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Research on the Measurement and Improvement Path of Airport Economic Development Efficiency

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Abstract

This paper adopts the super-efficiency SBM model to evaluate the efficiency of core airports in 17 airside economic demonstration zones during the period from 2019 to 2023, and employs the Malmquist index to analyze the dynamic changes in their output efficiency. The results indicate that among these 17 core airports, Ningbo Lishe International Airport, Shanghai Hongqiao International Airport, and Guangzhou Baiyun International Airport achieved the highest efficiency levels, whereas Beijing Daxing International Airport, Qingdao Jiaodong International Airport, and Guiyang Longdongbao International Airport exhibited relatively low efficiency. Over the five-year period, the overall productivity of all airports has witnessed a significant improvement. On the one hand, technological progress has played a driving role in enhancing overall efficiency; on the other hand, most airports maintain high scale efficiency, which has exerted a positive impact on overall productivity. Finally, this paper proposes targeted paths for improving the development efficiency of the airside economy from the dual perspectives of airport management and policy formulation.

Keywords: Airport Economic; Development Eficiency; SBM-Malmquist Index Model

1. Introduction

Within China's transportation system, which follows the principle of "taking railways as the backbone, highways as the foundation, and fully leveraging the comparative advantages of water transportation and civil aviation", air transportation plays a pivotal role in advancing regional economic development, facilitating industrial upgrading, and accelerating urbanization. Moreover, the development efficiency of airports serves as a crucial driving force for promoting the high-quality development of the airport economy and boosting regional economic growth.

Airport efficiency is a crucial reflection of the quality of airport construction and development. The *14th Five-Year Plan for Civil Aviation Development* points out that the national comprehensive airport system serves as a vital foundation for supporting the construction of a strong civil aviation country. It is imperative to further increase investment and construction efforts, expand high-quality supply, address hub capacity constraints, improve the national comprehensive airport system, and advance its pursuit of higher-quality development. The *Plan for the Development of a Modern Comprehensive Transportation System*, issued by the State Council during the 14th Five-Year Plan period, clearly indicates that China's comprehensive transportation development faces issues of unbalanced and inadequate growth, with significant disparities among various transportation networks. It is essential to achieve balanced and coordinated development of facilities and services, promote the deep integration of transportation with economic and social development, and comprehensively advance the high-quality development of transportation. Therefore, exploring the development efficiency and improvement paths of the airport economy holds certain reference value for enhancing the coordinated development of airports and urban economies, as well as promoting the integration of airports and cities.

Regarding the evaluation methods for the development efficiency of the airport economy, most scholars at home and abroad adopt the combined weighting-TOPSIS model, data envelopment analysis (DEA) model, and three-stage data envelopment analysis network method, with model adjustments made according to the research objects. The establishment of an airport operational efficiency evaluation system mainly starts from four dimensions: flight operation efficiency, passenger boarding efficiency, aircraft taxiing efficiency, and coordination efficiency, and constructs 11 indicators including the jet bridge utilization rate, jet bridge turnover rate, and flight stand change ratio (Hu Jie & Bao Fan, 2023).

For the evaluation of airport operational efficiency models, scholars often employ the combined weighting-TOPSIS model, three-stage data envelopment analysis network method, and super-efficiency DEA (CCR)-Malmquist model (Wei Ming, 2023). The results indicate that the development of China's airport industry mainly relies on scale efficiency, while technology remains relatively backward (Chu Yanchang & Chen Feichao, 2019).

Concerning the impact of technical efficiency on airport efficiency, the specific measurement of overall technical efficiency, pure technical efficiency, and scale efficiency has revealed that airport scale, low-cost carriers, and cargo transportation exert a significant influence on the technical and scale efficiency of Italian airports (Carlucci, Cirà, & Coccorese, 2018).

Based on the aforementioned analysis, this study collected relevant data from the core airports of 17 national-level air-transportation related economic zones over the period 2019–2023. A super-efficiency SBM model was established, and appropriate input and output indicators were selected to conduct calculation and static analysis of the airport economy's development efficiency. Furthermore, the Malmquist productivity index was employed to explore the dynamic changes in airport efficiency from 2022 to 2023. Finally, targeted and effective suggestions for improvement paths were proposed. The research findings are conducive to airports optimizing their scale structure, emphasizing technological progress, and advancing intelligent transformation and development. Moreover, they hold significant implications for airports enhancing their international competitiveness, improving comprehensive functions, and promoting regional economic development.

2. Research and Design

2.1. Indicator System Construction and Data Sources

This study takes the core airports of 17 national-level air-transportation related economic zones in China as the research objects. Input indicators include the number of airport runways, the number of aircraft stands, and the airport's floor area, while output indicators consist of the number of flight takeoffs and landings, passenger throughput, and cargo and mail throughput. Considering the interaction between airports and regional economies, the regional gross domestic product (GDP) is incorporated as an environmental variable or external factor affecting efficiency, and its correlation with airport performance is explored in subsequent analyses. Based on this, an evaluation index system for airport efficiency is constructed, as shown in Table 1, to study airport efficiency during the period from 2019 to 2023. Data on airport-related indicators are derived from the *Annual Business Volume of Civil Aviation Airports in East China*, and data on regional GDP are sourced from the *Statistical Communique on National Economic and Social Development* of each region.

Table 1. Core Input and Output Indicators of Airport Economy

Indicator type	Metric Name	Index Unit
Investment indicators	Number of runways at the airport	strip
	Number of aircraft positions	Unit
	Airport area	Square km
Output indicators	Flight takeoff and landing	Ten thousand times
	Passenger Throughput	Ten thousand people
	Cargo and mail throughput	Ten thousand tons
	Regional GDP	100 million yuan

2.2. Model Specification

(1) The Super-Efficiency SBM Model

Kaoru Tone (2001) proposed a slacks-based measure (SBM) model with undesirable outputs, which is widely applied to measure the economic efficiency of decision-making units (DMUs) with multiple inputs and multiple outputs. This model enables a comprehensive evaluation of regional economic efficiency from both desirable and undesirable output perspectives, effectively addressing the issues of input-output slack and congestion arising from the radial and angular characteristics of traditional models.

The super-efficiency SBM model is a further refinement of the data envelopment analysis (DEA) model, designed to overcome the limitation that standard DEA and SBM models cannot differentiate between DMUs with an efficiency value of 1. By allowing the efficiency values of some DMUs to exceed 1, this model can more precisely distinguish among units deemed equally efficient in traditional DEA models. The core objective of the super-efficiency SBM model is to further relax the constraints on efficient DMUs while retaining the non-radial and non-angular properties of the conventional SBM model, thereby quantifying excess efficiency.

In this study, the super-efficiency SBM model was employed to analyze and assess the relative efficiency of 17 DMUs (i.e., airports). This model can effectively identify units with higher efficiency and further rank those that have reached the production possibility frontier, facilitating the identification of the best-performing units and the provision of corresponding improvement recommendations.

Assume there are n decision-making units (DMUs), with each DMU having m input variables and s output variables. The objective of the conventional SBM model is to minimize input slack and maximize the reduction of output shortfalls. The basic structure of the model is presented as follows:

$$Min\ \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_i}}{1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_r}} \qquad (1)$$

Among them, s_i^- is input redundancy, and s_r^+ is output insufficient.

The super-efficiency SBM model permits efficiency values to exceed 1. It measures the relative efficiency of a decision-making unit (DMU) by excluding the evaluated DMU from the production possibility set, while retaining other DMUs as the reference benchmark.

Mathematically, it can be expressed by the following formula:

$$Min\ \rho^* = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_i}}{1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_r}} \qquad (2)$$

Under this model, if $\rho^* > 1$,it means that the efficiency of the decision unit exceeds the production possibility boundary.

(2) The Malmquist Index Method

The super-efficiency SBM model is a static efficiency evaluation method. To capture the dynamic changes in the input-output efficiency of decision-making units (DMUs), this study incorporates the Malmquist index approach — a method that requires no assumptions about decision-maker behaviors or evaluation objectives and allows for complete and effective decomposition. As a dynamic efficiency evaluation tool, the Malmquist productivity index can not only quantify the overall productivity changes of DMUs across different time periods, but also enable researchers to explore the underlying mechanisms driving productivity fluctuations by decomposing the index into technical efficiency change and technological progress change. In this research, the Malmquist productivity index will serve as a crucial analytical framework for examining the productivity dynamics of the target sample. Fare et al. (1994, hereinafter referred to as FGNZ) further decomposes the Malmquist index into three components, namely technical efficiency change, technological progress, and scale efficiency change. Due to the redundancy and complexity of mathematical formulas, this paper focuses on exponent decomposition, and therefore only presents the FGNZ decomposition model used in this study.

Its mathematical model is:

$$M(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_V^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)} \times \left(\frac{D_c^t(x^t, y^t)}{D_c^{t+1}(x^t, y^t)} \frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^t(x^{t+1}, y^{t+1})}\right)^{1/2} \times \frac{D_c^{t+1}(x^{t+1}, y^{t+1}) / D_V^{t+1}(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t) / D_v^t(x^t, y^t)} = TE\Delta_{FGNZ} \times T\Delta_{FGNZ} \times S\Delta_{FGNZ} \quad (3)$$

Among them, M is the Malmquist productivity index, t is time, D is the distance function, C and V are two different possible sets, x is input, y is output, and TEΔ, TΔ, and SΔ represent changes in technical efficiency, technological progress, and returns to scale, respectively.

3. Empirical Analysis

3.1. Static Evaluation of Airport Economy Development Efficiency

This section employs the super-efficiency SBM model and utilizes MATLAB software to conduct a year-by-year calculation of the development efficiency of 17 core airports spanning the period from 2019 to 2023. The empirical results are presented in Tables 2 and 3.

As indicated in Table 2, in terms of the number of DEA-efficient core airports in each year during 2019−2023, an average of six core airports attained a DEA-efficient state, namely, their efficiency values exceeded 1. According to the data in Table 3, Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, and Ningbo Lishe International Airport maintained an efficient operational status with efficiency values above 1 for five consecutive years. Furthermore, Chengdu Shuangliu International Airport and Xi'an Xianyang International Airport achieved efficiency values exceeding 1 in four out of the five years, demonstrating a high level of operational efficiency. Changsha Huanghua International Airport and Hangzhou Xiaoshan International Airport sustained high efficiency for two consecutive years.

The empirical data suggest that these airports can convert their existing infrastructure investments into relatively optimal outputs corresponding to their business volumes. In addition to possessing advanced operation and management systems, these airports also exhibit significant economies of scale and strong market competitiveness.

Table 2. Effective Areas for Development Efficiency of Seventeen Core Airports (2019–2023)

Year	DEA valid area
2019	Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Chengdu Shuangliu International Airport, Ningbo Lishe International Airport, Xi'an Xianyang International Airport, Beijing Capital Airport
2020	Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Chengdu Shuangliu International Airport, Ningbo Lishe International Airport, Xi'an Xianyang International Airport
2021	Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Chengdu Shuangliu International Airport, Changsha Huanghua International Airport, Ningbo Lishe International Airport, Xi'an Xianyang International Airport
2022	Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Chengdu Shuangliu International Airport, Changsha Huanghua International Airport, Xiaoshan International Airport, Ningbo Lishe International Airport, Changchun Longjia International Airport
2023	Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Xiaoshan International Airport, Ningbo Lishe International Airport, Xi'an Xianyang International Airport

Table 3. Efficiency Measurement Results of 17 Core Airport Economic Zones (2019–2023)

Airport/Year	2019	2020	2021	2022	2023	Mean
Zhengzhou Xinzheng International Airport	0.530108525	0.63399583	0.573669292	0.560453722	0.312763805	0.522198235
Beijing Daxing International Airport	0.0190181	0.191264365	0.35356374	0.264179687	0.311222749	0.227849728
Qingdao Jiaodong International Airport	0.457439123	0.43231917	0.44403903	0.461011004	0.258411903	0.410644046
Chongqing Jiangbei International	0.572001868	0.658487668	0.653172191	0.660476568	0.392584256	0.58734451

Airport						
Guangzhou Baiyun International Airport	1.038007122	1.116435914	1.125002907	1.150353877	1.169441424	1.119848249
Shanghai Hongqiao International Airport	1.144410251	1.152446392	1.171173317	1.106866446	1.129627146	1.14090471
Chengdu Shuangliu International Airport	1.050794216	1.120816622	1.098239718	1.0712536	0.427573279	0.953735487
Changsha Huanghua International Airport	0.718363571	0.787267239	1.000850922	1.025663424	0.749290241	0.856287079
Hangzhou Xiaoshan International Airport	0.620620309	0.753131287	0.754307175	1.077792691	1.289518966	0.899074086
Ningbo Lishe International Airport	1.099229273	1.151848115	1.124903266	1.231818137	1.222298291	1.166019416
Xi'an Xianyang International Airport	1.165367542	1.120930725	1.112368513	0.59825248	1.065435777	1.012471007
Nanjing Lukou International Airport	0.641594266	0.684455583	0.594798265	0.706482083	0.464289094	0.618323858
Beijing Capital Airport	1.111118436	0.716870279	0.714968421	0.574211545	0.366849169	0.69680357
Changchun Longjia International Airport	0.499851949	0.527166279	0.559755786	1.000913469	0.456409369	0.60881937

Nanning Wuxu International Airport	0.50719101	0.515769032	0.50669282	0.600735988	0.418079045	0.509693579
Fuzhou Changle International Airport	0.616585434	0.615496683	0.633301623	0.559813731	0.383738572	0.561787209
Guiyang Longdongbao International Airport	0.274382428	0.29603446	0.283077011	0.263411736	0.209728037	0.265326734
Mean	0.709769613	0.733807979	0.747287294	0.759628835	0.625133007	/

Drawing on average efficiency and operational stability, this paper classifies the sample airports into three tiers with distinct characteristics.

First is the high-efficiency and stable type (Tier 1), mainly including Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, and Ningbo Lishe International Airport, whose efficiency values have remained consistently high (i.e., ≥1 in most years). The shared attributes of these airports lie in their mature hub status and optimized air transport network structures. As a global aviation hub, Guangzhou Baiyun International Airport leveraged its prominent scale economies and strong market appeal to maintain high resource throughput and conversion efficiency even during the pandemic period. Benefiting from its core geographical location in the Yangtze River Delta and high-value business-oriented passenger flow, Shanghai Hongqiao International Airport achieved intensive and efficient resource utilization. As a regional hub for both passenger and cargo transportation, Ningbo Lishe International Airport demonstrated superior output efficiency underpinned by its specialized operational model.

Second is the fluctuating development type (Tier 2), encompassing regional hub airports such as Chengdu Shuangliu International Airport, Xi'an Xianyang International Airport, Hangzhou Xiaoshan International Airport, Chongqing Jiangbei International Airport, and Beijing Capital International Airport. Their efficiency values exhibit notable phase-specific fluctuations, which are usually directly associated with major structural adjustments. The sharp efficiency decline of Chengdu Shuangliu International Airport in 2023 was directly triggered by the policy of relocating all international flights to Chengdu Tianfu International Airport under the "one city, two airports" framework, representing a strategic reallocation of aviation resources within the metropolitan area. Hangzhou Xiaoshan International Airport surged to the top of the efficiency rankings in 2023, primarily driven by the commissioning of a new terminal to accommodate the Hangzhou Asian Games; this infrastructure upgrade substantially boosted its operational capacity and passenger volume in the short term, reflecting the synergistic effect of mega-events and infrastructure expansion. The efficiency decline of Xi'an Xianyang International Airport in 2022, in addition to the impact of extreme weather events, also exposed potential long-term operational bottlenecks in runway operation schemes and taxiway capacity, which constrained the full utilization of its resource endowments.

Finally is the potential development type (Tier 3), primarily represented by airports with relatively low average efficiency levels, such as Zhengzhou Xinzheng International Airport, Qingdao Jiaodong International Airport, Nanjing Lukou International Airport, and Guiyang Longdongbao International Airport. These airports are mostly in the stage of hub function cultivation or are confronted with fierce regional competition. Despite possessing advanced infrastructure in some cases, the route network density, flight frequencies, and passenger-cargo aggregation effects of these airports have not yet been fully realized, leading to suboptimal utilization of existing resources. This phenomenon reflects a certain time lag in the transformation of "infrastructure investment" into "operational efficiency output".

From a longitudinal perspective, the overall average efficiency of the sample airports exhibited a moderate upward trend from 2019 to 2022, indicating that airports continued to explore operational potential during the pandemic through route network optimization and operational process refinement. Nevertheless, the decline in overall average efficiency in 2023 reflects that airports were confronted with heterogeneous challenges in the post-pandemic recovery phase, including disparities in the restoration pace of international routes, short-term disruptions induced by major hub layout adjustments, and the asynchronous recovery of regional economies.

In summary, the efficiency performance of an airport is not merely an isolated outcome of operational management, but rather a result of structural interaction between its internal capabilities and the external environment. Sustained high efficiency is often contingent on a mature hub network, a balanced passenger-cargo traffic structure, and in-depth integration with the regional economy. Conversely, significant efficiency fluctuations are closely associated with changes in core structural variables, such as national-level aviation resource allocation policies, large-scale infrastructure investment projects, and bottlenecks in airspace resources and ground support systems.

3.2. Dynamic Efficiency Evaluation of Airport Economy Development

The Malmquist index is capable of analyzing changes in production efficiency from period t to period t+1, and is widely applied in the fields of economics and production efficiency evaluation. Through multi-dimensional decomposition, this index can elaborate on the specific sources of efficiency changes for a given production unit across different time periods. These dimensions include five core components: technological change (TC), pure technical efficiency change (PEC), scale efficiency change (SEC), technical efficiency change (EC), and total factor productivity change (TFP).

Technological change (TC) measures the shift of the technology frontier: a TC value greater than 1 indicates technological progress, while a value less than 1 denotes technological regression. Pure technical efficiency change (PEC) reflects changes in management or organizational efficiency: a PEC value greater than 1 signifies improved management efficiency, whereas a value less than 1 indicates a decline in management efficiency. Scale efficiency change (SEC) assesses whether the production scale is moving closer to the optimal scale: an SEC value greater than 1 implies enhanced scale efficiency, while a value less than 1 indicates reduced scale efficiency. Technical efficiency change (EC) is defined such that a value greater than 1 indicates an improvement in technical efficiency, and vice versa. Total factor productivity change (TFP) integrates the above three indicators (PEC, SEC, and TC) to reflect changes in overall production efficiency: a TFP value greater than 1 indicates an improvement in overall efficiency, while a value less than 1 denotes a decline.

Table 4. Malmquist Index Measurement Results of 17 Core Airports (2022–2023)

Core Airport/Efficiency Value	Technological Change (TC)	Pure Technical Efficiency Change (PEC)	Scale Efficiency Change (SEC)	Technical Efficiency Change (EC)	Total Factor Productivity Change (TFP)
Zhengzhou Xinzheng International Airport	3.965375301	0.562780325	0.991602981	0.558054648	2.212896117
Beijing Daxing International Airport	3.042003937	1.29524481	0.909536332	1.178072213	3.58370031
Qingdao Jiaodong International Airport	3.909454741	0.560624536	0.999836809	0.560533047	2.191378578
Chongqing Jiangbei International Airport	3.152781498	0.4498234	1.321397318	0.594395434	1.873998926
Guangzhou Baiyun International Airport	1.660136911	0.854729634	1.189373482	1.016592761	1.687683166
Shanghai Hongqiao International Airport	1.808440028	1.030278044	0.990570645	1.020563186	1.845627317
Chengdu Shuangliu International Airport	3.214456772	0.415241963	0.961207226	0.399133575	1.282997623
Changsha Huanghua International	2.512257291	0.680485629	1.073559822	0.730542031	1.835309543

Airport					
Xiaoshan International Airport	2.709818339	1.20139574	0.995878628	1.196444341	3.242146818
Ningbo Lishe International Airport	1.60307102	1.031081393	0.962360216	0.992271712	1.590682025
Xi'an Xianyang International Airport	1.926448636	1.394493649	1.277103891	1.780913265	3.430837929
Nanjing Lukou International Airport	3.022237766	0.656551199	1.000964629	0.657184528	1.986167899
Capital Airport	4.681427724	1.011453637	0.63164002	0.638874596	2.990845245
Changchun Longjia International Airport	3.835483115	0.990727367	0.460260662	0.455992834	1.748952814
Nanning Wuxu International Airport	3.14638923	0.991456914	0.701941477	0.69594473	2.189713004
Fuzhou Changle International Airport	2.915046229	0.886217389	0.773484547	0.685475455	1.998192641
Guiyang Longdongbao International Airport	3.438223797	0.799303121	0.996115879	0.796198531	2.737508735

Drawing on the data presented in Table 4, this section conducts a comprehensive analysis of the Malmquist index for each core airport over the period from 2022 to 2023.

In terms of the technological change (TC) indicator, all sample airports registered notable technological improvements. This finding reflects that these airports have made substantial headway in introducing emerging technologies and optimizing operational models, which constitutes a critical driver of overall efficiency enhancement. From the perspective of pure technical efficiency change (PEC), Beijing Daxing International Airport, Shanghai Hongqiao International Airport, Hangzhou Xiaoshan International Airport, Ningbo Lishe International Airport, Xi'an Xianyang International Airport, and Beijing Capital International Airport all exhibited positive performance. This indicates that the synergistic effects of comprehensive management upgrading and technological advancement have played a productivity-promoting role, with their management efficiency improved significantly. In contrast, Zhengzhou Xinzheng International Airport, Qingdao Jiaodong International Airport, Chongqing Jiangbei International Airport, and Chengdu Shuangliu International Airport underperformed in management efficiency, implying potential issues such as inadequate optimization of management processes and irrational resource allocation schemes.

Regarding scale efficiency change (SEC), Chongqing Jiangbei International Airport, Guangzhou Baiyun International Airport, Changsha Huanghua International Airport, Xi'an Xianyang International Airport, and Nanjing Lukou International Airport achieved scale efficiency gains. This demonstrates that their operational scales have moved closer to the optimal level, and scale efficiency has exerted a positive effect on productivity growth. By comparison, Changchun Longjia International Airport displayed low scale efficiency, suggesting a suboptimal operational scale. Based on the technical efficiency change (EC) data, Beijing Daxing International Airport, Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Hangzhou Xiaoshan International Airport, and Xi'an Xianyang International Airport witnessed technical efficiency improvements, while the remaining airports recorded mediocre technical efficiency performance.

Overall, the total factor productivity change (TFP) indicator reflects a marked increase in the overall productivity of all core airports, with Beijing Daxing International Airport and Xi'an Xianyang International Airport registering the most prominent growth.

In summary, most airports have achieved remarkable outcomes in technological progress, yet there exists a substantial disparity in management efficiency and technical efficiency across individual airports, which directly constrains the improvement of total factor productivity. The relatively stable performance of scale efficiency indicates that the scale expansion of most airports has been implemented in a rational manner. To further enhance the comprehensive efficiency of each airport, it is imperative to prioritize the improvement of management efficiency, thereby ensuring that technological progress can be effectively translated into gains in overall productivity.

4. Paths to Improve the Development Efficiency of Airport Economy

Drawing on the analysis of efficiency values and Malmquist index results for each core airport, the pathways to enhancing airport efficiency can be refined and optimized from two dimensions: airport management and policy formulation.

4.1. The Airport Management Dimension

From the management perspective, optimize management processes and enhance management efficiency. Specifically, for airports with subpar management efficiency, such as Zhengzhou Xinzheng International Airport, Qingdao Jiaodong International Airport, Chongqing Jiangbei International Airport, and Chengdu Shuangliu International Airport, systematic reviews and optimization of existing management processes should be conducted. Meanwhile, lean management methodologies ought to be introduced to elevate resource utilization efficiency;

correspondingly, resource allocation and scale-based management should be optimized accordingly. For airports with inadequate scale efficiency, on the one hand, their expansion plans should be re-evaluated to ensure that newly added production capacity is aligned with actual demand, thereby avoiding resource wastage. On the other hand, airport infrastructure, particularly runways, terminals, and logistics facilities, should be upgraded to improve their carrying capacity and operational efficiency, thus optimizing resource allocation in turn.

From the technology perspective, strengthen technological research, development and introduction, and advance technological innovation and application. For airports that have achieved notable technological progress, such as the 17 core airports examined in this study, it is necessary to continuously increase investment in the R&D and introduction of emerging technologies, especially in domains including automation, artificial intelligence, and the Internet of Things, to elevate the intelligent operation level of airports. Additionally, the digital transformation of airports should be promoted, with big data analytics applied to optimize key operational links such as flight scheduling, passenger flow management, and security inspection procedures, so as to enhance overall operational efficiency and service quality.

From the talent perspective, strengthen talent cultivation. To this end, specialized training programs should be conducted for airport managers to improve their capabilities in modern airport management, crisis response, and digital transformation. Furthermore, a sound performance appraisal mechanism should be established to incentivize managers to continuously upgrade their management proficiency. In addition, cooperation should be forged with universities to cultivate and deliver high-caliber talents to the airport industry.

4.2. Policy Formulation

First and foremost, put forward diversified development policies and promote regional coordinated development. Specifically, based on the current development status and functional positioning of each airport, differentiated development policies should be formulated in light of local conditions. For instance, for airports with subpar management efficiency, the government ought to provide guidance and support to assist them in optimizing management processes; while for airports with rapid technological progress, the government should focus on supporting them to further expand their technological advantages and enhance their overall competitiveness. Meanwhile, the government should attach importance to regional cooperation, strengthen inter-airport collaboration within the region, accelerate resource sharing and coordinated development, and thus avoid redundant construction and resource waste among airports, ultimately realizing the coordinated development of the regional aviation economy.

Secondly, establish special funds to support technological innovation and R&D. To this end, the government should encourage airports and related enterprises to invest in technological R&D and innovation by setting up special funds or offering tax incentives, particularly in fields such as green aviation, environmental protection, intelligent transportation, and digital transformation of the aviation industry. Additionally, consideration should be given to constructing a technological innovation cooperation platform to promote collaboration between airports, universities, research institutions, and enterprises, thereby facilitating the rapid application and promotion of new technologies.

Thirdly, promote green and sustainable development and strengthen environmental protection policies. Regarding the environmental impact of airport operations, the government should formulate stringent environmental protection policies to urge airports to make improvements in green energy utilization, waste disposal, and carbon emission reduction. Meanwhile, through policy guidance, promote collaboration between airports and airlines in energy conservation and emission reduction technologies. Furthermore, guide sustainable development investment, and attract social capital to invest in the construction of airport green infrastructure—such as green buildings and renewable energy facilities — through policy support, so as to enhance the environmental friendliness of airports.

5. Conclusion

Drawing on the relevant data of the 17 core airports in national-level Airport Economic demonstration zones spanning the period from 2019 to 2023, this paper selects the number of runways, the number of aircraft stands, and airport apron area as input indicators, and adopts flight take-off and landing movements, passenger throughput, cargo throughput, and urban GDP as output indicators to construct a super-efficiency SBM model. On this basis, the paper conducts a static analysis of airport development efficiency, further calculates the Malmquist productivity index, and performs a dynamic analysis of airport development efficiency accordingly. The key findings are summarized as follows: (1) On average, six out of the seventeen sample airports have achieved DEA efficiency, with their efficiency values exceeding 1. (2) Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, and Ningbo Lishe International Airport have maintained efficient operation for five consecutive years; Chengdu Shuangliu International Airport and Xi'an Xianyang International Airport have demonstrated relatively high efficiency, while Beijing Daxing International Airport, Qingdao Jiaodong International Airport, and Guiyang Longdongbao International Airport have registered relatively low efficiency levels. (3) All seventeen airports have achieved significant technological improvements from 2022 to 2023; the management efficiency of Beijing Daxing International Airport, Shanghai Hongqiao International Airport, Hangzhou Xiaoshan International Airport, Ningbo Lishe International Airport, Xi'an Xianyang International Airport, and Beijing Capital International Airport has been significantly enhanced; Zhengzhou Xinzheng International Airport, Qingdao Jiaodong International Airport, Chongqing Jiangbei International Airport, and Chengdu Shuangliu International Airport have underperformed in terms of management efficiency; Chongqing Jiangbei International Airport, Guangzhou Baiyun International Airport, Changsha Huanghua International Airport, Xi'an Xianyang International Airport, and Nanjing Lukou International Airport have realized scale efficiency improvement, while Changchun Longjia International Airport has remained at a low scale efficiency level; Beijing Daxing International Airport, Guangzhou Baiyun International Airport, Shanghai Hongqiao International Airport, Hangzhou Xiaoshan International Airport, and Xi'an Xianyang International Airport have achieved technical efficiency enhancement, whereas the remaining airports have shown mediocre technical efficiency performance; the overall productivity of all core airports has been significantly improved, with Beijing Daxing International Airport and Xi'an Xianyang International Airport recording the most prominent growth.

Based on the above analysis, this paper puts forward optimization paths from two dimensions: airport operation and management, and policy formulation. The specific measures are as follows: (1) Optimize management processes and enhance management efficiency. (2) Strengthen technological research, development and introduction, and promote technological innovation and application. (3) Intensify talent cultivation efforts. (4) Introduce diversified development policies and promote regional coordinated development. (5) Establish special funds to support technological innovation and R&D initiatives. (6) Promote green and sustainable development and tighten environmental protection policies.

Author Contributions:

Conceptualization, Bo Lin.; methodology, Jiaxin Liang.; software, Jiaxin Liang.; validation, Jiaxin Liang.and Jie Tang.; formal analysis, Jiaxin Liang.; investigation, Jiaxin Liang.; resources, Jiaxin Liang.; data curation, Jiaxin Liang.; writing—original draft preparation, Jiaxin Liang.; writing—review and editing, Jiaxin Liang.,Bo Lin. and Jie Tang.; visualization, Jiaxin Liang.; supervision, Bo Lin.; project administration, Bo Lin.,Jie Tang.,; funding acquisition, Bo Lin. All authors have read and agreed to the published version of the manuscript." Please turn to the credit taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Conflict of Interest:

The authors declare no conflict of interest.

Data Availability Statement:

Data availability status	Recommended Data Availability Statement
Data available in a publicly accessible repository	The original data presented in the study are openly available in 2019-2023 Zhengzhou Resident Population Main Data Bulletin at https://tjj.zhengzhou.gov.cn; Daxing District 2019-2023 National Economic and Social Development Statistical Bulletin at https://www.bjdx.gov.cn; East China Civil Aviation Airports 2019-2023 Civil Aviation Transport Production Situation in East China at http://hd.caac.gov.cn; Jiutai District, Changchun 2019-2023 National Economic and Social Development Statistical Bulletin at http://www.jiutai.gov.cn/dzxx/; Nanning 2019-2023 National Economic and Social Development Statistical Bulletin at https://tj.nanning.gov.cn/tjsj/tjgb/; Fuzhou 2019-2023 National Economic and Social Development Statistical Bulletin at http://tjj.fuzhou.gov.cn/zwgk/tjzl/; Guiyang 2019-2023 National Economic and Social Development Statistical Bulletin at http://tjj.guiyang.gov.cn/2020_zwgk/2020_zdlygk/2020_sjfb/tjgb/index.html; 2019-2023 Yubei District Statistical Yearbook at http://www.ybq.gov.cn/bm/qtjj/zwgk_70831/fdzdgknr_70834/ysjs_108648/; Seventh National Population Census Data: Aviation Zone Population at https://www.gov.cn/guoqing/2021-05/13/content_5606149.htm; 2019-2023 Huadu District, Guangzhou National Economic and Social Development Statistical Bulletin at https://www.gz.gov.cn/zwgk/sjfb/; 2019-2023 Changning District, Shanghai National Economic and Social Development Statistical Bulletin at https://www.shcn.gov.cn/col5727/index.html; Civil Aviation Administration of China, "2023 National Civil Transport Airport Production Statistical Bulletin" at http://www.caac.gov.cn/big5/www.caac.gov.cn/PHONE/XXGK_17/XXGK/TJSJ/202403/P020240320504230898437.pdf; Jiutai District People's Government, Changchun - Jiutai District Overview at http://www.jiutai.gov.cn/?id=237;
3rd Party Data	Restrictions apply to the availability of these data. Data were obtained from "Civil Aviation 2020 from a Statistical Perspective", and are available from Xiukai Xu ISBN：9787536477803.
Dataset available on request from the authors	The raw data supporting the conclusions of this article will be made available by the authors on request.

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