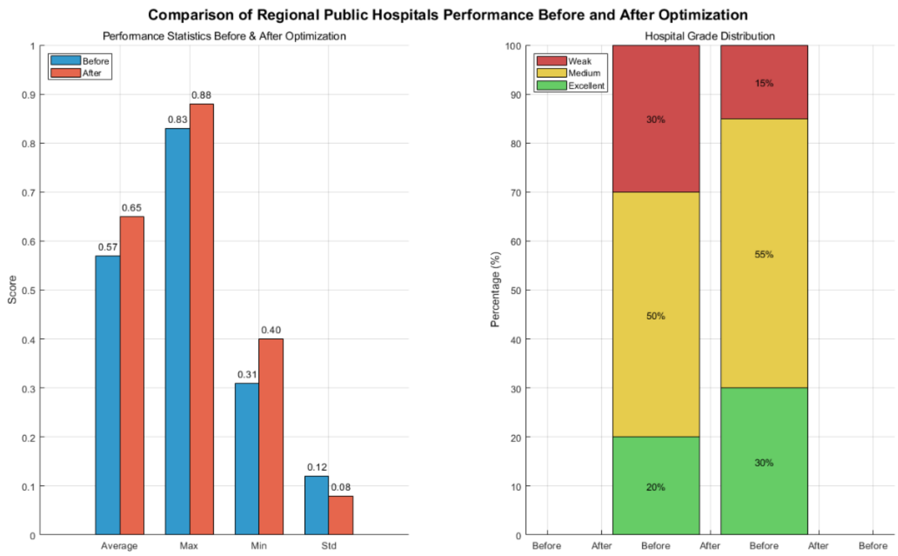

Figure 2. Comparison of regional public hospital performance before and after optimization

Under the multi-objective optimization model, the indicator weight structure is adjusted, and the allocation of key driver variables becomes more reasonable. The overall comprehensive scores show an upward trend, indicating that structural optimization can effectively enhance performance levels within existing resource constraints. Moreover, the post-optimization score distribution is more concentrated, with reduced range and standard deviation, reflecting a mitigation of inter-hospital disparities through the multi-objective balancing mechanism.

From the perspective of grade structure, hospitals show an upward shift after optimization: the proportion of medium-grade hospitals increases, the number of weak-grade hospitals significantly decreases, and the proportion of hospitals rated good or above rises. This indicates that the model not only improves overall performance but also exerts a structural pull effect, offering practical guidance for optimizing the regional public hospital performance system.

In summary, after optimization, the comprehensive performance of regional public hospitals improves, the distribution becomes less dispersed, and the system structure is more stable, validating the applicability and effectiveness of the multi-objective optimization method in regional public hospital technological innovation performance evaluation.

3.2.3 Analysis of efficiency objective optimization

Within the multi-objective optimization framework, the efficiency objective constitutes a crucial component of the performance system, reflecting primarily the level of resource utilization and operational output capacity. By analyzing the model solution results, the efficiency objective can be evaluated from four perspectives: resource utilization efficiency, input–output matching, changes in core efficiency indicators, and goal achievement status. Table 1 presents a comparison of efficiency objectives before and after optimization.

Table 1. Comparison of technological innovation efficiency objectives before and after optimization

Indicator Category	Indicator	Before Optimization	After Optimization	Trend
Resource input	Annual research funding ratio	Avg. 2.80%; regional disparities	Core-input and weight increased	Improved
Resource structure	Primary-level R&D funding ratio	Avg. 0.95%; insufficient input	Allocation priority increased	Improved
Talent Allocation	Staff with Master's degree or above	Avg. 18.00%; uneven distribution	Core driver variable	Strengthened
Technology promotion	Appropriate technology deployments	Avg. 2.30 items/year; some hospitals reported zero deployments	Weight and priority increased	Improved
Innovation conversion	In-hospital new technology adoption rate	Avg. 32.67%	Structural matching enhanced	Improved
Overall resource utilization	Comprehensive efficiency level	Regional disparities	Efficiency structure balanced	Optimized

Note: R&D = research and development

The optimization results indicate that multi-objective optimization significantly adjusted the weight structure of efficiency-related indicators. The weights of key resource input variables (e.g., research funding ratio and primary-level appropriate technology research and development (R&D) funding ratio) were reinforced, concentrating resources in areas with high marginal contribution. This improved input–output matching and overall resource utilization efficiency. The dispersion of indicator weights decreased, and system operational stability increased, demonstrating a more balanced efficiency system post-optimization.

Analysis of the original data shows that the sample hospitals' research funding ratio (2.8%) and primary-level R&D funding ratio (0.95%) exhibited substantial structural imbalance, indicating potential for improving resource allocation efficiency. Regression results further show that the proportion of medical staff with a master's degree or above and research funding ratio have significant positive effects on performance capability ($\beta = 0.42$ and $\beta = 0.35$, respectively with $p < 0.01$). The optimization model strengthened the weights of these core variables, tightening the linkage between resource input and performance output, and improving input–output conversion efficiency.

Additionally, the number of appropriate technology deployments is relatively low (average 2.30 items/year, with some hospitals at zero), reflecting inadequate technology diffusion efficiency. Post-optimization, the increased weight for the efficiency dimension helps channel resources toward high-efficiency segments, promoting technology dissemination and service capability improvement.

Overall, under budget constraints, the multi-objective optimization improved the efficiency objective function value, validating the model's effectiveness in coordinating efficiency enhancement with structural stability, and laying the foundation for subsequent coordination with fairness and innovation objectives.

3.2.4 Analysis of innovation fairness optimization

Within the multi-objective optimization framework, the fairness objective aims to enhance the balance of resource allocation and mitigate regional development disparities. Based on the optimization model results, the effects can be analyzed from several aspects, including trends in regional differences, indicator dispersion, structural balance, and the mitigation of resource concentration. Table 2 presents a comparison of fairness before and after optimization.

Table 2. Comparison of fairness and balance indicators before and after optimization

Indicator	Before Optimization	After Optimization	Trend
Inter-regional score gap	Significant	Reduced	Improved
Indicator standard deviation	High	Lowered	Enhanced balance
Coefficient of variation	High	Lowered	Increased stability
High-scoring hospital concentration	Significant	Weakened	Alleviated
Structural balance	Partially imbalanced	Significantly improved	Enhanced

The original results show that hospitals in the eastern and central regions scored higher than those in the western region, indicating pronounced regional disparities and uneven resource allocation and talent investment. After introducing the fairness objective in the optimization model, constraints were applied to the indicator structure, enhancing regional coordination while improving efficiency, resulting in a convergence of performance differences.

From a statistical perspective, fairness improvement is mainly reflected in reductions in standard deviation and coefficient of variation, indicating lower indicator dispersion and a more stable structure. Post-optimization, the weights of key variables are more evenly distributed, shifting the indicator system from a relatively concentrated structure to a multi-dimensional collaborative structure, thereby reducing the excessive concentration of resources in a few advantaged regions.

3.2.5 Analysis of innovation and social value optimization

Under the "Healthy China" strategy, the evaluation of S&T innovation performance in regional public hospitals emphasizes not only operational efficiency and resource fairness but also the enhancement of technological innovation capability and social health value. In constructing the multi-objective optimization model, the innovation and service value objective functions were incorporated, shifting the performance evaluation system from a traditional operational orientation toward a value-creation orientation. Based on the model results, the effects can be analyzed from four perspectives: adjustment of innovation indicator structure, changes in results transformation, improvement of social service value, and alignment with strategic objectives.

Table 3 presents a comparison of innovation and social value objectives before and after optimization.

Table 3. Comparison of fairness and balance indicators before and after optimization

Indicator Dimension	Before Optimization	After Optimization	Trend
Innovation indicator weights	Relatively low	Significantly increased	Strengthened
Results transformation indicators	Marginal position	Core position	Improve
Social service indicators	Dispersed	More concentrated	Optimized
Innovation-oriented structure	Academically biased	Value-oriented Strengthened	Transformed
Strategic alignment	Moderate	Significantly improved	Enhanced

The results indicate that the weights of innovation-related indicators increased significantly after optimization. The innovation dimension shifted from a supporting role to an essential component, with indicators related to research investment, technology promotion, and results transformation contributing more, reflecting a performance structure shift from "academic orientation" toward "value orientation".

Based on original data, sample hospitals still have room for improvement in areas such as appropriate technology deployment, new technology promotion, and patent transformation, with some results not yet effectively translated into practical applications, revealing a tendency to focus on academic output while neglecting practical application. By including results transformation indicators in the innovation and social value objective function, the optimization model strengthened their structural position, promoting the extension of innovation outcomes to clinical applications and social services.

Additionally, the social service value dimension was reasonably allocated in the optimized structure, increasing attention to public health benefits. Enhancing the weights of social value indicators helps balance efficiency and innovation capability with health governance objectives, reflecting a shift in the performance evaluation system from "institutional performance" to "social value performance".

3.2.6 Summary of structural optimization trends

Based on the results of the multi-objective optimization model and the comparative analysis of indicator structures, the S&T innovation performance system of regional public hospitals demonstrates clear structural optimization trends, primarily reflected in the strengthening of innovation orientation, value structure reconstruction, and enhancement of evaluation functions.

Before optimization, the performance structure was relatively biased toward academic output scale, with indicators such as the number of publications and research projects occupying high weights, showing a "scale-expansion" characteristic. After optimization, the weights of value-oriented indicators, including results transformation efficiency, technology promotion and application, and innovation resource allocation efficiency, increased. The innovation structure shifted from "academic-oriented" toward "quality and transformation-oriented," highlighting the practical contribution of innovation to clinical services and regional health needs.

At the level of the objective structure, the multi-objective model integrates research efficiency, innovation quality, and results transformation value into a unified framework, achieving coordinated optimization across different innovation objectives. This prevents structural imbalance caused by dominance of single academic output indicators and enhances the overall coordination of the S&T innovation performance system.

At the methodological level, this study transforms the evaluation of S&T innovation performance from static weighted ranking to structural optimization. By using multi-objective linear programming, the indicator weights are dynamically reconstructed, turning the evaluation system from a "result measurement tool" into a "structural adjustment tool" and improving the governance and regulatory capacity of innovation management.

Empirical results show that under existing resource constraints, multi-objective optimization can simultaneously enhance innovation efficiency and results transformation, improving the alignment between innovation activities and regional health demands. This validates the applicability and explanatory power of the model in optimizing the S&T innovation performance of regional public hospitals. Therefore, the multi-objective optimization approach has practical value for wider application in the reconstruction of the performance evaluation system of regional public hospitals.

4 Discussion

This study examines the structure of innovation performance in regional public hospitals through a multi-objective optimization framework. The findings point to a reconfiguration of the underlying decision structure when efficiency, quality, and transformation objectives are considered simultaneously under resource constraints. Rather than reflecting isolated improvements in individual indicators, the observed changes indicate a shift in how different objectives are weighted and coordinated. The discussion is organized around four aspects: the nature of trade-offs among innovation objectives, the role of key resource inputs, the sources of regional differences, and the logic of structural adjustment under a multi-objective setting.

4.1 Trade-Offs among Innovation Objectives

Innovation performance in regional public hospitals is shaped by multiple objectives that do not move in the same direction. Improvements in efficiency, for example, often require concentration of resources, while gains in quality and transformation depend on sustained investment and longer development cycles. Under limited resources, these objectives interact in ways that create unavoidable trade-offs.

The optimization results suggest that the decision structure shifts away from a single focus on academic output toward a more balanced configuration. By assigning weights across different objective dimensions, the model limits the dominance of scale-based indicators such as publication counts and allows quality and transformation-related factors to play a more visible role. This shift indicates that improvements in innovation performance depend less on expanding output alone and more on how competing objectives are jointly managed within the system.

4.2 Role of Talent and Research Investment

The empirical results highlight the importance of human capital and financial input in shaping innovation outcomes. The proportion of staff with advanced degrees and the level of research funding are consistently associated with higher performance, indicating that these factors form the core of the decision space in which innovation activities operate.

Within the optimized structure, greater weight is placed on these variables, reflecting their contribution to sustained innovation capacity. This adjustment suggests that reallocating resources toward high-impact inputs is more effective than simply increasing overall activity levels. In practice, the relationship between resource allocation and innovation outcomes is not linear, and the model captures this by emphasizing the relative importance of key inputs rather than treating all indicators equally.

4.3 Regional Differences in Innovation Performance

The analysis also reveals marked differences in innovation performance across regions. These differences are closely related to variations in resource availability, the concentration of skilled personnel, and the presence of collaboration networks. In regions where resources are already concentrated, existing advantages tend to reinforce themselves over time, leading to widening gaps in performance.

The introduction of a balancing mechanism within the optimization framework alters this pattern to some extent. By moderating the concentration of weights on a limited set of indicators, the model reduces the tendency for resources to cluster excessively in already advantaged settings. Although this does not eliminate regional differences, it changes the structure through which these differences are produced.

4.4 Structural Adjustment under a Multi-Objective Framework

The results indicate that changes in innovation performance are closely linked to adjustments in the internal structure of the evaluation system. Rather than improving individual indicators in isolation, the model redistributes weights across efficiency, quality, and transformation objectives, leading to a more stable and balanced configuration.

During this process, variables with stronger explanatory power receive greater emphasis, while the influence of purely scale-based indicators becomes more limited. This shift reduces dispersion in the system and alters how performance is generated. In this sense, the optimization process does not simply reorder outcomes; it changes the way in which those outcomes are produced.

Taken together, these findings suggest that multi-objective optimization functions as a tool for restructuring the decision environment rather than merely refining measurement. By adjusting how objectives are prioritized under given constraints, the framework provides a basis for understanding how innovation performance can be shaped through changes in decision structure.

5 Decision Mechanism and Managerial Implications

The results of the multi-objective optimization model point to a shift from static evaluation toward a more adaptive decision structure. Rather than treating performance assessment as a fixed measurement process, the findings suggest that the evaluation system operates as a mechanism through which priorities are adjusted under resource and policy constraints. In this setting, the coordination of efficiency, quality, and transformation can be understood as an outcome of how decision variables are structured and updated over time. Three aspects of this mechanism can be identified.

5.1 Dynamic Adjustment of Indicator Weights

The optimization results indicate that the relative importance of different indicators is not stable, but varies with changes in resource conditions and development stages. A fixed weighting structure tends to preserve an academic output orientation, while the optimized results show a redistribution toward quality and transformation-related indicators.

From this perspective, the evaluation system can be interpreted as a dynamic adjustment process in which weights are periodically updated to reflect changing priorities. The role of key variables, such as talent structure and research investment intensity, becomes more pronounced in this process, as these factors consistently contribute to improved outcomes. As a result, the evaluation framework shifts from a static scoring scheme to a mechanism that adjusts the internal balance among competing objectives.

5.2 Allocation of Innovation Resources

The empirical results show that human capital and research funding play a central role in shaping innovation performance. Within the optimized structure, greater emphasis is placed on these inputs, indicating that the allocation of resources is closely tied to the distribution of decision weights.

This relationship suggests that resource allocation can be understood as part of the decision process rather than as an external intervention. Adjustments in funding structure and talent composition are reflected in the weighting scheme, which in turn influences performance outcomes. In this sense, the model captures how changes in resource distribution translate into changes in system behavior, without requiring uniform increases in overall input.

5.3 Link between Innovation and Transformation

The increase in the weight assigned to transformation-related indicators highlights a closer connection between research activity and practical application. In the optimized structure, transformation is no longer treated as a secondary outcome but as an integral component of innovation performance.

This shift can be interpreted as a change in how innovation activities are evaluated and prioritized. The linkage between research output and clinical application becomes more direct, and the evaluation system reflects this by assigning greater importance to indicators related to adoption and implementation. As a result, the decision structure aligns more closely with the practical role of public hospitals in regional healthcare systems.

6 Conclusions

This study examines the evaluation of innovation performance in regional public hospitals as a multi-objective decision problem. By incorporating efficiency, fairness, and innovation value into a unified framework, a multi-objective optimization model is constructed to adjust the indicator weight structure under resource and policy constraints.

The empirical results reveal that the existing evaluation structure is characterized by regional disparities and an overemphasis on scale-based academic output, with limited attention given to transformation and practical value. After optimization, the decision structure becomes more balanced, with increased weight assigned to indicators related to research investment and outcome transformation. This adjustment reduces dispersion in performance outcomes and reflects a shift from output-driven assessment toward a configuration that accounts for multiple objectives simultaneously.

Further analysis identifies talent structure and research funding intensity as key variables influencing innovation performance. These factors occupy a central position within the optimized decision structure, indicating that resource allocation plays a decisive role in shaping system outcomes. Rather than relying on uniform expansion of activities, improvements in performance are associated with how key inputs are weighted and coordinated.

The findings suggest that the proposed framework functions as a decision-support mechanism, enabling the evaluation system to move beyond static scoring and toward a structure in which priorities can be adjusted under changing conditions. In this sense, the model provides an analytical basis for understanding how innovation performance can be shaped through changes in decision structure.

Several limitations should be noted. The analysis is based on data from a limited regional sample, which may restrict the generalizability of the results. The use of a weighted-sum approach introduces a degree of subjectivity in the selection of parameters, and the assumption of linear relationships does not capture potential nonlinear interactions among indicators. Future research may address these issues by incorporating alternative optimization methods, such as dynamic multi-objective models, DEA, or data-driven weighting techniques, and by extending the analysis to broader datasets.

Author Contributions

Conceptualization, Y.Y.W. and L.H.Z.; methodology, Y.Y.W.; software, Z.Q.L.; validation, L.H.Z., Z.Q.L., and X.L.; formal analysis, Z.Q.L.; investigation, Y.Y.W.; resources, Y.Y.W.; data curation, Y.Y.W.; writing—original draft preparation, Y.Y.W.; writing—review and editing, X.L.; visualization, Z.Q.L.; supervision, L.H.Z.; project administration, X.L.; funding acquisition, Y.Y.W. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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