MEASURING EFFICIENCY OF PUBLIC HIGHER EDUCATION USING DEA MODEL FOR SICHUAN IN CHINA

ZHIPEI XU

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
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Name-Surname	Mr. Zhipei Xu
Program	Vocational Education
Dissertation Advisor	Assistant Professor Tiamyod Pasawano, Ed.D.
Academic Year	2023

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..... Committee
(Assistant Professor Tiamyod Pasawano, Ed.D.)

Approved by the Faculty of Technical Education, Rajamangala University of Technology Thanyaburi in Partial Fulfillment of the Requirements for the Degree of Doctor of Science in Technical Education

.....Dean of Faculty of Technical Education

(Assistant Professor Arnon Niyomphol, M.S.Tech.Ed)

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Dissertation Title	Measuring Efficiency of Public Higher Education with DEA-BCC Model in Sichuan Province, China
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ABSTRACT

The study employed a dynamic unbalanced panel data approach to analyze the educational efficiency in public undergraduate universities. Unlike traditional static methods, the study considered the dynamic nature of educational inputs and their time-dependent impact on outputs. By utilizing unbalanced panel data, the study adequately accounted for the variations in the number of observations from each university, which accommodated the unique characteristics of the dataset.

The analysis employed were two complementary methods: the DEA-BCC model and the Malmquist productivity index. The DEA-BCC model was used to evaluate the relative efficiency of universities, which considered the lagged effects of educational inputs and their impact on outputs. Additionally, the MPI analysis provided a comprehensive assessment of output changes, which captured both technical efficiency and technological progress. The study was spanned from 2018 to 2022 and covered multiple public undergraduate universities in Sichuan province, China. Time series input and output indicators data of 27 public universities were collected to ensure comprehensive and up-to-date data. Descriptive statistics and Min-Max normalization were performed by using SPSS professional edition software to enhance data comparability and visualization. Considering both static and dynamic indicators, the data were subjected to BCC and Malmquist measurements by using DEAP2.1 software.

The study results reveal significant imbalances in educational efficiency and manifested in regional and institutional differences. The research provides a robust efficiency assessment and shed light on the long-term impact of educational inputs on overall university performance. The findings were of paramount importance to policymakers and university administrators, as they uncovered the effectiveness of resource allocation and policy decisions in the education sector. Moreover, the study contributed to the literature on educational efficiency by integrating dynamic considerations and unbalanced panel data and offering valuable insights into the complex long-term relationship between educational inputs and outputs value of .80.

Keywords: DEA, Malmquist, PCA, efficiency, public university

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Zhipei Xu

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List of Abbreviations

DEA	Data Envelopment Analysis
DUM	Decision-making units
PPS	The Production Possibility Set
PCA	Principal Component Analysis
EWM	Entropy Weight Method
GDP	Gross Domestic Product
RQ	Research Questions
TFP	Total Factor Productivity
TFPCH	Total Factor Productivity Change
SE	Scale Efficiency
PTE	Pure Technical Efficiency
TP	Technical Progress
TE	Technical Efficiency
MOE	Ministry of Education of the People's Republic of China
UNESCO	The United Nations Educational, Scientific and Cultural Organization.

CHAPTER 1
INTRODUCTION

1.1 Background and Statement of the Problem

The opportunity to access higher education has always been a highly scarce resource, not only in China but also a global issue today. According to UNESCO statistics, approximately 235 million students are enrolled in universities globally. However, despite the strong demand, the overall enrollment rate is only 40%. There are significant variations among different countries and regions. The Global Education Monitoring Report highlights that "the global higher education enrollment rate increased from 100 million in 2000 to 207 million in 2014, doubling over the period, but there are significant disparities both among countries and within nations. In 2013, among the wealthiest population aged 25 to 29 in the Philippines, 52% completed at least four years of higher education, while only 1% of the poorest population achieved the same."(Unesco, 2017)."The core and essence of their research lies in how individuals maximize their desires under conditions of scarce resource constraints."(ChenBin, 2022; Zhang, 2009).Unlike the economic sector, the public nature of higher education dictates that universities cannot directly produce exchangeable goods like businesses and reap economic benefits. The main connection between higher education institutions and the economy lies in the allocation of funds. As the funding provider, the government is concerned with the efficiency of fund utilization and the social benefits it generates. Subsequently, attention has turned to performance-based funding, a market-oriented approach that has gained popularity among policymakers worldwide(Jongbloed, 2023). As higher education institutions primarily focus on talent development, they rely on various resources to fulfill this function effectively. The efficiency of resource allocation plays a crucial role in determining whether it hinders or enhances talent cultivation and improves teaching quality. To assess this efficiency, appropriate methods and measures must be employed for evaluation.

The rational evaluation of higher education is an intriguing topic, and scholarly research mainly revolves around the scientificity and fairness of assessment methods, the accuracy, and effectiveness of evaluation processes, as well as the diagnostic and

applicative nature of assessment results(Hu & Xu, 2022). Due to the vast territory of China and the diverse types of higher education institutions, there are significant differences in the quantity and timeliness of outputs among different types and regions of universities. Using the same set of measurement indicators for performance ranking lacks applicability. Moreover, quantifiable indicators designed for various activities in higher education also face numerous challenges. Baodeng Lin（2022）has suggested that "evaluations should be tailored to different university types, and a classification-based approach should be adopted to formulate an evaluation indicator system for higher education, ensuring high credibility and validity in the evaluation process."(Lin, 2022). Liu Lei et al. have also pointed out the serious consequences of a quantitative-focused approach in higher education performance assessment. These consequences include the standardization of evaluation criteria, the utilitarian nature of evaluation results, the narrow focus on incentive methods, and the disregard for the development patterns of higher education(Liu et al., 2023).In evaluating the undergraduate teaching process in China, the factors of concern mainly fall into two categories: "human" and "material." "Human" refers to the participants in the teaching process, including teachers, staff, and students. "Material" includes tangible resources, such as buildings, books, equipment, sports facilities, etc., and intangible resources, such as teaching and research levels, student abilities, and employment conditions. Given the situation of inadequate supply of higher education resources, the evaluation results serve as a regulatory tool, with the primary focus on ensuring the allocation of various educational resources to achieve a reasonable level of resource supply. This provides the necessary resource support for the regular operation of higher education institutions and ultimately aims to gradually improve the quality of higher education.

In China's higher education assessment context, the government serves as the main authority. Given the scarcity of resources, the evaluation system primarily emphasizes incentives rather than constraints. However, the current institutional arrangement overlooks a crucial foundation: the close correlation between the outputs and inputs of higher education institutions. An evaluation system that solely focuses on outcomes without considering inputs is deemed unfair and unscientific. Therefore, it is essential to analyze and improve the current evaluation approach from the perspective of

inputs, aiming to reconcile the contradictions between educational demand and supply, which is a pressing task for education administrators. Furthermore, achieving a balance between educational demand and supply is a long-term endeavor, and enhancing the efficiency of educational resources stands as a fundamental approach to address this contradiction in the short term.

In February 2019, the Chinese central government officially issued an educational development plan entitled China's education modernization 2035 (Ministry of Education of the People's Republic of China [MOE], 2019)[1].As of December 31, 2022, there are a total of 3,072 higher education institutions in China, which can be categorized as follows:

Regular Higher Education Institutions: There are 2,820 regular higher education institutions, including 1,275 undergraduate institutions and 1,545 vocational colleges and polytechnics.

Adult Higher Education Institutions: There are 252 adult higher education institutions.

Among the regular higher education institutions, 96% of them are locally managed.

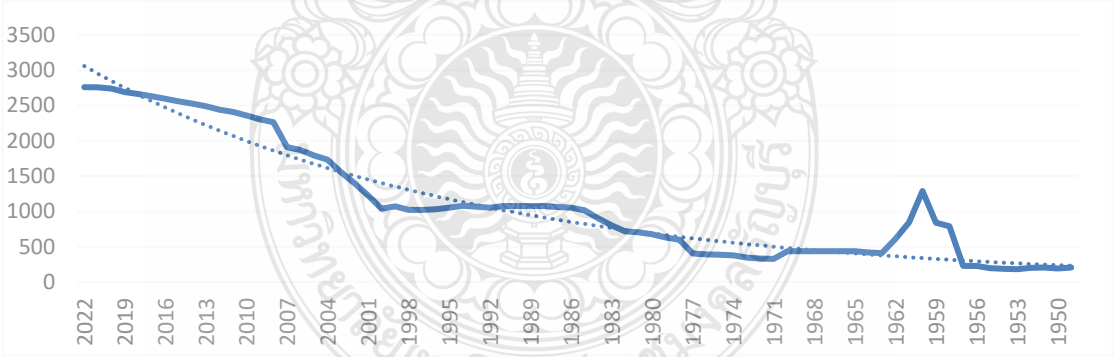

Figure 1.1 1950-2022 Changes in the number of colleges and universities in China

Data source: National Bureau of Statistics of China

[1] In February 2019, the Chinese central government officially issued an educational development plan entitled China's education modernization 2035 (Ministry of Education of the People's Republic of China [MOE], 2019). Developed over 3 years, the plan is intended to serve as the framework for China's education reform and development in the coming period. As such, it systematically describes the concepts, goals, and tasks of this reform and development. (Zhu, 2019)

With the transformation of China's higher education from elite-oriented to mass-oriented and then to universal access, promoting high-quality development in higher education requires effectively managing the relationship between absolutes and relatives, as well as quantity and quality(ChenBin, 2022). From a regional perspective, China's higher education resources, especially high-quality ones, are significantly unevenly distributed due to the combined influence of political, economic, and cultural factors. The increasing disparity in local fiscal conditions has led to a widening gap in educational investments among regions. In 2016, Guangdong, with the highest education budget, was 23 times greater than the lowest, Tibet. 2018 Shenzhen's education investment exceeded the combined total of Beijing and Shanghai in 2017. In 2019, Guangdong Province's total education budget reached 491.876 billion yuan, accounting for 9.80% of the country's entire education budget, maintaining its position as the top-ranking province in terms of education expenditure nationwide (Tan & Feng, 2022). The imbalance between central and local fiscal investments and the investment disparities among local finances will inevitably lead to differences in the inter-school allocation of educational resources. Merely adopting a results-oriented approach as the system for evaluating higher education cannot truly reflect the efficiency of development in local universities. Therefore, the starting point for educational evaluation should be based on provincial self-assessment, followed by inter-provincial comparative evaluations to better identify actual issues in the process of educational development. This article is based on this logic, intending to focus on higher education in Sichuan Province, a relatively familiar area, as the research sample. It will explore the efficiency of higher education based on the assumption that inputs and outputs should have a logical relationship and select appropriate research methods.

Sichuan Province, located in southwestern China, holds a significant position in the higher education landscape of China. It is home to a total of 134 higher education institutions, including 27 public undergraduate universities. The gross enrollment rate of higher education stands at 51.9%, with a total student population of 2.7614 million, including 990,100 regular undergraduate students(Department Of Development Planning, 2022).In November 2022, Sichuan Province formulated the "14th Five-Year Plan for Education Development in Sichuan Province," setting forth the objectives for

education development in the province from 2021 to 2025. In the field of higher education, the plan aims to steadily increase the level of higher education popularization, achieving a harmonious development of scale, speed, quality, structure, and efficiency in educational development. By 2025, the gross enrollment rate in higher education is expected to reach 58.5%, with a total student population of 2.8332 million, including an estimated 1.0252 million regular undergraduate students(Education, 2022).n the development of higher education, specific measures have been proposed to promote the classification development of higher education institutions, accelerate the construction of first-class universities and disciplines, strengthen first-class undergraduate education, and enhance the level of graduate education. Particularly, it is emphasized that through classification establishment, guidance, support, and evaluation, higher education institutions will be guided to position themselves scientifically and develop their unique characteristics. Based on the goal of "classification development," this article holds significant practical significance in conducting a classification evaluation of higher education institutions based on their different types.

Public undergraduate universities are the most important component of higher education in Sichuan Province. Therefore, this article intends to select the 27 public undergraduate institutions as the research subjects to evaluate the efficiency of these institutions. Such evaluation is crucial for ensuring effective resource allocation, improving educational quality, and promoting sustainable regional development.

Summary: The scarcity of higher education resources has led scholars to continuously focus on the effectiveness of higher education resource allocation. The development of China's higher education from elitism to massification has prompted a greater emphasis on the relationship between quantity and quality (ChenBin, 2022). However, due to the differentiated nature of central and local resource inputs, more than a single results-based evaluation system is required to objectively and scientifically evaluate higher education efficiency. Therefore, selecting homogenous universities for efficiency evaluation holds greater research value. Sample studies based on regional boundaries should also serve as the starting point for higher education evaluation. Sichuan Province, with 134 higher education institutions, including 27 public undergraduate universities, holds a prominent position as an educational province in

China. Additionally, due to the author's work-related convenience in accessing information on higher education in Sichuan Province, selecting Sichuan Province as the sample region for efficiency research is both practical and guiding.

1.2 Purpose of the Study

"Evaluating the efficiency of higher education in a rational manner and guiding regions and universities to fully utilize limited resources, improve resource utilization efficiency, and enhance internal development have become pressing issues that require careful consideration from universities and governments at all levels"(Liu et al., 2023). This research, based on the "efficiency theory," sets "How to rationally evaluate and optimize the efficiency of public undergraduate universities in Sichuan Province" as the overall purpose. In achieving this purpose, it aims to gradually accomplish four sub-objectives:

(1) Constructing an Appropriate Framework for Efficiency Evaluation in Higher Education Institutions: Identify rational approaches and research tools for assessing efficiency in public undergraduate universities within Sichuan Province.

(2) Determining an Input-Output Indicator System for the Higher Education Efficiency Evaluation in this Study: Identify an appropriate input-output indicator system for evaluating efficiency in public undergraduate universities within Sichuan Province, and gather relevant data to establish a robust foundation for the measurement process.

(3) Analyzing the Efficiency of Public Undergraduate Universities in Sichuan Province from 2018 to 2022: Based on collected data, employ selected efficiency measurement models and utilize the Data Envelopment Analysis (DEA) empirical approach to analyze the efficiency scores of public undergraduate universities in Sichuan Province.

(4) Identifying Causes of Efficiency Disparities and Improvement Strategies for Public Undergraduate Universities in Sichuan Province: Based on empirical analysis outcomes, observe whether disparities and potential areas for improvement exist in input and output efficiency among public undergraduate universities in Sichuan Province, and ascertain the underlying reasons.

(5) Providing Strategic Plans and Policy Recommendations for Enhancing Overall Efficiency and Quality of Higher Education in Sichuan Province for Government and University Administrators.

These five Purposes are interdependent and progress in a step-by-step manner. Sub-objective (1) serves as the foundation for exploring sub-objectives (2) and (3), while sub-objectives (2) and (3) provide evidential support for sub-objective (4). Objective (5) is a summary of the previous four sub-objectives and the resultant policy recommendations. The purpose of this paper is to provide a novel perspective on the evaluation of input-output efficiency for public undergraduate universities in Sichuan Province and to offer a practical and feasible basis for optimizing the allocation of higher education resources. Ultimately, the research aims to make contributions to the effective distribution of financial resources in higher education in Sichuan Province, China.

1.3 Research Questions and Hypothesis

1.3.1 Research Question

RQ1: How to measure the educational efficiency of public undergraduate universities in Sichuan Province?

In this research question, it is necessary to determine suitable methods and indicators for measuring educational efficiency. Various efficiency evaluation methods can be explored, such as Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Efficiency Frontier Analysis, etc(Agasisti et al., 2019). Can an appropriate evaluation system be found to measure the educational efficiency of public undergraduate universities in Sichuan Province?

RQ2: Is there a significant difference in the educational efficiency of public undergraduate universities in Sichuan Province? If so, what are the reasons for this difference?

RQ3: How to enhance the educational efficiency of public undergraduate universities in Sichuan Province?

Based on the research findings from the previous two questions, specific policy recommendations can be proposed for educational authorities and different universities to provide decision support for further improving the educational efficiency of public undergraduate universities in Sichuan Province.

RQ4: What insights can be drawn from research on educational efficiency in similar regions both domestically and internationally?

This question aims to conduct a comprehensive analysis of educational efficiency studies in similar regions around the world, exploring their research methods, findings, and experiences to draw valuable insights and lessons. These insights will serve as references for the research on educational efficiency in public undergraduate universities in Sichuan Province.

1.3.2 Research Hypothesis

Hypothesis 1: There are varying levels of educational efficiency among public undergraduate universities in Sichuan Province.

This hypothesis suggests that there may be differences in educational efficiency among different public undergraduate universities. Some universities may be better at utilizing resources and providing higher-quality education, while others may exhibit lower efficiency levels.

Hypothesis 2: There is a positive relationship between educational resource inputs and educational efficiency.

This hypothesis posits that increasing educational resource inputs such as faculty, students, and funding may lead to improved educational efficiency, resulting in better educational outcomes.

Hypothesis 3: There is a relationship between educational efficiency and school size.

This hypothesis suggests that school size may influence educational efficiency. Larger universities may have more resources, but they may also face more complex management challenges that can impact their educational efficiency.

Hypothesis4:Educational policies and management measures influence educational efficiency.

This hypothesis proposes that educational policies and management measures can significantly influence the educational efficiency of public undergraduate universities. Well-designed policies and effective management measures may contribute to enhancing educational efficiency.

1.4 Theoretical Perspective

1.4.1 Public Goods Theory

The concept of public goods was first introduced in Hume's "A Treatise of Human Nature" in 1895, where he identified services such as "draining of a meadow" as essential public goods that do not conflict with the interests of others (Hume, 1896). In 1919, the term "public goods" was formally introduced into the field of economics by Lindahl in his "Lindahl equilibrium" theory, where he defined public goods based on the market equilibrium price principle distinct from private goods. Samuelson (1954) later defined public goods as products whose consumption by one individual does not reduce the quantity and quality available to others(Lindahl, 1919). Subsequently, Buchanan (1993) expanded the scope of public goods, arguing that collectively provided goods could also be considered public goods, and introduced the concept of "quasi-public goods" (Mu, 1993). Unlike pure public goods, quasi-public goods have non-exclusivity without non-rivalry or non-exclusivity only with non-rivalry, or they satisfy non-rivalry and non-exclusivity under certain conditions.

Scholars generally agree that education is not a pure public good. Samuelson (1995) pointed out that education can be partly excludable as it may lead to individual gains at the expense of others due to variable returns. Education also exhibits a degree of rivalry (Samuelson, 1995). For instance, the selection process of students during admissions results in one student gaining educational opportunities at the expense of others, and the quality of teaching decreases as the number of students increases. Therefore, a more accurate classification for education would be quasi-public goods. Leveraging the theory of public goods as the theoretical basis, this study is grounded on the following reasons:

Efficiency in Resource Allocation: The theory of quasi-public goods considers the intermediate state between public and private goods, which exhibit both exclusivity and rivalry. For instance, educational resources in universities, such as library facilities and laboratory equipment, may possess characteristics of quasi-public goods. Therefore, in evaluating the efficiency of higher education institutions, it is crucial to consider the effective allocation of resources to ensure their optimal utilization (Moroz, 2022).

Evaluation of Output Efficiency: The theory of quasi-public goods emphasizes that their outputs have an impact on individuals and society as a whole. Therefore, in higher education efficiency evaluation, it is essential to focus on the social benefits of educational outcomes, such as students' employment situation and the contribution of knowledge dissemination to socio-economic development, to understand the comprehensive benefits of higher education institutions.

Shared and Spillover Effects: The supply of quasi-public goods can also generate spillover effects, which have a positive impact on society as a whole (Fongwa, 2019). The teaching and research outcomes in higher education may exhibit characteristics of quasi-public goods with spillover effects. The theory of public goods provides a theoretical basis for understanding the sharing and spillover effects of higher education.

Provision and Consumption of Public Goods: The supply and consumption of quasi-public goods may face asymmetry. In higher education efficiency evaluation, it is essential to consider both the provision of quasi-public goods by higher education institutions and the consumption patterns of students. The theory of quasi-public goods offers an analytical framework for balancing the supply and consumption aspects.

In summary, the theory of public goods provides a more nuanced and comprehensive theoretical basis and analytical framework for evaluating the efficiency of higher education institutions. It aids in understanding the characteristics of higher education resources and outputs, enabling a better assessment of institutional efficiency, optimization of resource allocation, and enhancement of the quality and efficiency of higher education.

1.4.2 Human Capital Theory

The Human Capital Theory was initially proposed by American economists Schultz and Becker in the early 1960s. The theory was first introduced to explain the "labor income share" in national income and the significant role of human capital in the Gross Domestic Product (GDP). As the research deepened, the Human Capital Theory evolved into a comprehensive theoretical system. In his work "Human Capital," Gary S. Becker regarded non-material factors such as education, health, and knowledge as a specific form of capital. The core concept of Human Capital Theory

revolves around the role of human capital in socio-economic development(Teixeira, 2023). Denison argued that 23% of economic growth in the United States from 1929 to 1957 was attributed to the accumulation of human capital through investment in education(Wang & Zhang, 2022). The Human Capital Theory reveals the significant role of education in economic and social development, leading various countries to increasingly focus on improving human capital through education investments and enhancements in matching human capital supply with demand. China has entered a new stage of high-quality development, where human capital quantity and scale are substantial. However, there is still a deficiency in technological innovation. One of the essential reasons lies in the mismatch between human capital investment and actual demand, the disparity between human capital supply and economic development needs, and the deviation between human capital investment and returns(Wang & Zhang, 2022). In addition to increasing human capital stock, improving the matching between human capital supply and demand should be a crucial focus for the country. Based on this, the main reasons for using the human capital theory as the theoretical foundation for educational efficiency evaluation in education are as follows:

Firstly, assessing the return on education investment: The human capital theory emphasizes the impact of education on individuals' future income and employment opportunities. In educational evaluation, this theory can be utilized to assess the influence of different types of educational investments on individuals' career development and income levels, thereby determining the return on education investment and its benefits.

Secondly, measuring educational quality and outcomes: The human capital theory focuses on the accumulation of individual skills and knowledge, which can be employed to measure the quality and outcomes of education. Educational evaluation can be based on student's academic achievements, skill levels, knowledge mastery, and their performance in the labor market after graduation to judge the effectiveness of education.

Analyzing the relationship between education and economic growth: The human capital theory highlights the positive contribution of education to economic growth. In educational evaluation, it is possible to explore the relationship between education and economic indicators such as employment opportunities, innovation capacity, and labor market efficiency, thereby analyzing the impact of education on

economic growth.

Explaining the phenomenon of education inequality: The human capital theory can help explain the phenomenon of education inequality, which refers to why individuals with better education tend to achieve higher income and employment opportunities. Through educational evaluation, it is possible to examine the disparities in educational opportunities and resource allocation among different groups and consider ways to improve educational equity.

Guiding education policies and planning: Based on the human capital theory, educational evaluation can provide policymakers with recommendations regarding educational policies and planning. By analyzing the impact and effects of education investment, more targeted education policies can be formulated to enhance the efficiency and quality of education.

In conclusion, the Human Capital Theory provides a theoretical foundation and analytical framework for evaluating the efficiency of higher education. It deepens our understanding of the impact of higher education on individuals and society, offering scientific support for assessing the contributions and social benefits of institutions, as well as their influence on individual employment and economic development. Moreover, this theory provides valuable insights and methods for optimizing higher education resource allocation and improving institutional efficiency.

1.4.2 Efficiency Theory

The origin of efficiency theory can be traced back to the late 19th century's marginal utility theory and the analysis of production productivity of factors. However, significant advancements in the development of efficiency theory occurred in the 20th century, particularly in the latter half. Within the extensive framework of efficiency theory, contributions from economists such as Vilfredo Pareto and Enrico Barone laid the foundation for efficiency analysis. Vilfredo Pareto's concept of Pareto Efficiency, which describes a resource allocation state where no reallocation of resources would make any individual better off without making others worse off, emphasizes the optimality of resource allocation and establishes the basis for the development of efficiency theory(BI, 2008). Nonetheless, classical economics' discussion of efficiency was centered around typical firms, lacking theoretical support for comparisons among different individuals.

Leibenstein, by modifying the assumption of the "rational person" in traditional economics, introduced the unique "X-inefficiency" theory (Leibenstein, 1966). The "X-inefficiency" theory posits that technical inefficiency can reach a relatively stable state, and the causes of inefficiency are diverse, not limited to inefficient allocation. Simultaneously, the "X-inefficiency" theory can be applied to comparing efficiency differences among firms, successfully facilitating the comparison of efficiency disparities among enterprises. Thus, empirical studies based on the "X-inefficiency" theory have been developed. Farrell (1957), Fare and Lovell (1978), and others defined a firm's economic efficiency as the product of three components: pure technical efficiency, allocative efficiency, and scale efficiency(BI, 2008). Empirical analyses of technical and allocative efficiency both follow the fundamental principle of "avoiding waste of resources." Scale efficiency reflects the concept of economies of scale in economics and contributes to the quantitative treatment of efficiency theory.

In the field of education, the initial application of efficiency theory primarily focused on cost efficiency, i.e., how to achieve maximum student output given a fixed cost. However, as the education sector placed greater emphasis on quality and performance, efficiency theory gradually expanded to the evaluation of education quality and outcomes. Economist Eric Hanushek from Stanford University introduced the human capital theory, emphasizing the impact of education on individuals' future income and employment opportunities, thus establishing a connection between efficiency theory and educational outcomes. His research demonstrates the close correlation between education quality, investment, and economic growth, providing a theoretical foundation for educational efficiency evaluation(Hanushek & Woessmann, 2010, 2020).

The generation and development of efficiency theory provide theoretical and methodological support for educational efficiency evaluation. Among the various efficiency evaluation methods, evaluating education as a quasi-public good is more scientifically reasonable. The emergence and development of efficiency theory in economics, coupled with its application in the education sector, provide a solid theoretical foundation for educational efficiency evaluation. By integrating efficiency analysis with educational practices, we can better understand how to optimize educational services within resource constraints, enhancing education quality and

performance.

In conclusion, based on the theories of public goods and human capital, educational evaluation is guided by a theoretical framework, while efficiency theory offers methodological guidance and practical foundations. These aforementioned theories constitute the theoretical basis of this study, providing a clear roadmap for research objectives and direction and establishing a robust foundation for future endeavors.

1.5 Definition of Terms

This section provides clear and concise definitions for key terms used in this study to ensure consistency and accuracy throughout the following content.

1.5.1 Public Undergraduate Universities

Public undergraduate universities refer to higher education institutions that are established and managed with government funding. In such universities, the main financial support comes from government allocations, and faculty and staff are typically civil servants or government employees. The management and decision-making of these universities are directly or indirectly influenced by the government. Public undergraduate universities play a significant role in China's higher education system, with a total of numerous universities, including but not limited to 1275 general institutions.

In contrast, private undergraduate universities are higher education institutions established and managed with private funds or by non-governmental organizations. As the focus of this research is to ensure the comparability and reliability of the results, this study will concentrate on public undergraduate universities.

1.5.2 Higher Education Efficiency

Higher education efficiency refers to the maximization of student learning outcomes, teaching quality, and social benefits through optimal resource allocation and utilization in higher education institutions under specific resource conditions. The evaluation of higher education efficiency encompasses multiple dimensions, primarily including teaching production efficiency, management and resource utilization efficiency, distribution efficiency, and social benefits. The higher education efficiency defined in this study does not merely consider absolute values from the output

perspective but employs input and output as efficiency measures, employing research methods such as Data Envelopment Analysis (DEA) to evaluate the relative efficiency of specific educational institutions.

1.5.3 Higher Education Input and Output

Higher education input refers to the resources invested by higher education institutions in teaching, research, and other academic activities. These resources include funds, facilities, faculty and staff, library resources, academic support services, and more. Input resources encompass various material and non-material conditions necessary for higher education institutions to achieve educational goals and provide academic services.

Higher education output refers to the results or benefits created by higher education institutions for students and society. These outputs include student learning outcomes, academic research achievements, social services, and contributions to socio-economic development. Higher education outputs reflect the knowledge, skills, and values provided by higher education institutions to students, as well as the positive impact they have on social development and progress.

As this study uses input-output indicators as variables for efficiency research, a comprehensive understanding of these definitions and the construction of a suitable input-output indicator system are essential foundations for this research.

1.5.4 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a mathematical method used to evaluate relative efficiency, widely applied in fields such as economics, management, and operations research. DEA's primary goal is to evaluate the efficiency among a set of decision-making units, which can be companies, schools, hospitals, and more. These decision-making units utilize certain quantities of input resources to produce specific quantities of output. DEA enables decision-makers to identify highly efficient units and explore potential improvement opportunities for less efficient units. As an effective tool for management decision-making and policy formulation, especially in assessing and comparing the efficiency of multiple decision-making units, DEA is well-suited for studying higher education institutions, which are typical multi-input, multi-output entities with strong regional homogeneity and homogeneity.

1.5.5 Malmquist Index

The Malmquist Index is a method used to measure changes in technical efficiency and is often used in conjunction with Data Envelopment Analysis (DEA). The Malmquist Index compares the efficiency differences between two-time points or different decision-making units, analyzing trends in technical progress and efficiency changes. In this study, the Malmquist Index will be applied to evaluate the technical efficiency and productivity changes of higher education institutions.

The definitions above will ensure consistency and accuracy of the terms used in this paper, providing a clear conceptual foundation for the subsequent exposition.

CHAPTER 2
LITERATURE REVIEW

The goal of this chapter is complemented with the introduction. This chapter will contribute further to the literature review during the design of the study constructing an appropriate framework for efficiency evaluation in higher education institutions: identify rational approaches and research tools for assessing efficiency in public undergraduate universities within Sichuan province. This chapter is divided into the following parts:

2.1 Higher Education Evaluation

2.1.1 Definition of connotation

2.1.2 Methods for Measuring the Efficiency of Higher Education

2.1.3 Objects for Measuring the Efficiency of Higher Education

2.2 DEA research method

2.3.1 Application of CCR Model

2.3.2 Application of BCC Model

2.3.3 Application of Malmquist Index

2.3 Application of DEA in Measuring Higher Education Efficiency

2.3.1 Application of CCR Model

2.3.2 Application of BCC Model

2.3.3 Application of Malmquist Index

2.4 Input-Output Indicators for Higher Education Efficiency Evaluation

2.4.1 Basic framework of input-output indicators

2.4.2 The selection of efficiency indicators for higher education

2.4.3Application of Principal Component Analysis (PCA)

2.1 Higher Education Efficiency Evaluation

2.1.1 Definition of connotation

In various literature, educational efficiency is also referred to as educational production efficiency(Levin, 1974), education public efficiency(Jackson, 1982), or education utilization efficiency (Grosskopf et al., 2014). Returning to the core

definition of "efficiency" in economics, it is frequently employed to assess the relationship between input and output within an economic system. This entails determining whether the minimum resource input achieves a predetermined objective or if the given resource input yields the utmost benefit(Zhang, 2009). The study of educational efficiency has garnered significant attention both domestically and internationally. In the exploration of educational efficiency, early research focused on "what constitutes educational efficiency" (Lockheed & Hanushek, 1988)and "which factors influence educational efficiency" (Daraio et al., 2021). As research has progressed, substantial interest has emerged in how to measure and enhance education, leading to extensive inquiries (Johnes et al., 2017).

2.1.2 Methods for Measuring the Efficiency of Higher Education

Up to this point, a plethora of literature exists concerning the measurement of educational efficiency, utilizing various methodologies such as parametric and non-parametric approaches. These include techniques like Data Envelopment Analysis, Malmquist Index, Bootstrapping, Robust Frontiers, Meta-Frontier, or Stochastic Frontier Analysis (Witte & L O Pez-Torres, 2017), offering pathways for improving educational efficiency. However, due to the semi-public nature of higher education and the complexity of quantifying the relationship between inputs and outputs, parametric methods suffer from substantial limitations. Non-parametric methods, on the other hand, hold advantages in measuring higher education efficiency, given their flexibility in not requiring predetermined function forms and uniform units of measurement (Hanushek & Woessmann, 2020; Pham Van et al., 2022). Among the non-parametric methods, Data Envelopment Analysis (DEA) is widely used for evaluation. It involves directly constructing an economic mathematical model using input and output data to assess the relative efficiency of different sectors, hence referred to as DEA efficiency. The fundamental principle of this method involves establishing a relatively efficient production frontier by maintaining constant inputs or outputs for Decision-Making Units (DMUs). Through mathematical programming and statistical techniques, the DMUs are projected onto the DEA production frontier, and their relative efficiency is evaluated by comparing the extent to which they deviate from this frontier(Johnes et al., 2017). Detailed elaboration on DEA theory will be provided in Chapter Three.

2.1.3 Objects for Measuring the Efficiency of Higher Education

The measurement of educational efficiency can be broadly categorized into two main approaches. The first approach focuses on the Economic Value of Education, which examines the impact of education on economic growth(Gylfason, 2001; Hanushek & Woessmann, 2010; Sanderson, 1995). This falls within the realm of macro-level research. The second approach delves into the Economic Aspects of Educational Institutions, analyzing the effective allocation and utilization of resources within educational institutions. This includes studying the input and output efficiency of these institutions (Cheng et al., 2022; Ding et al., 2023; Elsayed & Khalil, 2017; Kuah et al., 2010; Ratner et al., 2023), constituting micro-level research.

Research pertaining to educational institutions often focuses on institutions within the researcher's own country, offering a broad scope aimed at describing the efficiency of educational institutions within that nation and making comparisons. For instance, Cai et al. measured the efficiency of educational institutions across various regions in China and provided suggestions for the overall development of higher education in China(蔡文伯 & 黄晋生, 2019). Nazarko measured 19 technical universities in Poland, suggesting that the impact of higher education institutions on their achievements outweighs the influence of their resource quantity (Nazarko & V S Aparauskas, 2014). Thanassoulis et al. evaluated the efficiency of higher education institutions in the UK and noted a decline in productivity for most institutions(Thanassoulis et al., 2011).

Furthermore, some scholars have engaged in international comparisons of educational efficiency. Xu et al. utilized panel data from 53 countries in the fields of education and technology, discovering that significant educational efficiency and technological progress are concentrated in several developing countries. Wolszczak found that from 2000 to 2014, educational technology efficiency contributed to development to varying degrees, depending on the pace of economic development and the promotion of educational technology policies (Xu & Liu, 2017). Wolszczak-Derlacz conducted research evaluating the relative efficiency of 500 higher education institutions in ten European countries and the US between 2000 and 2012. Various models were estimated using different input-output sets and assumed frontiers: global, regional, and

country-specific(Wolszczak-Derlacz, 2017).

However, the development of higher education ultimately manifests in each individual at the micro level, with local colleges and universities accounting for over 90% in China. Variations exist among different regions due to disparities in educational foundations and economic development levels. The vision for higher education development also varies by region. Hence, analyzing the local higher education situation based on regional differences is crucial for formulating policies that best suit the respective areas. Spillane argues that different local policymakers' varying perceptions and understandings of teaching reform from national reform initiatives help explain differences among local educational institutions in their responses to external policies. Different interpretations of reform recommendations lead to significant policy implementation discrepancies (Spillane, 1998).

Furthermore, research on educational efficiency and equity has always been an unavoidable issue in this field. To pursue equity in higher education and address inequalities in real reform, striking a balance between equity and efficiency is essential. Scholars who advocate using efficiency as a means to promote equity believe that safeguards should be established through national policies and institutional arrangements, fostering efficient and orderly development. Competition among institutions at different levels should be avoided, as it can lead to chaos; "order is essential for effectiveness." The relationship between equity and efficiency is dynamic, continually evolving, promoting their better realization. As higher education becomes more accessible to the masses, this contradiction will increasingly manifest at the micro-teaching level, necessitating a greater focus on fairness in the educational process and a shift from an economics-centric perspective to a multidisciplinary approach (Zhang & Lv, 2002).

Si and Qiao utilized Data Envelopment Analysis (DEA) with the CCR and BCC models to analyze and calculate the comprehensive technical efficiency, pure technical efficiency, scale efficiency, scale income, and scale elasticity of basic education expenditure from 2005 to 2014. They found that increasing investment in junior high school stages in the investment structure of basic education is more effective in improving overall expenditure performance than in other stages(Si & Qiao, 2017).

Nellutla employed the CCR model to measure educational efficiency in Andhra Pradesh (Nellutla et al., 2018).

Based on the aforementioned summary, the emergence and development of educational efficiency assessment underscore the significance of this research. The current state of research on the evaluation objects of educational efficiency lacks a micro-level analysis at the provincial level, indicating a gap in the research landscape. This study aims to address this gap by focusing on local public undergraduate colleges and universities, using Sichuan Province in China as an example. By doing so, it directs attention to the developmental needs of local higher education and seeks differentiated research. Furthermore, it aims to provide stronger decision-making support for local government higher education policies.

2.2 The Data Envelopment Analysis (DEA) research method

2.2.1 The emergence and development of DEA

The Data Envelopment Analysis (DEA) model was introduced by Charnes, Cooper, and Rhodes in 1978, serving as a computational approach to assess the relative efficiency of individual decision-making units (DMUs) (Charnes et al., 1978). Its purpose is to ascertain the effectiveness of resource allocation and operational processes within these entities(Rostamzadeh et al., 2021). The fundamental concept of the DEA model involves the collection of metric data from various DMUs and utilizes this data to compute composite technical efficiency, pure technical efficiency, and DMU scale efficiency values. DEA significantly enriches the production function theory within microeconomics and, concurrently, holds distinct advantages in avoiding subjective factors and minimizing errors. This has garnered substantial attention since its inception (胡博, 2017).

Yang Guoliang et al. asserts that the DEA method comprises several pivotal elements which dictate the specific form and application of the model. These crucial elements encompass: 1) The Production Possibility Set (PPS) can be assumed as constant returns to scale, variable returns to scale, non-increasing returns to scale, or non-decreasing returns to scale. 2) A performance measurement scale used to assess performance quality, which includes radial measures, non-radial measures, and the like.

3) Various preference types, with commonly used preferences such as Pareto, average, and matrix preferences. 4) The type of variables where input-output data of Decision Making Units (DMUs) can possess different characteristics like non-discretionary variables, uncontrollable variables, bounded variables, or negative variables. 5) The hierarchy of the problem. 6) The determinacy of data. The combination of these elements can give rise to diverse models of the DEA method suited for addressing different issues(杨国梁 et al., 2013).

Based on the aforementioned classification of elements, the primary DEA models include:

1) Based on Production Possibility Set (PPS) Assumptions: CCR-DEA model(Charnes et al., 1978).

2) The DEA model based on the assumption of variable returns to scale within the production possibility set is referred to as the BCC-DEA model(Banker et al., 1984). Cobb-Douglas DEA model (Banker & Maindiratta, 1986a)、NIRS, NDRS, and FDH models(Deprins et al., 1984).

3) based on Different Measurement Scales: Russell Measure model(Lovell, 1978a)、Pareto-Koopmans model(Charnes et al., 1985a)、SBM model (Slacks-Based Measure)(Tone, 2001)、RAM model (Range Adjusted Measure) (Cooper et al., 1999).

4)Based on Different Preferences: Weight Restriction model(Allen et al., 1997)、Cone Ratio Constraint model(Charnes et al., 1989).

5)Based on Variable Types: NDV-DEA model (Non-discretionary Variable DEA) (Rajiv et al., 1986)、NCV-DEA model (Non-controllable Variable DEA) BND-DEA model (Bounded Variable DEA)、 Undesirable Variables DEA model(Liu et al., 2010)、 Ordinal Variable DEA model(Cook & Zhu, 2006)、- DEA model with No Clear Inputs(Thanassoulis et al., 1996) DEA model with Category Existence (Syrj Nen, 2004)

6）Multi-Stage and Multi-Level DEA Models: Two-stage DEA model (Seiford & Zhu, 1999)Network DEA model (F Re & Grosskopf, 2000)Hierarchical DEA model(Meng et al., 2008).

Furthermore, considering diverse research objectives, additional DEA models have been developed, including Super Efficiency DEA Model、Cross Efficiency DEA Model(Doyle & Green, 1994; Sexton et al.) Statistically-based DEA Models(Land et al., 1994; Thore, 1987)Fuzzy Number DEA Model(Ho et al., 2010; Zadeh, 1978).
Due to its characteristic of not requiring the a priori specification of utility or production function forms when assessing efficiency, the DEA model possesses considerable flexibility in practical applications. The underlying principles of its application will be extensively discussed in the theoretical framework of Chapter 3.

2.2.2 The scope of application of DEA

In the application process of the DEA model, decision-making units (DMUs) can encompass a wide array of sectors, including agriculture, banking, education, aviation, computer industry, sports, stock markets, government, and more (Kuah et al., 2010). The extensive applicability of the DEA model is corroborated by numerous sources in the literature.

"In the healthcare industry, researchers have utilized DEA to analyze the input-output efficiency, focusing on the public and welfare aspects of the healthcare sector (Liu & Lyu, 2020; Wei et al., 2011). In evaluating the performance of companies and enterprises, Yang introduced a two-stage DEA model to provide valuable managerial insights while assessing the dual impacts of operations and business strategies within the Canadian life and health insurance industry (Yang, 2006). Sueyoshi et al. summarized four decades of DEA applications in the fields of energy and environment, encompassing the concept and methodology of environmental assessment using DEA. They noted a significant surge in the number of articles applying DEA to energy and environmental studies, particularly after the 2000s (Sueyoshi et al., 2017). Henriques conducted a systematic review of literature in the banking industry domain, analyzing 59 papers categorized into ten classes based on different perspectives of two-stage DEA research, including economic context, geographical regions of banking units, methodological features, and model types (internal or external). The study offered a comprehensive summary of the models employed, suggesting that the primary objectives of most papers involved extending or enhancing DEA models型(Henriques et al., 2020). Nurmatov conducted a literature survey on the application of DEA in tourism and hotel studies.

After a comprehensive review of 350 tourism-related articles utilizing DEA, limitations in existing research were emphasized, and important directions for future research were outlined(Nurmatov et al., 2021). Puertas proposed the DEA-GreenMetric index, highlighting the multidimensional focus of universities on not only environmental but also social and economic issues in the context of sustainability. The study suggested that universities need to exert greater efforts to enhance performance related to environmental variables (energy, water usage, waste management) rather than infrastructure, transportation, or education improvement(Puertas & Marti, 2019). Table 2.1 provides an overview of model variations and applications, offering readers further insights. Furthermore, several scholars have specifically reviewed the development of the DEA model(Kuah et al., 2010; Panwar et al., 2022; 胡博, 2017; 杨国梁 et al., 2013), aiding researchers in gaining a comprehensive understanding of the evolution of DEA applications."

Table 2.1 Research on DEA

author	Model	Application field
(Charnes et al., 1978)	DEA-CCR	Medical treatment(Wei et al., 2011),Insurance company, Ports(Elsayed & Shabaan Khalil, 2017), Education (Visbal-Cadavid et al., 2017)
(Banker et al., 1984)	DEA-BCC	Pharmaceutical industry(Liu & Lyu, 2020), resource utilization efficiency(Cheng et al., 2022), Airports(Razali & Shah, 2010), Education(Sant I N & Sicilia, 2015)
(Tone, 2001)	DEA-SBM	Highway operation(Xu et al., 2023), the container terminal (Liu et al., 2022)
(Andersen & Petersen, 1993)	Super-efficiency	Mobile currency(Muvingi et al., 2023), educational evaluation(Sun & Yang et al., 2023)
(F A Re & Grosskopf, 1997)	Network DEA	Construction projects(Luo et al., 2022), the public transport system(Kang et al., 2023)

author	Model	Application field
(Banker & Maindiratta, 1986b)	Cobb-Douglas-DEA	Tariff Amendment(Costa et al., 2015), software development(Pendharkar et al., 2008)
(Lovell, 1978b)	Russell-DEA	Healthcare(Azadi & Saen, 2013)
(Charnes et al., 1985b)	Pareto-Koopmans DEA	Network structure evaluation(Khati & Mukherjee, 2020), bank performance evaluation (Maleki et al., 2019)

The current state of research on the DEA methodology and its applications validates the scientific rationale behind the method chosen for this study. Given the inherent differences among various research subjects, the application of DEA continues to offer ample room for development. Particularly in the realm of method application, there exists an area of underexplored research pertaining to variable handling. Consequently, this study's focus on DEA variable handling as a developmental aspect contributes to its innovation and practical significance within the research process.

2.3 Application of DEA in Measuring Higher Education Efficiency

2.3.1 Application of CCR Model

According to Section 2.2, the application of DEA involves both basic and variant models. Scholars have employed both basic and variant DEA models in measuring higher education efficiency. In the CCR model, each decision-making unit's (DMU) inputs and outputs are quantified, and by determining weights, these inputs and outputs are combined to ascertain the efficiency scores for each DMU. This model assumes a competitive relationship among DMUs, implying that an increase in the efficiency of one DMU may lead to a decrease in the efficiency of others. The mathematical expression of the CCR model is a linear programming problem with the objective of maximizing the efficiency score of the evaluated DMU while ensuring that the efficiency scores of other DMUs do not exceed 1. As a result, the optimal solution yields weight combinations that enable each DMU to reach its highest efficiency level.

The CCR model can only evaluate the relative efficiency of DMUs, i.e., their efficiency levels relative to other DMUs. It cannot provide specific guidance on how to improve efficiency to reach optimal levels, nor can it indicate how inputs and outputs should be adjusted to enhance efficiency.

2.3.2 Application of BCC Model

Addressing the limitations of the CCR model, Banker, Charnes, and Cooper introduced the BCC model in 1984 as a specialized approach for evaluating the technical efficiency of decision-making units(Banker et al., 1984). The BCC model is an improved version of the CCR model, primarily designed to address some of the deficiencies and shortcomings of the CCR model. In assessing DMU efficiency, the BCC model accounts for the possibility of increasing returns to scale. This implies that in the BCC model, the production process of DMUs may exhibit increasing returns to scale, where efficiency improves with the expansion of production scale. This makes the BCC model more closely aligned with real-world situations and better able to reflect the impact of production scale on efficiency. The mathematical expression of the BCC model is a linear programming problem involving the determination of appropriate weights to combine inputs and outputs for evaluating the efficiency scores of each DMU. Similar to the CCR model, the BCC model assumes a competitive relationship among DMUs, where an increase in the efficiency of one DMU could potentially lead to a decrease in the efficiency of others. The BCC model provides more accurate treatment of cases involving increasing returns to scale, enhancing the assessment of DMU efficiency, and offering more targeted optimization recommendations.

Wu (2020) employed a three-stage DEA model to assess the efficiency of higher education institutions across 31 mainland Chinese provinces in the year 2016(Wu et al., 2020). The authors concluded that the pure technical efficiency of higher education institutions in various provinces of China was relatively high. However, they observed that the scale efficiency was comparatively low, resulting in an overall lower level of efficiency.

Łukasz Brzezicki conducted an efficiency analysis using the BCC model on cross-sectional data from both public and private universities in Poland for the years 2011 to 2014. The study's findings indicated that public universities exhibited higher

efficiency in terms of graduate quantity, while their efficiency was lower when considering graduate salary levels. Conversely, for private institutions, the situation was reversed. The level of efficiency was influenced by variables associated with specific universities and the socio-economic conditions of their respective regions. The study examined the efficiency of educational activities in public and private universities from the perspectives of graduate quantity, educational quality, and the labor market (Brzezicki & Others, 2020; Dumitrescu et al., 2020).

Salas (2020) utilized the DEA analysis method to examine cross-sectional data from 45 public universities in Spain. The study revealed that universities with a higher proportion of funded scholars tended to have lower efficiency levels. Conversely, a higher proportion of scholars obtaining tenure positively contributed to the overall production efficiency of Spain's higher education sector(Salas-Velasco, 2020).

Dumitrescu (2020) employed the DEA model to assess Romanian public universities from 2012 to 2018. The study findings indicated that 11 universities exhibited efficiency when the Variable Returns to Scale (VRS) method was applied, whereas only two universities demonstrated efficiency under the Constant Returns to Scale (CRS) approach(Dumitrescu et al., 2020).

Mammadov & Aypay (2020) conducted a DEA efficiency analysis on 15 research universities in Turkey and concluded that the rationale for establishing research-oriented universities in Turkey according to international standards is much weaker than it appears. Turkish higher education now must and should align itself with international "standards" to accommodate the evolution of the knowledge society and globalization (Mammadov & Aypay, 2020a).

2.3.3 Application of Malmquist Index

The mentioned research outcomes represent static data analyses conducted by scholars from different countries using the DEA model for various research purposes. However, analyzing the performance of research subjects over time and understanding their own progress should also be a crucial concern in higher education efficiency analysis. Hence, the combination of the DEA model with the Malmquist Index analysis using panel data has also been widely applied in higher education efficiency evaluation.

Leipeng (2021)conducted a study based on panel data from 36 tourism colleges for the years 2014 to 2017. The study divided the process of technological achievement transformation into two stages: research creation and outcome transformation. Leipeng utilized the DEA-BCC model and the DEA-Malmquist Index model to measure the efficiency of technological achievement transformation (Peng & Shenghan, 2021).

Wangjialan (2020)employed the Malmquist Productivity Index model to investigate the technical efficiency, technological change, and productivity performance of eight universities in New Zealand during the period from 2013 to 2018. The study indicated that the average catch-up and frontier-shift efficiency of New Zealand universities remained relatively unchanged, implying that these universities did not make significant progress during those years (Wang et al., 2020).

In their study, Wuzhaoxue (2021) employed a three-stage Data Envelopment Analysis (DEA) and the Malmquist Productivity Index method to evaluate the static and dynamic efficiency of research input and output data in universities directly under the Ministry of Education. The author concluded that the three-stage DEA model provides a more accurate measurement of research input and university output efficiency compared to traditional DEA methods(Xue et al., 2021).

Zong Xiaohua et al. utilized the DEA-BCC model and Malmquist index to assess the research efficiency and its changes in "Double First Class" universities directly under the Ministry of Education, selected as samples from 2010 to 2015. The study revealed that the overall research efficiency of these universities was relatively low, with slow improvement during the period (宗晓华 & 付呈祥, 2019).

Lisana Sumarah Pratignyo et al. applied the Data Envelopment Analysis method and the Malmquist index to analyze the efficiency values of seven educational programs in the academic years 2017 to 2019. The study identified the most effective decision units and the most productive educational plans(Pratignyo et al., 2023).

Among the various models of variation, the fundamental DEA model remains the most essential to follow. While model adjustments and innovations have their cutting-edge value, they primarily stem from cases where complexities arise, and additional factors or constraints need consideration. In such instances, introducing

modified models might be more appropriate. These modified models can offer a more accurate reflection of real-world situations, providing a more comprehensive and in-depth efficiency assessment.

However, in this study, we have deliberately constrained our research sample scope and maintained a focused objective with controlled conditions. The study's purpose is to provide reliable information for policy formulation for local governments and universities. Therefore, utilizing the traditional DEA model aligns well with the research goals of this paper and effectively serves its intended purpose.

2.4 Input-Output Indicators for Higher Education Efficiency Evaluation

2.4.1 Basic framework of input-output indicators

In DEA research, a fundamental step is the selection of appropriate input and output indicators. According to Li Jiao, when setting the input-output indicators for higher education efficiency evaluation, one should follow the principles of fairness and objectivity, comprehensiveness, operability, determinacy, and comparability(李娇 & 王松博, 2020). Based on these principles, the basic framework for studying higher education efficiency is constructed.

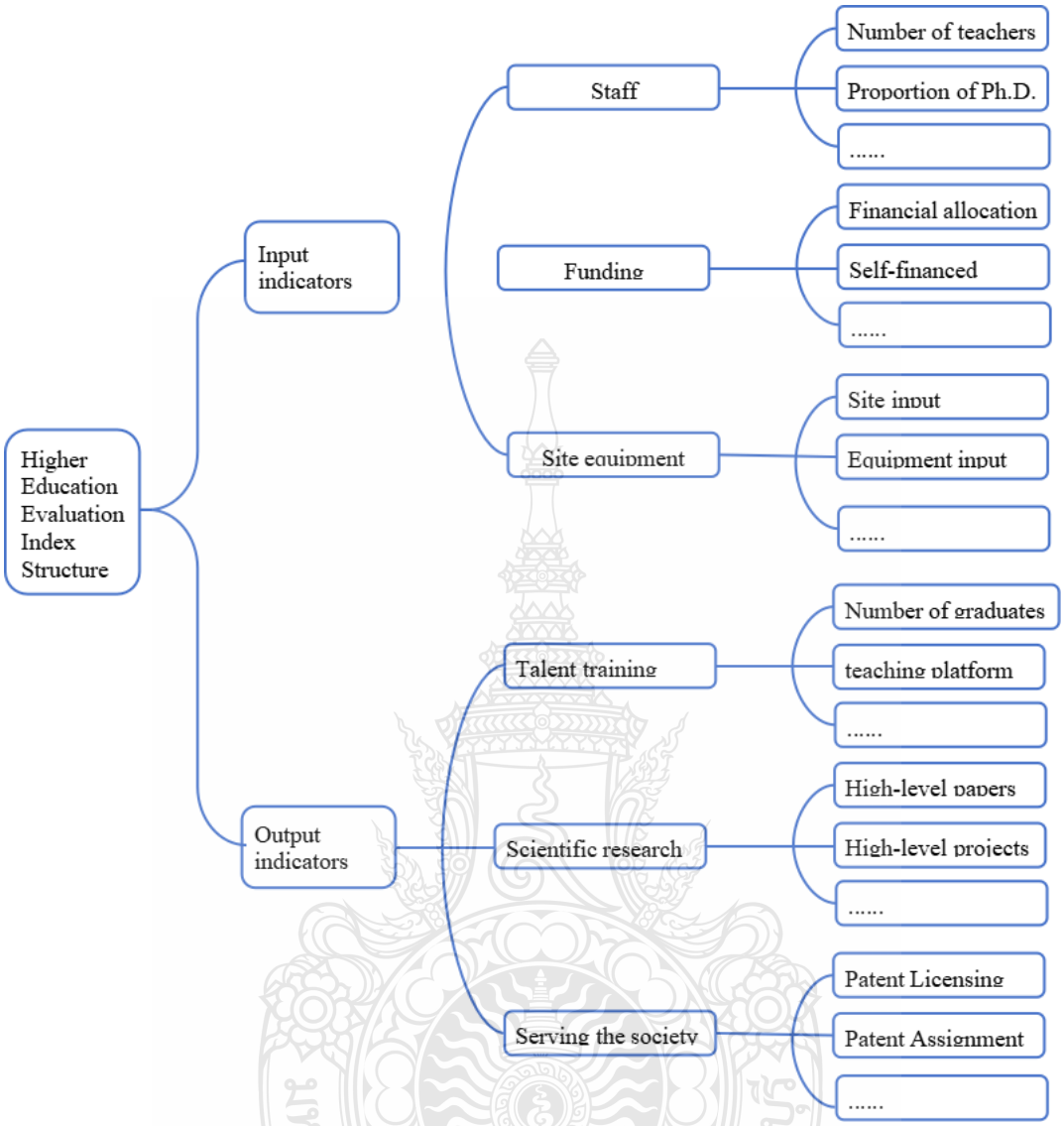

Figure 2.1 Basic Framework of Higher Education Input-Output

Source: Li Jiao & Wang Songbo. (2020). Preliminary Exploration of Indicator System Design for University Discipline Development Based on Input-Output Theory. Higher Education Forum, 11, 76-78.(李娇 & 王松博, 2020)

2.4.2 The selection of efficiency indicators for higher education

In existing research, the selection of efficiency indicators for higher education has been as follows:

Table 2.2 Review of Input-Output Indicators

Categories of Indicators	Level 1 Indicators	Level 2 Indicators	Authors
Input indicators	Staff	Number of teachers	(Lee & Johnes, 2022; Liang et al., 2021) (Chen et al., 2021; Ding et al., 2023; Sun & Wang et al., 2023)
		Number of researchers	(Ghimire et al., 2021; Mammadov & Aypay, 2020)
		Proportion of Ph.D. professors	(Cossani et al., 2022; Navas et al., 2020)
	Funding	Financial allocation	(Cossani et al., 2022)
		expenditure	(Ghimire et al., 2021; Stumbrienė et al., 2022; Sun & Wang et al., 2023; Tavares et al., 2021)
		Teaching input	(Chen et al., 2021; Torres-Samuel et al., 2020)
		Research input	(Torres-Samuel et al., 2020)
	Site equipment	Number of graduates	(Chen et al., 2021)
		Number of Sites	(Cossani et al., 2022)

Categories of Indicators	Level 1 Indicators	Level 2 Indicators	Authors
Output indicators	Talent training	Number of graduates	(Mammadov & Aypay, 2020; Navas et al., 2020; Stumbrienė et al., 2022; Tavares et al., 2021)
		Number of undergraduate students	(Chen et al., 2021)
		Number of graduate students	(Chen et al., 2021; Sun & Wang et al., 2023)
	Scientific research	Number of publications	(Cossani et al., 2022; Ding et al., 2023; Ghimire et al., 2021; Mammadov & Aypay, 2020; Navas et al., 2020)
		research funding	(Chen et al., 2021; Ding et al., 2023; Ghimire et al., 2021; Mammadov & Aypay, 2020)
		Number of scientific research achievements	(Cossani et al., 2022; Tavares et al., 2021)
		academic satisfaction	(Sun & Wang et al., 2023)
	Serving the society	Number of Patent Assignment	(Torres-Samuel et al., 2020)、
		Number of Patent Licensing	(Agasisti, 2023)

2.4.3Application of Principal Component Analysis (PCA)

In order to further enhance the applicability of indicators in DEA analysis, scholars have introduced new methods for handling indicators in recent years, among which Principal Component Analysis (PCA) is widely applied.

Ashour proposed that in the measurement process, the requirement for a sufficient number of research samples in DEA analysis can lead to errors in the results when there are too many variables. Therefore, Principal Component Analysis (PCA) is considered an important statistical tool for reducing the dimensionality of the original variables. To obtain new variables representing principal components, factors for each variable have already been determined, which aids in identifying their influences(Ashour, 2022).

Panwar et al. discussed in their "Review on the 40 Years of Existence of Data Envelopment Analysis Models" that PCA (Principal Component Analysis) was used to reduce the number of criteria, and the additive DEA (Data Envelopment Analysis) model was employed to measure the efficiency of suppliers or efficient suppliers. (Panwar et al., 2022).

Cao selected 9 highly developed countries in higher education and 13 indicators as references for global higher education quality and sustainability. Principal Component Analysis (PCA) was employed to reduce the dimensionality of these 13 indicators and extract factor coefficient score matrices. Among them, four major components were used for further analysis. Entropy Weight Method (EWM) was used to allocate weights for each sub-indicator to obtain a quantifiable Quality Sustainability Measurement (QSM)(Cao et al., 2023).

In addition, the PCA-DEA research method has also been widely applied in various fields. Ž Stević applied the PCA–DEA–MCDM model to develop an efficiency evaluation model for transportation companies (Stevi C et al., 2022). Chen combined the PCA model with the DEA-Malmquist model based on qualitative and quantitative data from 205 listed companies to analyze the efficiency of low-carbon supply chain financing from both static and dynamic perspectives(Chen et al., 2023). Shi et al. selected risk management indicators from 26 commercial banks in China for the years 2011 to 2019, used Principal Component Analysis (PCA) to remove redundant

input indicators and employed the DEA-BCC model in combination with window analysis to evaluate the technical efficiency of risk management in Chinese commercial banks(Shi & Yu, 2021). Peixoto used multivariate statistical techniques, Principal Component Analysis, and Data Envelopment Analysis to measure the performance of Brazilian HUF participating in REHUF(Peixoto et al., 2020).

While the PCA method has been employed in some research related to higher education, its usage remains relatively limited. This is primarily due to the current focus of efficiency studies in higher education on large-scale panel data that are easy to collect. In these cases, the emphasis is often on having a sufficient sample size, and many researchers do not engage in data preprocessing and dimension reduction. However, in the case of this study, which focuses on provincial undergraduate institutions, the sample size is limited yet holds significant implications for the development of regional higher education. To enhance the rigor of this research, the PCA-DEA method has been introduced for the efficiency analysis of local undergraduate institutions, representing one of the innovative aspects of this study.

CHAPTER 3
RESEARCH METHODOLOGY

This study is a research and development which aims to provide a novel perspective on the evaluation of input-output efficiency for public undergraduate universities in Sichuan Province and to offer a practical and feasible basis for optimizing the allocation of higher education resources. Ultimately, the research aims to make contributions to the effective distribution of financial resources in higher education in Sichuan Province, China. This chapter was conducted with following structures:

3.1 Theoretical Framework

3.2 Sampling Technique

3.3 Instrumentation

3.4 Procedure of the Data Collection

3.5 Data process in Gand analysis

3.6 Statistical analysis

3.1 Theoretical Framework

This study focuses on measuring the efficiency of public undergraduate universities in Sichuan Province to identify existing "inefficiencies" in input-output efficiency and analyze their specific causes. Furthermore, it aims to offer policy recommendations to decision-makers. Building upon the theoretical foundation of quasi-public goods efficiency evaluation, this paper will employ the DEA-BCC model to analyze cross-sectional data of public undergraduate universities in Sichuan Province. The Malmquist index analysis will also be used to assess time series data. Drawing from the input-output theory and considering the characteristics of public undergraduate universities in Sichuan Province, appropriate input and output indicators will be selected to evaluate the current efficiency of these universities from both static and dynamic perspectives. This study will provide valuable guidance for research methods and design by constructing a logically coherent research framework.

3.1.1 DEA Modle

Data Envelopment Analysis (DEA) is a novel systematic analysis method developed by A. Charnes and W.W. Cooper, among other scholars, based on the concept

of "relative efficiency." It evaluates the relative effectiveness or efficiency of units (departments) of the same type using multiple input and output indicators (Charnes et al., 1978). DEA applies mathematical programming models to calculate the relative efficiency between decision-making units (DMUs) and assess the evaluation objects. Typically, it selects a set of input and output evaluation indicators for a given group of decision-making units and computes the efficiency scores for the specific DMUs of interest. This process evaluates the performance of the DMUs relative to the given group of decision-making units, indicating their relative efficiency. In other words, through the comprehensive analysis of input and output data, DEA provides quantitative measures of the overall efficiency of each DMU.

Based on these efficiency measures, DEA ranks and classifies decision-making units, identifies effective units, and assesses the reasons and extent of inefficiency for other units. DEA not only evaluates and ranks the relative effectiveness of decision-making units of the same type but also enables further analysis of the reasons for inefficiency and provides valuable management decision-making information for policymakers. DEA addresses a multi-input multi-output efficiency evaluation problem, which is one of its prominent advantages. The consideration of multiple inputs and outputs is a significant feature and strength of DEA, especially in the context of complex systems. Some key points illustrating DEA's suitability for systems with multiple inputs and outputs are as follows:

(1)DEA evaluates decision-making units by considering the weights of each input and output from the most favorable perspective to the DMU, avoiding the need to determine the weights based on subjective priorities.

(2)DEA assumes that each input is related to one or more outputs, and that there is a certain relationship between inputs and outputs without requiring explicit expressions of this relationship.

(3)One of the most prominent advantages of DEA is that it does not require any weight assumptions. The weights of each input and output are derived from the actual data of the decision-making units, ensuring optimal weights. Consequently, DEA eliminates many subjective factors and demonstrates strong objectivity in its analysis.

Since the first DEA model was proposed and used to evaluate the relative efficiency among departments in 1978, the DEA method has continuously been improved and widely applied in practice, especially in various public services sectors such as schools and hospitals. Over time, theoretical research related to DEA has deepened, and its application areas have expanded significantly. The advantage of using DEA to evaluate the relative efficiency of departments is irreplaceable by other methods. In other words, DEA has a unique advantage in assessing the relative efficiency of multi-input and multi-output social and economic systems.

In the second part of this paper, I have provided a detailed overview of the development of the DEA model and its application in measuring the efficiency of higher education. The present study intends to use the DEA-BCC model to measure the cross-sectional data of public undergraduate universities in Sichuan province.

To better understand the DEA model, we first define the symbols used.

Table 3.1 DEA Modle Symbol Definition 1

Symbol	**Definition**	**Symbol**	**Definition**
DUM	decision-making units	T	Production Possibility Set, PPS
n	Number of DUM		
m	Number of Input	x	input
s	Number of Output	y	output
j	No. DUM (j=1,2...n)		

3.1.1.1 Research Object of DEA: Decision-Making Units (DMUs)

An economic system or a production process can be conceptualized as a decision-making unit (DMU) operating within a defined range of possibilities. The DMU aims to optimize its activities by inputting specific quantities of production factors and generating corresponding outputs. Although the nature of these activities may vary, their ultimate objective remains maximizing efficiency. Each DMU represents a distinct economic significance and is characterized by its input-output relationship while pursuing its decision-making objectives.

The concept of Decision Making Units (DMUs) is broad and can represent various entities such as a university, a company, or even a country. To ensure research

reliability, analysis is generally conducted on multiple DMUs of the same type. DMUs of the same type share the following characteristics:

（1）They have similar objectives and tasks.

（2）They operate in a similar external environment.

（3）They have the same set of input and output indicators.

Additionally, when there is slight variation in the external environment and internal structure over different time periods, the same DMU at different time intervals can also be considered as DMUs of the same type.

The evaluation of each DMU is based on its "input" and "output" data. By assessing the inputs and outputs, we can determine the efficiency or performance of the decision-making units, which is known as the evaluation of their relative efficiency. In the research, it is essential to clarify the research objectives since different models may have different input-output indicators for the same DMUs. Based on experience, the effectiveness of each DMU involves two aspects:

It is established on the basis of mutual comparison, making it relative efficiency.

The effectiveness of each DMU is closely related to the ratio of input composite to output composite (or understood as the input-output ratio in the case of multiple inputs and multiple outputs).

In the first part of this paper, a detailed analysis of the current situation and characteristics of higher education in China was conducted. The distinctions between public and private universities, central and local universities, and undergraduate universities, and vocational-technical schools were also explored. Consequently, defining the scope of Decision Making Units (DMUs) is crucial for conducting efficiency evaluations based on input-output analysis, ensuring that DMUs share the same objectives, variables, and environment. Therefore, this study selects public undergraduate universities in Sichuan Province as the DMUs, taking into consideration the aforementioned factors.

Furthermore, existing research has primarily focused on macro-level comparative analysis, especially in comparing data between provinces. However, there needs to be more research at the micro-level within a province's scope. Nevertheless, it

is essential to understand that the development of higher education in China ultimately relies on local policies and support. Hence, choosing public undergraduate universities in Sichuan Province as the DMUs holds practical significance.

3.1.1.2The Production Possibility Set (PPS)

The Production Possibility Set (PPS) in DEA is denoted as T, representing all possible production activities. Let x denote the inputs, and y represent the outputs. According to the definition of the Production Possibility Set proposed by Banker (Banker, 1984a), we consider n Decision-Making Units (DMUs) denoted as DMU_j $(j = 1, 2, ..., n)$, where each DMU_j has m inputs x_{ij} $(i = 1, 2, ..., m)$ and s outputs y_{rj} $(r = 1, 2, ..., s)$.

Definition 1: The set $T = \{(x, y) \mid$产出y能用投入x生产出来$\}$ is called the Production Possibility Set (PPS), which encompasses all possible production activities.

In the use of DEA method, the production possibility set T generally satisfies the following four axioms:

Axiom 1 (Triviality Axiom): The set T is non-empty and includes the origin (0, 0) in its interior.

Axiom 2 (Convexity Axiom): The set T is convex. If (x, y) and (x', y') are in T, and there exists a non-negative scalar λ such that $(\lambda x + (1-\lambda)x', \lambda y + (1-\lambda)y')$ is also in T.

Axiom 3 (Inefficiency Axiom): If $(x, y) \in T$, then there exists no (x', y') such that $x' < x$ and $y' > y$.

Axiom 4 (Cone Axiom): The set T is a cone. If $(x, y) \in T$, then for any non-negative scalar λ, $(\lambda x, \lambda y)$ also belongs to T.

If the production possibility set T is the minimal set satisfying axioms 1, 2, 3, and 4, then T has the following unique representation:

$$\boldsymbol{T = \{(\lambda x, \lambda y) \mid (x, y) \in T, \lambda \geq 0\}}$$

Where (x, y) is any point in T, and λ is a non-negative real number. This representation indicates that T is a set composed of all non-negative linear combinations of its interior points. In other words, each point in T can be represented by non-negative linear combinations of its interior points. This is the unique representation form of the production possibility set T.

3.1.1.3 CCR MODLE

The fundamental principle of DEA (Data Envelopment Analysis) is as follows: Consider a set of n decision-making units (DMUs) with their respective input and output vectors denoted as $X_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0,\ Y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0, \quad j = 1, \cdots, n$). Since different inputs and outputs may have varying significance and effects in the production process, evaluating the efficiency of a DMU requires a "comprehensive" analysis of its inputs and outputs. This involves treating all inputs collectively as one input vector and all outputs as one output vector, requiring appropriate weights to be assigned to each input and output. Let the weight vectors for inputs and outputs be denoted as $v = (v_1, v_2, \cdots, v_m)^T$ and $u = (u_1, u_2, \cdots, u_s)^T$, respectively. With this, the following definition can be established.

$$\theta_j = \frac{u^T Y_j}{v^T X_j} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}, (j = 1, 2, \cdots n)$$

Definition 2: The efficiency evaluation index of the *j*th decision-making unit (DMU), denoted as DMU_j is defined as follows:

$$\textit{Maximize} \quad \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} = \theta_o$$

$$\textit{subject to} \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1,\ j = 1, 2, \cdots, n,$$

$$u_r \ge 0, v_i \ge 0,\ \forall r, i.$$

where

U_i represents the weight assigned to the output of DMU_i,

Yrj represents the output of DMU i for the jth output,

V*i* represents the weight assigned to the input of DMU k, and

X*u* represents the input of DMU k for the jth input. The efficiency index

quantifies the relative efficiency of the *j*th DMU with respect to the others in the set based on the given weights.

3.1.1.4 BCC Modle

The CCR model assumes that the production process exhibits constant returns to scale, which means that when input quantities increase in proportion, output quantities should also increase in proportion. However, in reality, the production process may also exhibit increasing or decreasing returns to scale. In order to analyze the scale efficiency of decision-making units, Banker, Charnes, and Cooper introduced a variable returns to scale model based on the four axioms of the production possibility set and the Shepard distance function in 1984(Banker, 1984b; Banker et al., 1984). This model is later known as the BCC model.

$$
\begin{aligned}
\textit{Maximize} \quad & \sum_{r=1}^{s} \mu_r y_{ro} - u_o, \\
\textit{subject to} \quad & \sum_{i=1}^{m} \omega_i x_{io} = 1, \\
& \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} \omega_i x_{ij} - u_o \le 0, \quad j = 1, \ldots, n, \\
& \mu_r, \omega_i \ge 0, \qquad r = 1, \ldots, s; \; i = 1, \ldots, m.
\end{aligned}
$$

The dual form of the BCC model with slack variables is as follows:

$$
\begin{aligned}
\textit{Maximize} \quad & \theta_{\mathbf{o}} - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \\
\textit{subject to} \quad & \sum_{j=1}^{n} x_{ij} \lambda_j + s_i^- = \theta_o x_{io}, \; i = 1, \ldots, m \\
& \sum_{j=1}^{n} y_{rj} \lambda_j - s_r^+ = y_{ro}, \quad r = 1, \ldots, s \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j, s_i^-, s_r^+ \ge 0, \quad \forall i, j, r
\end{aligned}
$$

where is a non-Archimedean infinitesimal. According to Banker and Thrall (1992), they proposed the following discriminant method to determine the scale efficiency in the BCC model based on the values obtained from the model(Banker & Thrall, 1992).

Theorem 1: Suppose the set of input-output combinations is efficient. Then the scale efficiency under the model (1) can be determined based on the following conditions:

(i) The scale efficiency is constant if and only if a non-zero scalar λ exists, such as in some optimal solution.

(ii) The scale efficiency is increasing if and only if for all optimal solutions.

(iii) The scale efficiency is decreasing if and only if for all optimal solutions.

Here, represents the optimal solution in the model.

3.1.2 The Malmquist Index system

The traditional DEA model can analyze the "technical efficiency" of Decision Making Units (DMUs) based on cross-sectional data, but it cannot capture the continuous time series information of the DMUs and provides limited information for decision-makers to make effective decisions. However, the production process is a continuous time series process, where production technology is constantly changing and improving. Therefore, it is essential to conduct dynamic analysis.

When the data of the evaluated DMUs are in panel data format, the Malmquist Total Factor Productivity (TFP) index analysis is commonly used to dynamically evaluate the relationships among efficiency changes, technological progress, and technical efficiency. This approach enables a comprehensive and dynamic assessment of the efficiency changes and technological advancements over time, providing decision-makers with valuable insights for making informed decisions.

Table 3.2 Malmquist Index symbol Meaning 1

Symbol	Meaning	Symbol	Meaning
TE	Technical Efficiency	PTE	Pure Technical Efficiency
SE	Scale Efficiency	TPF	Total Factor Productivity
t	Cross-sectional time		

The Malmquist index was initially proposed by Malmquist in 1953 and later computed using DEA (Data Envelopment Analysis) by Fare et al. (F A Re et al., 1992). It decomposes the Malmquist index into technical efficiency change and technological change. By selecting cross-sectional time data of decision-making units (e.g., consecutive years, quarters, months, or weeks) for dynamic analysis, one can discover patterns and reasons related to efficiency changes, providing decision-makers with more

informative insights for effective decision-making.

The Malmquist index is a novel comprehensive efficiency evaluation model that measures the Total Factor Productivity (TFP) of decision-making units from a dynamic perspective. It deconstructs production efficiency into technical and efficiency components. This model is more comprehensive and scientifically grounded than the static perspective that examines the production rate of single factors. In the higher education sector, technological change and progress are reflected in the level of Technical Efficiency (TE). Technological innovation and dissemination are demonstrated by the level of Pure Technical Efficiency (PTE), while the level of Scale Efficiency (SE) represents the extent of widespread production and utility. Together, these components form the measurement indicators for efficiency levels.

The measurement indicators for efficiency levels are jointly determined by the levels of Scale Efficiency (SE) and Pure Technical Efficiency (PTE). The derivation is as follows:

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \frac{D_0^{t}(x_{t+1}, y_{t+1})}{D_0^{t}(x_t, y_t)} \right]$$

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{S_0^{t}(x_t, y_t)}{S_0^{t}(x_{t+1}, y_{t+1})} \times \frac{D_0^{t}(x_{t+1}, y_{t+1}/VRS)}{D_{0t}(x_t, y_t/VRS)} \times \left[\frac{D_0^{t}(x_{t+1}, y_{t+1})}{D_0^{t+1}1(x_{t+1}, y_{t+1})} \times \frac{D_0^{t}(x_t, y_t)}{D_0^{t}+1(x_t, y_t)} \right]^{\frac{1}{2}}$$

Where xt and x_{t+1} represent the input and output quantities in two consecutive periods, t and $t+1$ in the panel data, while yt and y_{t+1} represent the output quantities for the same periods. D0t and D0t+1 represent the technology distance functions at time periods t and $t+1$, respectively, given the fixed technology level.

the Total Factor Productivity (TFP) index can be further decomposed into the product of Scale Efficiency (SE), Pure Technical Efficiency (PTE), and Technical Progress (TP) from left to right. The TFP index can also be interpreted as the product of Comprehensive Technical Efficiency (TE) and Technical Progress (TP).

The decomposition formula for the TFP index is as follows:

$$TEP = TP \times PTE \times SE$$

In the context of the DEA model, the meanings of each index are as follows:

Comprehensive Technical Efficiency (TE): A value of 1 directly indicates whether the panel data achieves DEA efficiency. If TE equals 1, it means that the decision-making units (DMUs) are DEA efficient; otherwise, they are inefficient.

Scale Efficiency (SE): This represents the level of production scale efficiency, indicating how well the DMUs are utilizing their production resources. If SE equals 1, it indicates that the production scale is efficient and the DMUs are operating at an optimal scale.

Pure Technical Efficiency (PTE): This represents the level of pure technical efficiency, which reflects the extent to which DMUs are utilizing their production technology effectively. A PTE value of 1 indicates that the DMUs are using their technology efficiently.

In the Malmquist productivity index analysis, if both SE and PTE are more significant than 1, it suggests that the production scale efficiency and production technology efficiency have been increasing year by year. Conversely, if they are less than 1, it indicates a decrease in efficiency over time.

Technical Progress (TP) and Total Factor Productivity (TFP): If TP and TFP in the Malmquist index analysis are more significant than 1, it implies that the DMUs are experiencing technological growth and improvements in production efficiency over time. Conversely, if they are less than 1, it suggests a decline in technological progress and production efficiency over time.

According to the DEA-BCC model and the theory principle of Malmquist index, the technical route to measure the efficiency of public undergraduate universities in Sichuan province is designed.

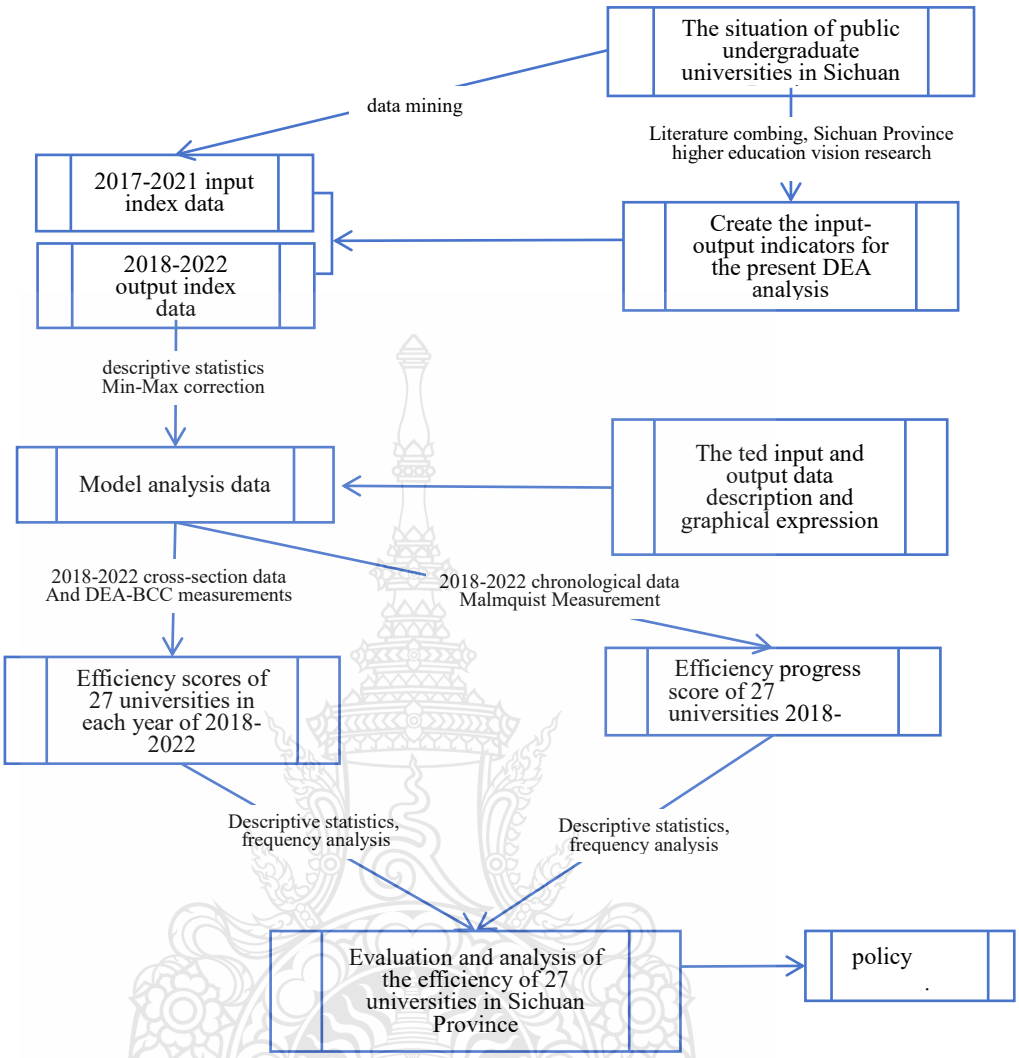

Figure 3.1 Technology Roadmap

3.2 Sampling Technique

3.2.1 Sample Selection

The research object of this study is the public undergraduate universities in Sichuan Province. According to the data from the China Education Statistical Yearbook, as of December 2022, there are a total of 27 public undergraduate universities in Sichuan Province (Department Of Development Planning, 2022). In this research, we will adopt a census method, which means using all the public undergraduate universities in Sichuan Province as the research sample rather than a random sampling method. The main reason for choosing this census method is to ensure that we can obtain

comprehensive and detailed data and accurately assess the efficiency of all public undergraduate universities in Sichuan Province and analyze their time series changes.

In the realm of higher education research, employing a comprehensive survey method, known as a census, is commonly applied to study all universities within a specific region or of a particular type. In our study, our primary focus lies in assessing the efficiency of all public undergraduate universities in Sichuan Province and analyzing their time series variations. By conducting a census survey, we aim to gather an extensive dataset to ensure the utmost representativeness and reliability of our research findings.

The advantages of adopting a census method are as follows:

Enhanced Representativeness: A census survey allows for a complete and accurate reflection of the status of all public undergraduate universities in Sichuan Province, thus guaranteeing highly representative research results.

Comprehensive Insight: The inclusion of all universities enables us to obtain comprehensive data, facilitating the identification of subtle differences and trends and consequently leading to more comprehensive and informed conclusions.

Detailed Data: A census survey provides in-depth data from all universities, thereby eliminating issues related to limited sample size and potential data gaps.

Despite the challenges associated with data collection and processing in a census survey, we are committed to ensuring data accuracy and reliability by leveraging publicly available data and official school reports. In the design of our research framework, we will treat each public undergraduate university in Sichuan Province as a distinct Decision Making Unit (DMU). As illustrated in Table 3-2, we will meticulously plan the data collection and analysis procedures to ensure the validity and robustness of our study.

Table 3.3 Sichuan Provincial Public Undergraduate Universities

Decision-making units	Name of the school
DUM1	Chengdu University of Technology
DUM2	Xinhua University
DUM3	Sichuan University of Science & Engineering
DUM4	Southwest University of Science and Technology
DUM5	Sichuan Agricultural University
DUM6	Chengdu University of Traditional Chinese Medicine
DUM7	Sichuan Normal University
DUM8	China West Normal University
DUM9	Southwest Petroleum University
DUM10	Chengdu University of Information Technology
DUM11	Southwest Medical University
DUM12	North Sichuan Medical College
DUM13	Chengdu Medical College
DUM14	Leshan Normal University
DUM15	Yibin University
DUM16	Sichuan University of Arts and Science
DUM17	Panzhihua University
DUM18	Xichang University
DUM19	Mianyang Teachers' college
DUM20	Neijiang Normal University
DUM21	Aba Teachers University
DUM22	Chengdu Normal University
DUM23	Chengdu Sport University
DUM24	Sichuan Police College
DUM25	Sichuan Tourism University
DUM26	Chengdu Technological University
DUM27	Sichuan Conservatory of Music

3.2.2 Selection of Input and Output Indicators

The crux of conducting efficiency measurements in higher education using Data Envelopment Analysis (DEA) lies in the judicious selection of representative input and output indicators. In this study, we performed a thorough review of relevant literature to

synthesize commonly employed input and output indicators. Drawing from the education development plan of Sichuan Province, we further scrutinized and finalized the specific input and output indicators to be employed in our research.

In the realm of higher education efficiency measurement utilizing DEA, scholars have extensively explored and identified pertinent indicators in the input dimension, encompassing human resources, financial resources, and physical resources. For the output dimension, indicators associated with talent cultivation, scientific research, and social services have been recurrently chosen. This approach is harmonious with the "Education 2030 Agenda" promulgated by UNESCO in November 2015(Mundial et al., 2016), articulating a vision for higher education. Notably, CAI Wen-bo advocates enhancing efforts in areas such as talent cultivation, scientific research, social services, cultural preservation and innovation, faculty development, and international exchange and collaboration to achieve seamless integration between Chinese higher education and global higher education standards(蔡文伯王亚芹, 2019).

Drawing from an exhaustive literature review, we have identified the input and output indicators that have recurrently featured in recent scholarly work on higher education efficiency measurement using DEA.

Table 3.4 Index selection in the literature

Indicator category	**Level1 indicators**	**Level2 indicators**	**Secondary indicators**
Input indicators	Human input	Number of staff Number of researchers Number of PhD students Number of full-time teachers and the proportion of doctoral degree professors	(Lee & Johnes, 2022; Liang et al., 2021)(Chen et al., 2021; Ding et al., 2023; Sun et al., 2023)(Ghimire et al., 2021; Mammadov & Aypay, 2020)(Navas et al., 2020; Sun et al., 2023)(Cossani et al., 2022; Ding et al., 2023)(Cossani et al., 2022)(Cossani et al., 2022; Navas et al., 2020)...

Indicator category	Level1 indicators	Level2 indicators	Secondary indicators
Input indicators	Financial input	Total revenue	(Cossani et al., 2022; Ding et al., 2023)(Ghimire et al., 2021; Stumbrienė et al., 2022; Sun et al., 2023; Tavares et al., 2021)(Chen et al., 2021; Torres-Samuel et al., 2020)(Torres-Samuel et al., 2020)
		government input	
		expenditure	
		teaching input	
		research input	
	Material input	Number of scientific research equipment, infrastructure area	(Chen et al., 2021)(Cossani et al., 2022)(Mammadov & Aypay, 2020)
	Personnel training	Number of graduates	(Mammadov & Aypay, 2020; Navas et al., 2020; Stumbrienė et al., 2022; Tavares et al., 2021)(Chen et al., 2021)(Chen et al., 2021; Sun et al., 2023)(Chen et al., 2021; Sun et al., 2023)(Chen et al., 2021)
		Number of undergraduate students	
		Number of graduate students	
	Research	Number of publications	(Cossani et al., 2022; Ding et al., 2023; Ghimire et al., 2021; Mammadov & Aypay, 2020; Navas et al., 2020)(Chen et al., 2021; Ding et al., 2023; Ghimire et al., 2021; Mammadov & Aypay, 2020)(Cossani et al., 2022; Tavares et al., 2021)(Sun et al., 2023)(Ding et al., 2023)
		Research funding	
		Number of scientific Research achievements	
		academic satisfaction	
	To serve the society	Number of achievements transformed	(Torres-Samuel et al., 2020)(Cossani et al., 2022; Tavares et al., 2021)
		Number of patents	

Based on the literature review, researchers have shown consensus in selecting indicators for DEA analysis in higher education. These indicators exhibit certain characteristics:

（1）Comparability: Indicators should be comparable by using the same unit of measurement and collecting data within the same time frame for the same type of institutions.

（2）Relevance: Indicators should reflect different aspects of the same goal.

（3）Efficiency: Priority is given to selecting factors that have a significant impact on efficiency.

（4）Adjustability: The selected indicators should have the potential for variation to achieve improvements in efficiency.

Considering the above characteristics, researchers have chosen indicators that are aligned with the goals of higher education institutions and are suitable for DEA analysis. For this study, focusing on the efficiency of public undergraduate institutions in Sichuan Province, it is essential to start by understanding the educational vision and goals set by the provincial authorities.

In November 2022, Sichuan Province formulated the "14th Five-Year Plan for Education Development in Sichuan Province," which set the goals for education development in Sichuan Province from 2021 to 2025. In this study, the selection of input and output indicators is based on the educational goals set by Sichuan Province for higher education. The selection process takes into account the differences between public undergraduate universities and universities of other types. The indicators chosen are those that have the greatest impact on university efficiency and are widely used in the literature. Additionally, the output indicators are constructed based on the expectations for university development outlined in the "14th Five-Year Plan for Education Development in Sichuan Province."

Step 1: Based on the overall goals of the "14th Five-Year Plan for Education Development in Sichuan Province," select the output indicators. The document sets the following goals for the development of higher education in Sichuan Province:

Universalization of Education: Increase the gross enrollment rate in higher education from 51.9% in 2020 to 58.5%. Increase the scale of undergraduate students from 990,100 in 2020 to 1,025,200. Increase the scale of enrolled graduate students from 144,700 in 2020 to 162,900.

Education Quality: Implement the cultivation of top-notch undergraduate programs and build 500 provincial-level top-notch undergraduate programs, striving for around 400 national-level top-notch programs. Establish 3,200 provincial-level top-notch undergraduate courses, aiming for around 400 national-level top-notch courses.

Innovation and Development: Achieve a "triple increase" in the total amount of research funding, the number of research outputs, and the number of technology transfer achievements in higher education compared to the end of the "13th Five-Year Plan." Implement key provincial-level platform construction projects and foster the development of 20 provincial-level (technical) research centers and 10 national and provincial defense science and technology key laboratories. Strive to achieve a cumulative breakthrough of over 100,000 industry-university-research collaboration projects in universities.

Based on the above goals, the main output indicators in four aspects are determined: the number of undergraduate students, the number of provincial and ministerial-level top-notch undergraduate programs, the number of high-level academic papers, and the amount of technology transfer achievements.

Step 2: Based on the impact of output goals, determine the input indicators. Many researchers use both dynamic variables (such as financial inputs and budget expenditures) and stock variables (such as the total number of faculty and fixed assets) as input indicators. In this study, for stock inputs, the number of high-level talents/faculty members is used as the measuring indicator, while for dynamic inputs, each university's annual income indicators are chosen.

It is important to note that education output has a delayed effect, meaning that the inputs in a given year may not fully reflect their effects in the same year. Therefore, conducting input-output analysis using only current-year indicators may not be scientifically sound. To address this, the present study uses a novel approach by pairing the current year's inputs with the subsequent year's outputs as a set of analysis variables.

As a result, this study uses data from 2017 to 2021 for input indicators and data from 2018 to 2022 for output indicators, pairing the previous year's inputs with the following year's outputs as a set of analysis variables. This innovative approach accounts for the delay in education output and allows for a more comprehensive and accurate

assessment of the efficiency of decision-making units (DUMs) in Sichuan Province's public undergraduate institutions.

Table 3.5 DEA input-output indicators

Input Variables	Data Code	Indicator Name
Educational Input	X1	Number of Faculty Members
	X2	Stock of Fixed Assets (in RMB 10,000)
	X3	Annual Financial Income (in RMB 10,000)
Educational Output	Y1	Number of Undergraduate Students
	Y2	Number of Provincial and Ministerial-level First-Class Undergraduate Programs
	Y3	Amount of Scientific and Technological Achievements Transformation (in RMB 10,000)
	Y4	Number of High-level Research Papers Published

3.3 Instrumentation

3.3.1 Data Sources

In this section, the sources of the input-output indicators are described, along with their accessibility.

(1)China Education Statistical Yearbook (2017-2021) - The data on provincial and ministerial-level first-class undergraduate majors were obtained from the China Education Statistical Yearbook for the years 2017 to 2021. This publication is publicly available and provides comprehensive statistics on various educational aspects.

(2)Sichuan Provincial Education Statistical Yearbook (2017-2021) - Information on the number of faculty members and other relevant educational data for the years 2017 to 2021 were collected from the Sichuan Provincial Education Statistical Yearbook. This is a publicly accessible resource that compiles educational data specific to Sichuan Province.

(3) Sichuan Provincial Education Funding Statistical Report (2017-2022) - Data on the stock of fixed assets in the education sector for the years 2017 to 2022 were sourced from the Sichuan Provincial Education Funding Statistical Report. This report contains financial data related to education funding and is publicly available.

(4)Sichuan Provincial Education Department's Final Accounts Report (2017-2022) - Annual financial data, including the year-end financial income, for the years 2017 to 2022, were obtained from the Sichuan Provincial Education Department's final accounts report. These financial reports are publicly accessible and provide information on budget allocations and expenditures.

(5) China National Knowledge Infrastructure (CNKI) Journal Search - Data related to the number of high-level research papers published by the 27 public undergraduate universities in Sichuan Province were retrieved from the CNKI journal search. This academic database provides access to published research articles from various academic journals.

(6)Data from Sichuan Provincial Education Department - Information on the conversion of scientific and technological achievements was obtained through interviews and statistics from the relevant department of the Sichuan Provincial Education Department. This data was acquired through direct communication with the department.

The data sources (1)-(4) are publicly available and can be accessed by researchers through official publications and reports. The data from CNKI (5) and the Sichuan Provincial Education Department (6) were collected through appropriate channels and interviews to ensure their accuracy and reliability. The combination of these data sources allows for a comprehensive and reliable analysis of the input-output indicators for the public undergraduate universities in Sichuan Province.

3.3.2 Data Collection Tool

To gather and organize the data required for constructing input-output indicators, a data collection tool in a spreadsheet was utilized. The relevant data for the input indicators from 2017 to 2021 and the output indicators from 2018 to 2022 were selected and recorded in the spreadsheet. This selection enables the study to cover multiple years' worth of data, allowing for time-series analysis and dynamic efficiency assessment. During the data collection process, utmost care was taken to ensure data consistency and accuracy, guaranteeing the credibility and validity of the research findings.

Table 3.6 Input data collection form

No.	DUM	2017			2018			.....	2021		
		X1	X2	X3	X1	X2	X3	.....	X1	X2	X3
1	DUM1										
2	DUM2										
3	DUM3										
4	.....										
5	DUM27										

Table 3.7 Output data collection form

序号	DUM	2018				.....	2022			
		Y1	Y2	Y3	Y4	.....	Y1	Y2	Y3	Y4
1	DUM1									
2	DUM2									
3	DUM3									
4	.....									
5	DUM27									

3.3.3 Data Analysis Tools

In this study, we will employ the DEA-BCC model and the Malmquist index analysis as the primary research instruments and tools. The DEA-BCC model will be used to assess the cross-sectional data of public undergraduate universities in Sichuan Province, while the Malmquist index analysis will be utilized to analyze time-series data. The main measurement tools used will be SPSSPRO and DEAP2.1.

SPSSPRO (Scientific Platform Serving for Statistics Professional) is a new online data analysis platform that distinguishes itself from the traditional client mode of SPSS and SAS. It provides the basic functionality of SPSS software and will be used in this study for data description and data cleaning purposes.

Figure 3.1 SPSSPRO Interface

DEAP2.1 software is a DOS program that runs in a WINDOWS interface and is used for data analysis in DEA-CCR, DEA-BCC, Malmquist Index, and other models. The software includes a simple batch-processing program where users can create data files. By opening the "deap" program and following the running wizard, users can generate an output file that can be read by a text editor.

The DEAP2.1 software package includes five files for its execution:

（1）Executable file: DEAP.EXE

（2） Starter file: DEAP.000

（3） Data files: e.g., 123.DTA

The DEAP software requires the data to be listed in a text file in a specific order. The data arrangement should have each Decision Making Unit (DMU) on a separate row, with outputs listed first and inputs listed afterward (from left to right). For example, if there are 20 DMUs, each with 2 inputs and producing 2 outputs, the data file will have 20 rows, with the column order as follows: y1, y2, x1, x2.

(3) Wizard files: e.g., 123.INS

The wizard file is also a text file. You can start with the DBLANK.INS file provided with the program and then edit it using a text editor or text processing software to input relevant information.

(4) Output files: e.g., 123.OUT

The output file is a text file automatically generated by the DEAP software when running the wizard file. You can read the output file using a text editor like NOTEPAD or EDIT or text processing software like WORD or WORD PERFECT. The

output file can also be imported into spreadsheet software such as EXCEL or LOTUS.

These files are essential for running the DEAP2.1 software and performing the data analysis using DEA-CCR, DEA-BCC, Malmquist Index, and other relevant models.

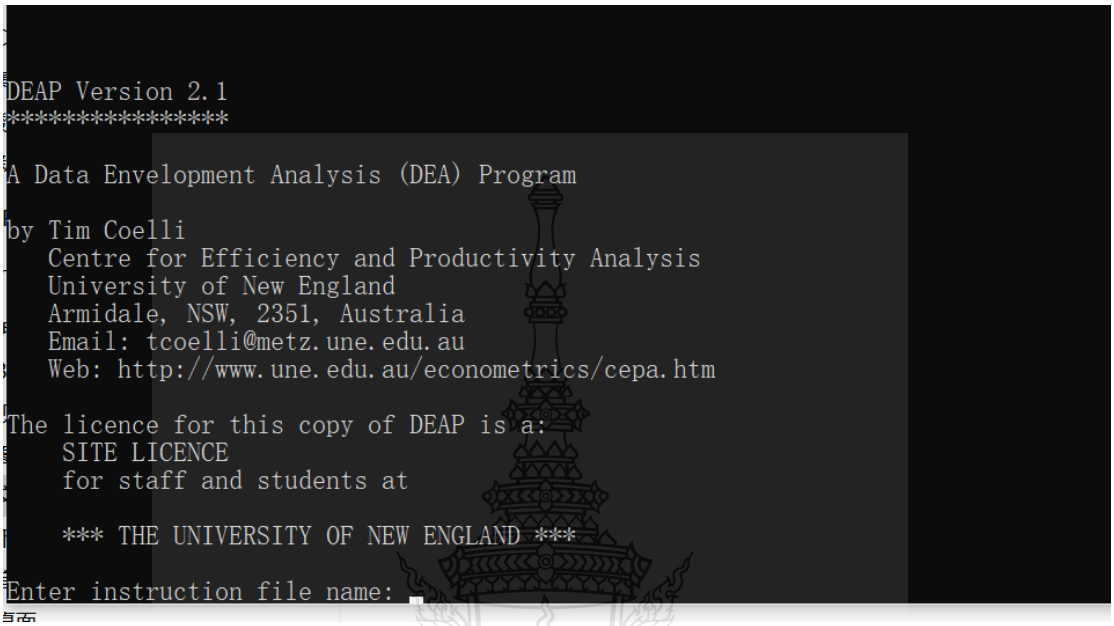

Figure 3.2 DEAP2.1 Running Interface

3.4 Procedure of the Data Collection

Based on the input-output indicator system constructed in Section 3.2, data for the input indicators from 2017 to 2021 and output indicators from 2018 to 2022 were collected. The data was used to create separate tables for the input indicators and output indicators.

Table 3.8 Input Indicators Data (2017-2018)

DUM	2017			2018		
	X1 (persons)	X2(in RMB 10,000)	X3 (in RMB 10,000)	X1 (persons)	X2 (in RMB 10,000	X3 (in RMB 10,000
DUM1	2,557	254,099.87	116,044.75	2,067	262,322.63	137,250.78
DUM2	1,856	103,934.91	90,371.51	1,808	110,518.68	96,558.42
DUM3	2,011	126,774.41	82,978.47	1,958	147,852.95	85,728.56
DUM4	1,964	230,257.55	95,028.64	1,985	241,293.60	123,683.77
DUM5	1,857	145,094.25	139,296.59	1,914	193,930.21	150,732.48
DUM6	1,363	143,478.89	75,517.08	1,343	150,858.00	100,235.67
DUM7	2,174	227,920.42	132,894.06	2,158	234,743.42	127,012.06

DUM	2017			2018		
	X1 （persons）	X2 (in RMB 10,000）	X3 (in RMB 10,000）	X1 （persons）	X2 (in RMB 10,000	X3 (in RMB 10,000
DUM8	1,999	158,101.65	72,738.67	2,050	168,581.65	95,419.60
DUM9	2,059	201,000.76	124,042.85	2,019	207,066.78	133,834.41
DUM10	1,377	134,867.41	63,563.36	1,367	137,071.91	70,383.89
DUM11	1,260	86,490.00	58,882.45	1,278	98,003.77	68,259.27
DUM12	1,059	81,033.53	49,430.30	1,047	85,210.67	49,735.93
DUM13	777	38,347.36	33,509.25	696	41,281.59	32,762.44
DUM14	850	67,844.15	33,159.16	887	72,193.06	37,445.28
DUM15	842	61,318.56	36,503.45	976	64,893.10	35,990.52
DUM16	877	41,860.98	21,530.70	900	59,893.28	28,576.90
DUM17	552	54,190.95	19,484.40	569	56,229.93	24,220.59
DUM18	998	78,779.19	32,950.69	994	83,000.84	42,294.66
DUM19	1,147	132,865.17	38,398.36	1,160	139,594.57	40,529.65
DUM20	1,248	57,575.68	37,271.52	1,200	60,235.57	42,389.08
DUM21	459	116,075.95	14,512.02	446	117,513.39	19,712.44
DUM22	732	69,988.81	32,326.33	792	84,527.69	34,338.20
DUM23	809	47,105.12	28,217.70	824	48,624.33	34,742.97
DUM24	471	45,574.24	17,676.42	516	45,511.16	17,982.24
DUM25	444	36,894.44	25,240.11	438	65,527.47	40,752.85
DUM26	699	73,738.43	28,417.28	703	76,513.75	34,626.58
DUM27	1,194	94,950.95	44,690.76	1,174	96,566.61	49,329.26

Table 3.9 Input Indicators Data (2019-2020)

DUM	2019			2020		
	X1 （persons）	X2(in RMB 10,000）	X3(in RMB 10,000）	X1 （persons）	X2(in RMB 10,000	X3(in RMB 10,000
DUM1	1,996	266,200.11	165,296.42	2,011	179,068.83	150,802.87
DUM2	1,727	112,387.41	105,054.71	1,688	120,480.51	109,625.06
DUM3	1,824	149,995.72	109,902.43	1,842	112,401.38	92,939.03
DUM4	1,987	250,662.52	129,759.07	2,002	152,103.17	136,559.43
DUM5	1,903	204,106.25	175,086.99	1,997	235,326.05	175,279.11
DUM6	1,292	158,799.42	105,729.45	1,274	137,052.41	85,884.02

DUM	2019			2020		
	X1 （persons）	X2(in RMB 10,000）	X3(in RMB 10,000）	X1 （persons）	X2(in RMB 10,000	X3(in RMB 10,000
DUM7	2,216	240,664.96	123,492.14	2,265	178,618.86	131,801.77
DUM8	1,843	178,708.25	129,732.31	1,839	99,698.89	97,680.05
DUM9	1,974	227,588.25	160,537.95	1,933	167,113.81	172,161.21
DUM10	1,333	173,834.06	77,697.83	1,355	115,646.81	81,293.55
DUM11	1,351	139,797.12	80,361.52	1,370	86,359.89	96,377.91
DUM12	1,018	93,997.26	55,060.74	1,007	48,996.47	54,400.96
DUM13	704	44,274.46	44,273.14	692	162,649.19	42,418.15
DUM14	881	74,026.14	49,963.56	1,848	78,150.20	93,686.00
DUM15	950	67,924.53	45,836.99	1,002	49,228.50	77,051.77
DUM16	713	61,650.25	35,838.26	752	59,539.57	35,692.27
DUM17	535	56,750.66	36,351.05	1,076	95,162.08	72,119.92
DUM18	970	85,341.63	50,402.60	979	63,817.48	51,655.95
DUM19	1,181	137,566.77	47,784.73	1,183	88,388.32	48,237.62
DUM20	897	67,478.65	50,279.42	984	31,064.02	61,885.47
DUM21	444	119,367.99	21,155.11	487	75,451.44	27,304.19
DUM22	795	85,195.23	34,169.56	973	68,401.56	34,926.39
DUM23	802	49,493.40	42,002.48	838	46,745.76	48,290.20
DUM24	535	48,444.62	25,648.76	544	24,150.40	29,627.95
DUM25	427	69,815.16	48,301.11	457	70,324.46	60,322.72
DUM26	682	79,290.58	38,700.56	674	71,635.74	39,099.00
DUM27	1,170	98,550.21	51,277.36	1,190	65,251.57	58,853.95

Table 3.10 Input Indicators Data (2021)

DUM	2021		
	X1（persons）	X2(in RMB 10,000）	X3(in RMB 10,000）
DUM1	2,037	292,709.79	167,110.86
DUM2	1,673	179,227.09	135,954.86
DUM3	1,870	184,582.20	125,766.26
DUM4	2,025	279,426.87	136,628.04
DUM5	1,994	324,828.54	179,257.03

DUM	2021		
	X1（persons）	X2(in RMB 10,000）	X3(in RMB 10,000）
DUM6	1,300	212,388.60	110,202.51
DUM7	2,296	256,346.94	173,875.72
DUM8	1,869	192,533.13	109,437.38
DUM9	1,951	248,068.77	199,156.04
DUM10	1,367	189,262.07	89,717.10
DUM11	1,390	171,285.55	91,332.62
DUM12	1,027	111,553.86	57,986.61
DUM13	693	57,761.55	51,693.08
DUM14	985	77,773.42	59,396.50
DUM15	995	83,106.91	84,952.66
DUM16	775	64,314.77	40,569.47
DUM17	522	63,221.36	38,304.73
DUM18	1,025	115,603.01	60,079.10
DUM19	1,160	139,594.57	40,529.65
DUM20	1,200	60,235.57	42,389.08
DUM21	446	117,513.39	19,712.44
DUM22	792	84,527.69	34,338.20
DUM23	824	48,624.33	34,742.97
DUM24	516	45,511.16	17,982.24
DUM25	438	65,527.47	40,752.85
DUM26	703	76,513.75	34,626.58
DUM27	1,174	96,566.61	49,329.26

Table 3.11 Output Indicators Data (2018-2019)

DUM	2018				2019			
	Y1 (persons)	**Y2 (item)**	**Y3 (in RMB 10,000）**	**Y4 (article)**	**Y1 (persons)**	**Y2 (item)**	**Y3 (in RMB 10,000）**	**Y4 (article)**
DUM1	30,538	12	530.00	1,061	30,859	12	460.00	1,071
DUM2	35,050	5	105.00	390	35,442	5	13.40	445
DUM3	32,489	5	0.00	361	34,423	5	148.60	256
DUM4	31,474	10	16.00	710	31,098	10	29.00	677
DUM5	38,443	10	154.60	1,024	37,985	10	247.20	977
DUM6	20,157	6	442.60	702	20,577	6	1709.90	715
DUM7	35,687	13	10.00	566	36,167	13	0.00	587
DUM8	28,692	8	0.00	295	27,126	8	0.00	295
DUM9	29,367	9	14005.80	939	30,068	9	20354.00	923
DUM10	21,558	11	2.00	297	22,046	11	5.20	286
DUM11	17,072	5	10.00	592	17,106	5	72.00	611
DUM12	16,437	2	0.00	243	17,189	2	0.00	202
DUM13	11,127	1	10.00	200	11,344	1	36.00	169
DUM14	17,205	7	2.00	88	16,520	7	0.00	74
DUM15	15,947	7	40.00	69	17,833	7	60.00	53
DUM16	12,330	7	0.00	97	13,303	7	0.00	98
DUM17	7,799	7	0.00	14	8,067	7	0.00	12
DUM18	16,726	3	0.00	69	17,796	3	0.00	50
DUM19	17,393	7	0.00	92	18,036	7	1.50	87
DUM20	17,965	7	0.00	129	18,977	7	1.00	119
DUM21	6,215	6	0.00	44	7,573	6	0.00	45
DUM22	11,862	5	0.00	102	13,974	5	0.00	91
DUM23	9,400	4	0.00	105	9,231	4	0.00	108
DUM24	5,391	3	0.00	18	5,411	3	0.00	20
DUM25	8,034	1	0.00	105	8,577	1	11.20	141
DUM26	11,512	5	4.00	62	12,430	5	9.80	72
DUM27	13,133	2	0.00	74	13,226	2	0.00	67

Table 3.12 Output Indicators Data (2020-2021)

DUM	2020				2021			
	Y1 (persons)	Y2(item)	Y3(in RMB 10,000）	Y4 (article)	Y1 (persons)	Y2(item)	Y3(in RMB 10,000）	Y4 (article)
DUM1	30,506	19	178.50	980	30,298	32	35.00	960
DUM2	37,535	10	64.90	465	38,637	31	131.60	425
DUM3	36,676	4	72.20	277	39,564	16	503.70	266
DUM4	32,338	12	35.60	584	33,718	27	81.60	636
DUM5	37,071	14	227.80	908	36,521	28	468.90	810
DUM6	21,068	6	2159.50	804	21,136	46	97.90	785
DUM7	37,608	20	50.00	542	37,324	44	3.00	543
DUM8	28,186	8	10.00	334	29,623	22	0.50	287
DUM9	30,829	15	22881.20	949	31,021	34	37400.00	947
DUM10	23,232	13	15.20	317	23,752	19	15.30	249
DUM11	16,757	1	0.00	697	16,417	31	4.00	203
DUM12	17,695	2	1.00	244	17,642	15	1.30	305
DUM13	11,844	2	0.00	161	12,488	18	5.00	172
DUM14	18,063	3	0.00	81	18,559	23	3.00	110
DUM15	20,158	5	72.00	65	21,873	18	521.30	91
DUM16	14,414	3	10.00	68	15,320	14	10.00	77
DUM17	8,452	1	0.00	14	8,735	14	0.00	12
DUM18	19,264	3	0.00	71	19,228	12	0.00	59
DUM19	18,617	4	0.00	81	18,932	21	5.00	69
DUM20	18,535	3	3.10	130	18,944	19	4.20	114
DUM21	8,919	6	0.00	45	9,461	6	0.00	36
DUM22	15,888	5	0.50	90	16,931	21	1.00	86
DUM23	9,026	3	0.00	111	8,946	15	0.00	115
DUM24	5,396	3	0.00	30	5,425	28	0.00	26
DUM25	8,779	1	13.00	122	9,335	10	18.00	84
DUM26	14,083	8	6.50	92	15,962	15	0.00	79
DUM27	12,811	2	0.00	97	12,022	28	0.00	104

Table 3.13 Output Indicators Data (2021)

DUM	2022			
	Y1(persons)	Y2(item)	Y3(in RMB 10,000）	Y4(article)
DUM1	30,161	32	12436.20	940
DUM2	38,168	31	209.50	374
DUM3	41,109	16	689.20	264
DUM4	33,074	27	296.30	591
DUM5	36,686	28	699.00	704
DUM6	21,034	46	151.00	870
DUM7	38,250	44	10.50	513
DUM8	30,259	22	11.20	240
DUM9	31,242	34	35615.60	1,101
DUM10	22,333	19	56.00	290
DUM11	16,889	31	2.80	527
DUM12	17,068	15	2.00	306
DUM13	13,039	18	0.10	220
DUM14	18,443	23	0.00	66
DUM15	23,285	18	635.00	80
DUM16	17,270	14	12.00	45
DUM17	9,092	14	0.00	16
DUM18	17,913	12	341.90	56
DUM19	19,365	21	5.00	68
DUM20	16,963	19	9.40	91
DUM21	8,572	6	0.00	23
DUM22	17,074	21	2.80	67
DUM23	8,999	15	0.00	136
DUM24	4,960	28	0.00	24
DUM25	9,919	10	1.70	96
DUM26	17,837	15	7.30	82
DUM27	11,664	28	0.00	108

3.5 Data process in Gand analysis

3.5.1Descriptive statistics

In this study, the collected data from Section 3.4 underwent a descriptive analysis. The data were analyzed using SPSSPRO, and the results are presented below. The descriptive analysis aimed to summarize and provide insights into the dataset's characteristics, enabling a comprehensive understanding of the variables' central tendencies, variabilities, and distributions. The utilization of SPSSPRO as the analysis tool facilitated the organization and presentation of key statistical measures, such as means, standard deviations, and frequency distributions, offering valuable information for further interpretation and investigation in our research.

Table 3.14 Descriptive Statistics of Input-Output Variables(2018—2022)

Variable Indicator	Variable Indicator	Mean	Median	Standard Deviation	Minimum Value	Maximum Value
X1	135	1,296.34	1,025	433.22	457	2,296
X2	135	103,692.33	95,028.64	49,017.62	14,512.02	254,099.87
X3	135	71,455.69	63,563.36	26,700.6	14,512.02	166,256.65
Y1	135	15,558.04	15,96	8,789.43	4,960	41,109
Y2	135	12.46	14	7.76	1	46
Y3	135	208.64	72	1,617.78	0	22,881.2
Y4	135	320.29	82	331.68	18	1,101

From the descriptive statistics, it can be observed that the variables exhibit considerable variations in their values. The mean and median values for each indicator differ significantly, indicating a considerable level of heterogeneity among the universities in terms of input and output measures. The standard deviations are also substantial, further supporting the notion of significant diversity among the institutions.

For instance, the average number of undergraduate students is approximately 15,558.04, but this varies widely, with a minimum of 4,960 students and a maximum of 41,109 students. Similarly, the average amount of funds generated from technology transfer is around 208.64 million RMB, yet this figure ranges from 0 to as high as

22,881.2 million RMB. These variations suggest a diverse range of efficiency levels and resource utilization practices among the universities.

The observed disparities in the variables imply that some institutions are more efficient in resource utilization while others may have room for improvement. The application of the DEA model will help identify those universities capable of achieving optimal output efficiency under given input conditions, as well as those institutions that can improve their resource allocation and operational effectiveness. Such analyses provide valuable insights and decision support to optimize resource allocation, enhance performance, and foster the overall development of the education system.

Based on the findings from the descriptive statistics, conducting DEA analysis is vital for evaluating the efficiency of Sichuan's undergraduate universities and providing valuable recommendations for improvement. The DEA analysis can assist universities in identifying areas for enhancement, optimizing resource allocation, and enhancing overall performance, thereby contributing to the sustainable development of the educational system.

3.5.2 Standardization - Min-Max

To ensure comparability and avoid bias in evaluation results caused by different units of measurement among indicators, the collected data underwent further processing in this section to enhance data comparability and facilitate visualization. The min-max standardization method was employed in this study.

Min-max normalization linearly transforms the original data into a specific range, typically [0, 1]. This normalization technique scales the data linearly, mapping it to the specified range so that all data points fall between 0 and 1, with the minimum value corresponding to 0 and the maximum value corresponding to 1. The formula for min-max normalization is as follows:

$$X_{normalized} = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

$$Xnormalized = Xmax - XminX - Xmin$$

Where:

$Xnormalized$ represents the normalized data,

X is the original data,

$X_{min}$is the minimum value of the data, and

X_{max} is the maximum value of the data.

By using this formula, we can scale the original data X to a range between 0 and 1. Min-Max normalization is suitable when the original data distribution has no clear boundaries or outliers and when we want to map the data to the range between 0 and 1. However, if the original data contains large extreme values or outliers, they can influence the normalization process, resulting in the normalized data being concentrated in a smaller range, with larger values being very close to 1.

Performing standardization helps eliminate the scale differences among indicators, enabling all indicators to be compared on the same scale. In the DEA evaluation, this ensures that each indicator's weight is treated more equally, leading to more reasonable evaluation results.

In the DEA analysis of public undergraduate universities in Sichuan Province, as determined from the analysis in Section 3.3, the selected indicators have considerable heterogeneity. Therefore, standardizing the data is advantageous for conducting a more reasonable study. This perspective is also supported by the research of Zhang et al(张星 & 张峥, 2020).

The input-output data from Section 3.4 were imported into the SPSSPRO software, and a min-max normalization was performed to organize the data, yielding the following results.

Table 3.15 Min-Max normalized data for input indicators(2017-2018)

DUM	2017			2018		
	X1	X2	X3	X1	X2	X3
DUM1	0.014171123	0.244444444	0.70757144	0.012299465	0.244444444	0.716451354
DUM2	0.002807487	0.088888889	0.832388171	0.000358289	0.088888889	0.843232178
DUM3	0	0.088888889	0.761542505	0.003973262	0.088888889	0.815043293
DUM4	0.000427807	0.2	0.733464273	0.000775401	0.2	0.723062879
DUM5	0.00413369	0.2	0.926249689	0.006609626	0.2	0.913579905
DUM6	0.011834225	0.111111111	0.420398905	0.045719251	0.111111111	0.432017483

DUM	2017			2018		
	X1	X2	X3	X1	X2	X3
DUM7	0.00026738	0.266666667	0.850009682	0	0.266666667	0.863288058
DUM8	0	0.155555556	0.656505021	0	0.155555556	0.61318432
DUM9	0.374486631	0.177777778	0.675177737	0.544224599	0.177777778	0.694569698
DUM10	5.34759E-05	0.222222222	0.459155163	0.000139037	0.222222222	0.472654845
DUM11	0.00026738	0.088888889	0.335057678	0.001925134	0.088888889	0.33599823
DUM12	0	0.022222222	0.317491494	0	0.022222222	0.338294282
DUM13	0.00026738	0	0.170599463	0.000962567	0	0.176602396
DUM14	5.34759E-05	0.133333333	0.338736895	0	0.133333333	0.319787546
DUM15	0.001069519	0.133333333	0.303936485	0.001604278	0.133333333	0.356109436
DUM16	0	0.133333333	0.203878392	0	0.133333333	0.230794766
DUM17	0	0.133333333	0.078536059	0	0.133333333	0.085949819
DUM18	0	0.044444444	0.325486182	0	0.044444444	0.355085894
DUM19	0	0.133333333	0.343937592	4.0107E-05	0.133333333	0.361725082
DUM20	0	0.133333333	0.359760989	2.6738E-05	0.133333333	0.387756231
DUM21	0	0.111111111	0.03471742	0	0.111111111	0.072284157
DUM22	0	0.088888889	0.190931976	0	0.088888889	0.249356829
DUM23	0	0.066666667	0.122824974	0	0.066666667	0.11814988
DUM24	0	0.044444444	0.011922875	0	0.044444444	0.01247614
DUM25	0	0	0.08503693	0.000299465	0	0.100058093
DUM26	0.000106952	0.088888889	0.181249827	0.000262032	0.088888889	0.20664472
DUM27	0	0.022222222	0.226092008	0	0.022222222	0.228664693

Table 3.16 Min-Max normalized data for input indicators(2019-2020)

DUM	2019			2020		
	X1	X2	X3	X1	X2	X3
DUM1	0.004772727	0.4	0.706686215	0.000935829	0.688888889	0.700932253
DUM2	0.001735294	0.2	0.901131428	0.003518717	0.666666667	0.931616366
DUM3	0.001930481	0.066666667	0.877368669	0.013467914	0.333333333	0.957260228
DUM4	0.000951872	0.244444444	0.757365349	0.002181818	0.577777778	0.795540679
DUM5	0.006090909	0.288888889	0.888295665	0.012537433	0.6	0.87308086
DUM6	0.057740642	0.111111111	0.445600155	0.002617647	1	0.447481258
DUM7	0.001336898	0.422222222	0.903150848	8.02139E-05	0.955555556	0.895294476
DUM8	0.00026738	0.155555556	0.6425074	1.3369E-05	0.466666667	0.682259537
DUM9	0.611796791	0.311111111	0.715621456	1	0.733333333	0.720932806
DUM10	0.000406417	0.266666667	0.505463498	0.000409091	0.4	0.519848405
DUM11	0	0	0.326343744	0.000106952	0.666666667	0.316938228
DUM12	2.6738E-05	0.022222222	0.352291903	3.47594E-05	0.311111111	0.350825749
DUM13	0	0.022222222	0.190434037	0.00013369	0.377777778	0.208249191

DUM	2019			2020		
	X1	X2	X3	X1	X2	X3
DUM14	0	0.044444444	0.362471991	8.02139E-05	0.488888889	0.376192979
DUM15	0.001925134	0.088888889	0.420426568	0.013938503	0.377777778	0.467869097
DUM16	0.00026738	0.044444444	0.261528673	0.00026738	0.288888889	0.286591607
DUM17	0	0	0.096600183	0	0.288888889	0.104428892
DUM18	0	0.044444444	0.395695593	0	0.244444444	0.394699715
DUM19	0	0.066666667	0.377797449	0.00013369	0.444444444	0.386511383
DUM20	8.28877E-05	0.044444444	0.37552906	0.000112299	0.4	0.386843343
DUM21	0	0.111111111	0.109518936	0	0.111111111	0.124512435
DUM22	1.3369E-05	0.088888889	0.302304351	2.6738E-05	0.444444444	0.331157155
DUM23	0	0.044444444	0.112478907	0	0.311111111	0.110265844
DUM24	0	0.044444444	0.012061191	0	0.6	0.012863426
DUM25	0.000347594	0	0.105646076	0.000481283	0.2	0.121026861
DUM26	0.000173797	0.155555556	0.252372126	0	0.311111111	0.304351434
DUM27	0	0.022222222	0.217184431	0	0.6	0.195358101

Table 3.17 Min-Max normalized data for input indicators(2021)

DUM	2021		
	X1	X2	X3
DUM1	0.332518717	0.688888889	0.697142383
DUM2	0.005601604	0.666666667	0.918642286
DUM3	0.018427807	0.333333333	1
DUM4	0.00792246	0.577777778	0.777725525
DUM5	0.01868984	0.6	0.877645301
DUM6	0.004037433	1	0.444659603
DUM7	0.000280749	0.955555556	0.920910675
DUM8	0.000299465	0.466666667	0.699853385
DUM9	0.95228877	0.733333333	0.727046391
DUM10	0.001497326	0.4	0.480594207
DUM11	7.48663E-05	0.666666667	0.329995297
DUM12	5.34759E-05	0.311111111	0.334947025
DUM13	2.6738E-06	0.377777778	0.22349166
DUM14	0	0.488888889	0.372984038
DUM15	0.01697861	0.377777778	0.506929652
DUM16	0.000320856	0.288888889	0.340535008
DUM17	0	0.288888889	0.114304683
DUM18	0.009141711	0.244444444	0.358322499
DUM19	0.00013369	0.444444444	0.398489585
DUM20	0.000251337	0.4	0.33204238

DUM	2021		
	X1	X2	X3
DUM21	0	0.111111111	0.099919776
DUM22	7.48663E-05	0.444444444	0.335113005
DUM23	0	0.311111111	0.111731998
DUM24	0	0.6	0
DUM25	4.54545E-05	0.2	0.137182218
DUM26	0.000195187	0.311111111	0.356220089
DUM27	0	0.6	0.185454646

Table 3.18 Min-Max normalized data for output indicators(20187-2022)

DUM	Year	Y1	Y2	Y3	Y4
DUM1	2018	0.549883663	0.764769497	1	0.963269054
DUM2		0.410841846	0.265348555	0.670892019	0.347107438
DUM3		0.370802423	0.341308517	0.743661972	0.320477502
DUM4		0.436064054	0.685474341	0.721596244	0.640955005
DUM5		0.675811597	0.402236924	0.671361502	0.929292929
DUM6		0.330392828	0.396864534	0.43943662	0.633608815
DUM7		0.641136604	0.677701478	0.820187793	0.5087236
DUM8		0.315345441	0.445497135	0.738028169	0.259871442
DUM9		0.593199986	0.588171658	0.766197183	0.851239669
DUM10		0.265653553	0.368224341	0.44600939	0.261707989
DUM11		0.240302556	0.207330004	0.391079812	0.532598714
DUM12		0.189111351	0.189182792	0.296713615	0.212121212
DUM13		0.102885704	0.047216469	0.164319249	0.172635445
DUM14		0.100989677	0.145317348	0.198591549	0.069788797
DUM15		0.119101772	0.12361444	0.194835681	0.052341598
DUM16		0.038011954	0.05890212	0.211267606	0.07805326
DUM17		0.026929548	0.099909325	0.058685446	0.001836547
DUM18		0.09986064	0.181685273	0.268075117	0.052341598
DUM19		0.129364276	0.36156526	0.338028169	0.073461892
DUM20		0.123261506	0.111166312	0.385446009	0.107438017
DUM21		0	0.305727413	0.015023474	0.029384757
DUM22		0.096479214	0.152450092	0.143192488	0.082644628
DUM23		0.074227587	0.076343162	0.179342723	0.085399449
DUM24		0.017137842	0.071251738	0.020657277	0.005509642
DUM25		0.058101475	0.042384325	0.007981221	0.085399449
DUM26		0.075308477	0.164920636	0.127699531	0.045913682

DUM	Year	Y1	Y2	Y3	Y4
DUM27		0.163442824	0.235469562	0.360093897	0.056932966
DUM1		0.664731845	0.79211688	0.769953052	0.972451791
DUM2		0.444349078	0.287244959	0.648356808	0.397612489
DUM3		0.385696434	0.411411851	0.718779343	0.22405877
DUM4		0.591255271	0.722178207	0.731455399	0.610651974
DUM5		0.737746394	0.564656313	0.698122066	0.886134068
DUM6		0.464264426	0.421406092	0.430046948	0.645546373
DUM7		0.609280712	0.700393517	0.812676056	0.528007346
DUM8		0.438181426	0.480351681	0.761971831	0.259871442
DUM9		0.646229377	0.608346121	0.74741784	0.836547291
DUM10		0.302592361	0.375556101	0.441314554	0.251606979
DUM11		0.291085788	0.245622678	0.399530516	0.550045914
DUM12		0.19076659	0.203075189	0.291079812	0.174471993
DUM13		0.098841111	0.056975176	0.12629108	0.144168962
DUM14	2019	0.12420256	0.15978102	0.215962441	0.056932966
DUM15		0.116323832	0.135502701	0.257746479	0.037649219
DUM16		0.076172952	0.118874222	0.222065728	0.078971534
DUM17		0.052579932	0.106690596	0.066666667	0
DUM18		0.150465961	0.195725702	0.266197183	0.034894399
DUM19		0.140906973	0.383946003	0.344131455	0.068870523
DUM20		0.150977324	0.120012615	0.362910798	0.09825528
DUM21		0.028164573	0.310508074	0.008920188	0.03030303
DUM22		0.107375154	0.200803723	0.171361502	0.072543618
DUM23		0.109567318	0.081395774	0.186384977	0.08815427
DUM24		0.01879411	0.071041945	0.041784038	0.007346189
DUM25		0.142115786	0.137612498	0.005164319	0.1184573
DUM26		0.10893697	0.174150838	0.129577465	0.055096419
DUM27		0.188564135	0.240842949	0.350704225	0.050505051
DUM1		0.816622168	0.805012662	0.736619718	0.888888889
DUM2		0.490363511	0.29346001	0.610328638	0.415977961
DUM3		0.516617922	0.418538308	0.655868545	0.243342516
DUM4		0.624158042	0.753337506	0.732394366	0.525252525
DUM5		0.869646198	0.598499944	0.692957746	0.822773186
DUM6	2020	0.494017786	0.447817789	0.406103286	0.727272727
DUM7		0.590217436	0.720087466	0.839906103	0.486685032
DUM8		0.624013115	0.514030884	0.664788732	0.295684114
DUM9		0.79085112	0.676596742	0.72629108	0.860422406
DUM10		0.342203392	0.497820227	0.425352113	0.280073462
DUM11		0.356629475	0.384619647	0.433802817	0.629017447
DUM12		0.219604837	0.232297765	0.277464789	0.213039486

DUM	Year	Y1	Y2	Y3	Y4
DUM13		0.161181066	0.066928909	0.130046948	0.136822773
DUM14		0.191999394	0.165877506	0.21314554	0.063360882
DUM15		0.169650607	0.145584677	0.245539906	0.048668503
DUM16		0.115499218	0.12471758	0.1342723	0.051423324
DUM17		0.1182764	0.108422448	0.050704225	0.001836547
DUM18		0.194377159	0.203510737	0.254929577	0.054178145
DUM19		0.180199229	0.377201914	0.35399061	0.063360882
DUM20		0.193710037	0.144101763	0.220657277	0.10835629
DUM21		0.035977824	0.316676131	0.007981221	0.03030303
DUM22		0.106461829	0.203023838	0.172769953	0.071625344
DUM23		0.148883565	0.084286141	0.176056338	0.090909091
DUM24		0.060314653	0.080798092	0.050704225	0.016528926
DUM25		0.182995853	0.151872564	0	0.101010101
DUM26		0.131000939	0.183386062	0.11971831	0.073461892
DUM27		0.199114707	0.247440037	0.348826291	0.07805326
DUM1		0.738127614	0.515230106	0.743661972	0.870523416
DUM2		0.515115735	0.320376167	0.592018779	0.379247016
DUM3		0.424747089	0.293506472	0.664319249	0.233241506
DUM4		0.660987613	0.425547298	0.73943662	0.573002755
DUM5		0.870686687	0.702331237	0.737089202	0.732782369
DUM6		0.386538378	0.375491248	0.397652582	0.709825528
DUM7		0.635220951	0.513733589	0.862910798	0.487603306
DUM8		0.450423631	0.251260334	0.662910798	0.252525253
DUM9		0.853800681	0.475469916	0.707042254	0.858585859
DUM10		0.361677188	0.304300173	0.435680751	0.217630854
DUM11		0.443371467	0.206897282	0.442723005	0.175390266
DUM12		0.216031583	0.082633443	0.272300469	0.269054178
DUM13	2021	0.151134762	0.460621414	0.124413146	0.146923783
DUM14		0.428792549	0.179593369	0.66713615	0.089990817
DUM15		0.338704443	0.083405132	0.269953052	0.072543618
DUM16		0.114708562	0.117697848	0.15258216	0.059687787
DUM17		0.311994399	0.236171742	0.304694836	0
DUM18		0.201165085	0.131925387	0.25915493	0.043158861
DUM19		0.182652002	0.213643466	0.354929577	0.052341598
DUM20		0.256566392	0.022993424	0.261502347	0.093663912
DUM21		0.069280175	0.170617791	0.028169014	0.022038567
DUM22		0.110560689	0.147171191	0.256338028	0.06795225
DUM23		0.182936767	0.075147997	0.192957746	0.094582185
DUM24		0.081865256	0	0.054929577	0.012855831

DUM	Year	Y1	Y2	Y3	Y4
DUM25		0.248102809	0.153566402	0.014084507	0.066115702
DUM26		0.133158821	0.157927477	0.115962441	0.061524334
DUM27		0.240148205	0.136694906	0.358215962	0.084481175
DUM1		0.826448861	0.893178965	0.755868545	0.852157943
DUM2		0.657713367	0.51575645	0.584976526	0.33241506
DUM3		0.602533675	0.533566557	0.677464789	0.231404959
DUM4		0.661359193	0.849002425	0.750234742	0.531680441
DUM5		0.892230412	1	0.735680751	0.635445363
DUM6		0.518243104	0.626045512	0.409859155	0.787878788
DUM7		0.86308617	0.772242837	0.877464789	0.460055096
DUM8		0.514099292	0.560009883	0.676995305	0.209366391
DUM9		1	0.744711172	0.715492958	1
DUM10		0.407297675	0.549130941	0.441314554	0.255280073
DUM11		0.416047051	0.489344353	0.452112676	0.472910927
DUM12		0.235450842	0.290687777	0.281690141	0.269972452
DUM13		0.201366175	0.111784482	0.124882629	0.191000918
DUM14	2022	0.243086562	0.178340268	0.261971831	0.049586777
DUM15		0.381494294	0.196078471	0.266666667	0.062442608
DUM16		0.141122632	0.133579282	0.163380282	0.03030303
DUM17		0.128857192	0.129942802	0.044600939	0.003673095
DUM18		0.246783405	0.304154502	0.280751174	0.04040404
DUM19		0.218444767	0.391404842	0.342253521	0.051423324
DUM20		0.249910991	0.16898445	0.289671362	0.072543618
DUM21		0.064467238	0.344090428	0.027230047	0.01010101
DUM22		0.151809574	0.227254599	0.272769953	0.050505051
DUM23		0.516622905	0.091746676	0.207511737	0.113865932
DUM24		0.082809885	0.133449143	0.049765258	0.011019284
DUM25		0.186250494	0.190904201	0.018779343	0.077134986
DUM26		0.147806791	0.239695343	0.112676056	0.064279155
DUM27		0.270023367	0.260384476	0.377464789	0.08815427

The normalized results can better reflect the relative magnitudes of different indicators within the overall dataset, ensuring comparability among them. This processed data can be utilized for subsequent DEA efficiency analysis to evaluate the comprehensive efficiency and relative performance of each university across multiple indicators.

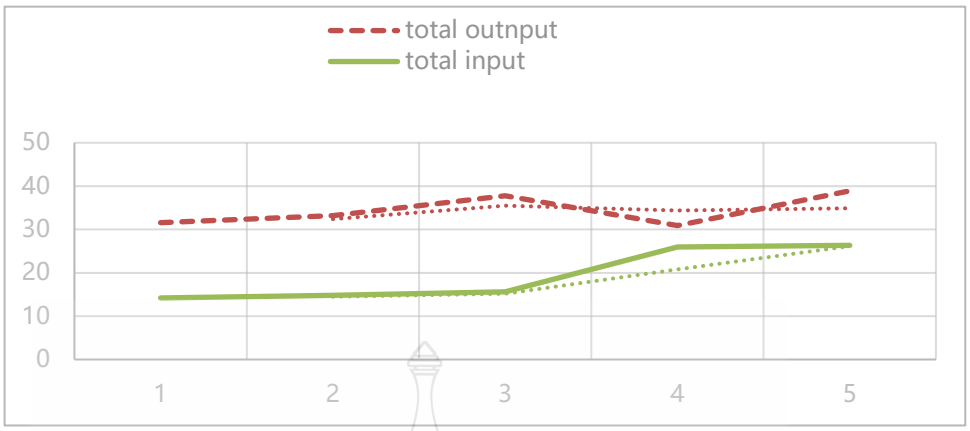

Figure 3.3 Input-output change trend(2018-2022)

The aggregated normalized input-output data over the past five years for public undergraduate universities in Sichuan Province shows a general upward trend in both inputs and outputs. However, in the year 2021, there was a divergence between input and output trends, mainly due to the impact of the COVID-19 pandemic. Interestingly, the education output exhibited a declining trend, which is an exceptional phenomenon in this context.

3.6 Statistical analysis

In this study, the process of indicator selection, data collection, and data cleaning, as described in Sections 3.2 to 3.4, was conducted to prepare the data for analysis. The DEA-BCC model and the Malmquist index framework will be employed to conduct data analysis on the 27 public undergraduate universities in Sichuan Province. The subsequent section presents the details of the statistical analysis process.

3.6.1 DEA-BCC Analysis

In this study, the data analysis was performed using the DEAP2.1 software. Firstly, we define and interpret the output results obtained from the DEAP2.1 software.

Table 3.19 DEAP2.1 Symbols Meaning1

Symbols	Meaning	Symbols	Meaning
firm	number of samples	crste	Comprehensive efficiency
vrste	Technical efficiency	scale	Scale efficiency
irs	Increasing returns to scale	drs	Decreasing returns to scale
---	Constant returns to scale		

The BCC model allows for the analysis of variable returns to scale, capturing the relative efficiency of DMUs under varying scale efficiencies.

Crste represents comprehensive efficiency, which is technical efficiency without considering scale returns.

Vrste represents technical efficiency, taking into account scale returns.

Scale refers to the change in output when all inputs are simultaneously increased by a factor. If the increase in output is exactly proportional to the increase in inputs, it is called constant returns to scale (---). If the increase in output is greater than the increase in inputs, it is called increasing returns to scale (irs). Conversely, if the increase in output is less than the increase in inputs, it is called decreasing returns to scale (drs). A DMU is an entity that undergoes efficiency evaluation, representing an entity that transforms certain "inputs" into certain "outputs."

DEA (Data Envelopment Analysis) strong disposability efficiency refers to the condition where any reduction in the quantity of one input cannot occur without reducing the quantity of output or increasing the quantity of at least one other input. Similarly, any increase in the quantity of one output cannot occur without increasing the quantity of input or reducing the quantity of at least one other output.

DEA weak disposability efficiency refers to the condition where proportional reductions in all inputs are not possible without reducing the quantity of output. Similarly, proportional increases in all outputs are impossible without increasing the

input quantity. However, partial reductions in one or more inputs (but not all) may be possible, leading to the term "weak efficiency."

These concepts and analyses form the basis of the DEA model, enabling the evaluation and comparison of the relative efficiency of different decision-making units under varying scale efficiencies.

Step 1: Preparation of Cross-Sectional Data for 27 Universities for the Years 2018-2022.

DUM	Y1	Y2	Y3	Y4	X1	X2	X3
DUM1	30,538	12	530.00	1,061	2,557	254,099.87	116,044.75
DUM2	35,050	5	105.00	390	1,856	103,934.91	90,371.51
.....	.....						
DUM27	38,443	10	154.60	1,024	1,857	145,094.25	139,296.59
.....							

Step 2: Set up the BCC Model Running Parameters.

Table 3.20 BCC model running parameters

123.dta	DATA FILE NAME
222.out	OUTPUT FILE NAME
27	NUMBER OF FIRMS
1	NUMBER OF TIME PERIODS
3	NUMBER OF OUTPUTS
4	NUMBER OF INPUTS
0	0=INPUT AND 1=OUTPUT ORIENTATED
1	0=CRS AND 1=VRS
3	0=DEA(MULTI-STAGE),1=COST-DEA,2=MALMQUIST-DEA, 3=DEA(1-STAGE), 4=DEA(2-STAGE)

Step 3: Observe the Running Results.

(1) EFFICIENCY SUMMARY:

The four columns represent firm sample order; crste, the comprehensive efficiency considering technical efficiency without scale effect; vrste, the pure technical efficiency considering scale effect; scale, the scale efficiency considering returns to scale (IRS, ---, DRS). Pure technical efficiency and scale efficiency are subcategories of comprehensive efficiency. The last column contains IRS, ---, DRS, representing increasing, constant, and decreasing returns to scale, respectively.

(2) SUMMARY OF OUTPUT SLACKS, SUMMARY OF INPUT SLACKS:

These indicate the values of slack variables for output and input indicators, respectively, representing the surplus values (s) in the original model.

(3) SUMMARY OF PEERS:

It shows the non-DEA efficient units projected relative to DEA efficient units. It is followed by corresponding weights, SUMMARY OF PEER WEIGHTS.

(4) SUMMARY OF OUTPUT TARGETS, SUMMARY OF INPUT TARGETS:

These are the target values for each unit, representing the values to achieve efficiency. For DEA efficient units, they are the original values.

(5) FIRM BY FIRM RESULTS:

This section provides detailed results for each decision-making unit (DMU).

Original value: Represents the original values.

Radial movement: Indicates the slack variable values for input indicators, i.e., input redundancies.

Slack movement: Indicates the slack variable values for output indicators, i.e., output shortfalls.

Projected value: Represents the target value to achieve DEA efficiency.

DEAP2.1 calculates efficiency scores for each DMU, represented by values ranging from 0 to 1, where 1 indicates total efficiency, and 0 indicates complete inefficiency.

Input and output weights: DEAP2.1 provides the weights for each indicator (input and output) used in the efficiency score calculation.

Optimal weights: DEAP2.1 also gives the range of optimal weights that can lead each DMU to achieve a 100% efficiency score.

Relative efficiency ranking: DEAP2.1 may provide the relative efficiency ranking among DMUs, indicating which DMUs are more efficient.

3.6.2 Malmquist Analyze

The Malmquist Productivity Index is employed to analyze the changes in productivity between two periods (the latter period compared to the former period, represented as the ratio of the two periods' productivity). Hence, it can be applied to assess the variations in technical efficiency (EC - efficiency change) and technological advancement (TC - technological change) during the period from 2018 to 2022 for the public undergraduate universities in Sichuan province. In the context of DEA analysis, this index reflects the shifts in the production frontier, indicating how the efficiency and technology of these universities have evolved over the specified period.

Table 3.21 DEAP2.1 Symbols Meaning 2

Symbols	Meaning	Symbols	Meaning
firm	number of samples	sech	Scale efficiency Index
effch	Comprehensive efficiency index	tfpch	Technological Progress Index
techch	Technological Progress Index	sech	scale efficiency index
pech	Pure Technical Efficiency Index		

Step 1: Prepare time-series data for input and output indicators of 27 public undergraduate universities from 2018 to 2022.

YEAR DUM Y1 Y2 Y3 Y4 X1 X2 X3

2018 DUM1 30,538 12 530.00 1,061 2,557 254,099.87 116,044.75

2018 DUM2 35,050 5 105.00 390 1,856 103,934.91 90,371.51

2018 ....

2018 DUM27 13,133 2 0.00 74 1,194 94,950.95

44,690.76

....

2022 DUM1 20,157 6 442.60 702 1,363 143,478.89 75,517.08

2022 ....

2022 DUM27 11,664 28 0.00 108 1,231 102,442.32 64,370.22

Step 2: Set up the Malnquist Model Running Parameters.

Table 3.22 Malnquist model running parameters

123.dta	DATA FILE NAME
555.out	OUTPUT FILE NAME
27	NUMBER OF FIRMS
5	NUMBER OF TIME PERIODS
3	NUMBER OF OUTPUTS
4	NUMBER OF INPUTS
0	0=INPUT AND 1=OUTPUT ORIENTATED
1	0=CRS AND 1=VRS
2	0=DEA(MULTI-STAGE),1=COST-DEA,2=MALMQUIST-DEA,3=DEA(1-STAGE), 4=DEA(2-STAGE)

Step 3: Observe the running results, which will display the following computation results:

Results from DEAP Version 2.1

Instruction file = 123.ins

Data file = 123.dta

Input orientated Malmquist DEA

DISTANCES SUMMARY

[Note that t-1 in year 1 and t+1 in the final year are not defined]

MALMQUIST INDEX SUMMARY

MALMQUIST INDEX SUMMARY OF ANNUAL MEANS

year	*effch*	*techch*	*pech*	*sech*	*tfpch*
2	*1.079*	*9.518*	*1.028*	*1.050*	*10.272*
3	*0.986*	*0.069*	*0.991*	*0.996*	*0.068*
4	*0.901*	*5.312*	*0.911*	*0.989*	*4.785*
5	*1.100*********		*1.104*	*0.996*********	
mean	*1.013*	*20.354*	*1.006*	*1.007*	*20.626*

.....

In the Malmquist productivity index analysis, we use TFPCH (Total Factor Productivity Change) to measure the change in total factor productivity. When TFPCH is greater than 1, it indicates an improvement in relative efficiency, suggesting an overall increase in productivity. When TFPCH equals 1, it indicates no change in relative efficiency, implying that productivity remains stable compared to the previous period. On the other hand, when TFPCH is less than 1, it indicates a decline in relative efficiency, suggesting a decrease in overall productivity.

The criteria for the other four decomposition indicators (EC, TC, SECH, EFFCH) are similar to TFPCH. For the EC indicator, when it is greater than 1, it signifies an improvement in technical efficiency. When EC equals 1, it indicates no change in technical efficiency; when EC is less than 1, it suggests a decrease in technical efficiency. Similarly, TC greater than 1 represents technological progress, TC equal to 1 represents technological stagnation, and TC less than 1 represents technological regression. For the SECH and EFFCH indicators, greater than 1 indicates an improvement in the corresponding efficiency measures, equal to 1 suggests no change and less than 1 implies a decline in efficiency measures.

By computing and comparing these decomposition indicators, we can gain comprehensive insights into the efficiency changes of each decision-making unit over the two periods, assess their technological progress, and provide valuable information for decision-makers. These results are essential for evaluating the overall performance of universities, optimizing resource allocation, enhancing education quality, and promoting the sustainable development of the entire education system.

CHAPTER 4
RESEARCH RESULT

This chapter reports the descriptive analysis of the responses from the experts and focuses on measuring the efficiency of public undergraduate universities in Sichuan Province to identify existing "inefficiencies" in input-output efficiency and analyze their specific causes. Furthermore, it aims to offer policy recommendations to decision-makers. Building upon the theoretical foundation of quasi-public goods efficiency evaluation, this paper will employ the DEA-BCC model to analyze cross-sectional data of public undergraduate universities in Sichuan Province The findings are presented as follows:

4.1 Data from DEA-BCC Analysis

4.2 Descriptive Statistics of Variables

4.3 Preliminary Analysis

4.1 Data from DEA-BCC Analysis

4.1.1 DEA-BCC Demographic Data

Input the well-organized data from Chapter 3 into DEAP2.1 and perform calculations according to the preset parameters. The results are as follows.

Table 4.1 BCC Operation Rresult(2021-2022)

firm	2022				2021			
	crste	vrste	scale	trend	crste	vrste	scale	trend
DUM1	1	1	1	-	0.871	1	0.871	drs
DUM2	1	1	1	-	1	1	1	-
DUM3	1	1	1	-	1	1	1	-
DUM4	0.966	1	0.966	drs	1	1	1	-
DUM5	1	1	1	-	0.947	1	0.947	irs
DUM6	1	1	1	-	1	1	1	-
DUM7	0.906	1	0.906	drs	0.849	1	0.849	drs
DUM8	0.941	1	0.941	irs	0.891	1	0.891	irs
DUM9	1	1	1	-	1	1	1	-
DUM10	0.788	1	0.788	irs	0.912	1	0.912	irs
DUM11	1	1	1	-	1	1	1	-
DUM12	0.966	1	0.966	irs	0.81	1	0.81	irs

firm	2022				2021			
	crste	vrste	scale	trend	crste	vrste	scale	trend
DUM13	0.06	0.098	0.616	irs	0.247	0.247	0.999	-
DUM14	0.135	0.181	0.747	drs	0.976	1	0.976	irs
DUM15	0.081	0.09	0.897	irs	1	1	1	-
DUM16	0.11	0.12	0.913	irs	0.677	0.686	0.988	irs
DUM17	0.078	0.187	0.419	irs	1	1	1	-
DUM18	1	1	1	-	1	1	1	-
DUM19	1	1	1	-	1	1	1	-
DUM20	1	1	1	-	0.711	1	0.711	drs
DUM21	0.392	0.57	0.688	drs	0.654	0.717	0.912	irs
DUM22	1	1	1	-	0.683	1	0.683	drs
DUM23	0.275	1	0.275	drs	0.648	0.957	0.677	drs
DUM24	0.607	1	0.607	drs	1	1	1	-
DUM25	0.353	0.464	0.76	drs	0.373	0.481	0.775	irs
DUM26	0.296	0.549	0.54	drs	0.726	1	0.726	drs
DUM27	1	1	1	-	1	1	1	-

Table 4.2 BCC Operation Rresult(2019-2020)

firm	2020				2019			
	crste	vrste	scale	trend	crste	vrste	scale	trend
DUM1	1	1	1	-	1	1	1	-
DUM2	1	1	1	-	1	1	1	-
DUM3	1	1	1	-	1	1	1	-
DUM4	0.948	1	0.948	irs	0.992	1	0.992	irs
DUM5	1	1	1	-	1	1	1	-
DUM6	0.909	1	0.909	irs	0.879	1	0.879	irs
DUM7	1	1	1	-	1	1	1	-
DUM8	0.901	1	0.901	irs	1	1	1	-
DUM9	1	1	1	-	1	1	1	-
DUM10	1	1	1	-	1	1	1	-
DUM11	0.943	1	0.943	irs	0.753	1	0.753	irs
DUM12	1	1	1	-	1	1	1	-
DUM13	1	1	1	-	0.04	0.097	0.416	irs
DUM14	0.869	0.89	0.976	irs	0.047	0.077	0.614	irs
DUM15	1	1	1	-	0.07	0.071	0.977	irs
DUM16	0.959	0.962	0.998	irs	0.045	0.076	0.594	irs
DUM17	1	1	1	-	0.073	0.124	0.586	irs
DUM18	0.896	0.932	0.961	drs	0.065	0.07	0.931	irs
DUM19	1	1	1	-	1	1	1	-

firm	2020				2019			
	crste	vrste	scale	trend	crste	vrste	scale	trend
DUM20	0.915	0.964	0.949	drs	1	1	1	-
DUM21	1	1	1	-	0.1	0.146	0.688	irs
DUM22	1	1	1	-	0.099	1	0.099	drs
DUM23	0.648	0.845	0.767	irs	0.028	0.083	0.34	irs
DUM24	1	1	1	-	0.065	0.134	0.482	irs
DUM25	0.962	0.972	0.99	irs	0.104	0.145	0.719	irs
DUM26	1	1	1	-	0.049	0.096	0.508	irs
DUM27	1	1	1	-	1	1	1	-

Table 4.3 BCC Operation Rresult(2018)

firm	2018			
	crste	vrste	scale	trend
DUM1	1	1	1	-
DUM2	1	1	1	-
DUM3	1	1	1	-
DUM4	1	1	1	-
DUM5	1	1	1	-
DUM6	0.869	1	0.869	irs
DUM7	1	1	1	-
DUM8	1	1	1	-
DUM9	1	1	1	-
DUM10	1	1	1	-
DUM11	0.796	1	0.796	irs
DUM12	1	1	1	-
DUM13	0.009	0.03	0.29	irs
DUM14	0.02	0.028	0.702	irs
DUM15	0.06	1	0.06	drs
DUM16	0.02	0.027	0.745	irs
DUM17	0.118	1	0.118	drs
DUM18	0.039	0.414	0.094	drs
DUM19	1	1	1	-
DUM20	1	1	1	-
DUM21	0.031	0.051	0.604	irs
DUM22	0.063	0.86	0.073	drs
DUM23	0.027	0.029	0.902	irs
DUM24	0.048	0.056	0.872	irs
DUM25	0.011	0.053	0.212	irs
DUM26	0.039	0.068	0.574	drs
DUM27	0.93	1	0.93	irs

Based on the data above, we averaged the efficiency performance for 2018-2022 and obtained the average efficiency of 27 public undergraduate universities in Sichuan Province during that period. The results are shown in the table below.

Table 4.4 Average Efficiency of 27 university(2018-2022）

firm	crste	vrste	scale
DUM1	0.96775	1	0.96775
DUM2	1	1	1
DUM3	1	1	1
DUM4	0.9916	1	0.9916
DUM5	0.979	1	0.979
DUM6	0.9496	1	0.9496
DUM7	0.9328	1	0.9328
DUM8	0.9664	1	0.9664
DUM9	0.9802	1	0.9802
DUM10	0.94	1	0.94
DUM11	0.9098	1	0.9098
DUM12	0.9438	1	0.9438
DUM13	0.2712	0.2944	0.6642
DUM14	0.4356	0.4572	0.8078
DUM15	0.416	0.6102	0.782
DUM16	0.3704	0.3818	0.848
DUM17	0.4456	0.6546	0.6242
DUM18	0.6208	0.6968	0.805
DUM19	0.9792	0.9864	0.9922
DUM20	0.9422	1	0.9422
DUM21	0.4184	0.4896	0.7682
DUM22	0.569	0.972	0.571
DUM23	0.3956	0.6138	0.6388
DUM24	0.4736	0.607	0.7456
DUM25	0.3682	0.4286	0.6932
DUM26	0.4144	0.537	0.6676
DUM27	0.986	1	0.986

Based on the table above, we can create an efficiency distribution chart for the 27 universities.

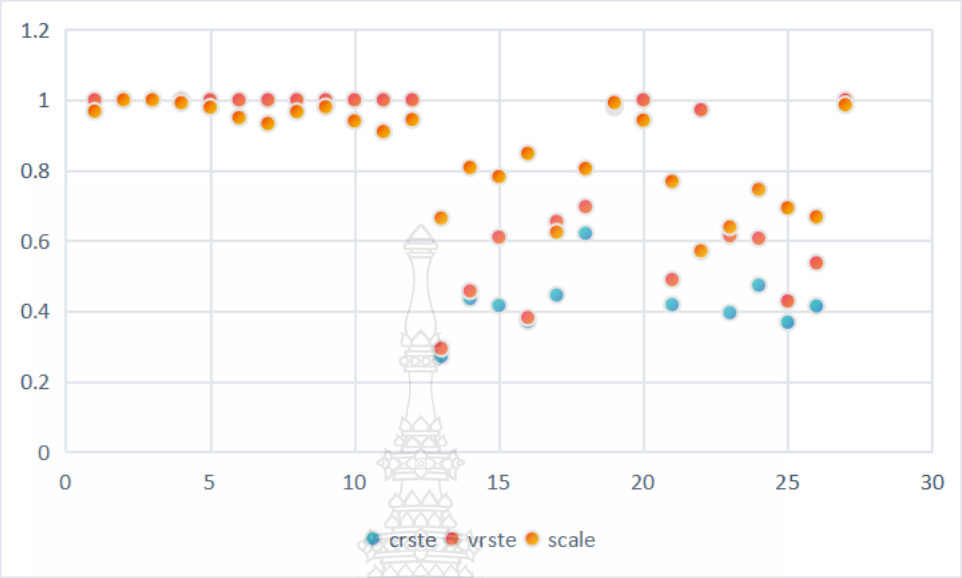

Figure 4.1 Efficiency Distribution Map of 27 University

This data reveals the current status and variations in efficiency among public undergraduate universities in Sichuan Province. University administrators can use these results to focus on improving and enhancing low-efficiency indicators, optimize the allocation of educational resources, and enhance the overall performance of the universities. Additionally, policymakers can use these findings to formulate more targeted policies, promoting the continuous development and optimization of the entire education system. Furthermore, the dynamic unbalanced panel data method employed in this study provides a new perspective and approach for educational efficiency research, offering valuable insights into understanding the complex relationship between educational inputs and outputs.

4.1.2 Malmquist Demographic data

The well-organized data from Chapter 3 was input into DEAP2.1, and the calculations were performed according to the preset parameters. The results are as follows.

Table 4.5 Malmquist Analyze of 27 university(2018-2020)

DUM	2018-2019					2019-2020				
	effch	**techch**	**pech**	**sech**	**tfpch**	**effch**	**techch**	**pech**	**sech**	**tfpch**
DUM1	1.000	1.095	1.000	1.000	1.095	1.000	0.118	1.000	1.000	0.118
DUM2	1.000	1.068	1.000	1.000	1.068	1.000	1.127	1.000	1.000	1.127
DUM3	1.000	0.436	1.000	1.000	0.436	1.000	1.056	1.000	1.000	1.056
DUM4	0.992	1.020	1.000	0.992	1.012	0.956	1.190	1.000	0.956	1.137
DUM5	1.000	0.612	1.000	1.000	0.612	1.000	1.040	1.000	1.000	1.040
DUM6	1.011	1.090	1.000	1.011	1.102	1.034	1.016	1.000	1.034	1.050
DUM7	1.000	0.973	1.000	1.000	0.973	1.000	1.221	1.000	1.000	1.221
DUM8	1.000	1.131	1.000	1.000	1.131	0.901	0.815	1.000	0.901	0.734
DUM9	1.000	1.857	1.000	1.000	1.857	1.000	0.256	1.000	1.000	0.256
DUM10	1.000	0.949	1.000	1.000	0.949	1.000	1.150	1.000	1.000	1.150
DUM11	0.946	1.040	1.000	0.946	0.984	1.253	0.933	1.000	1.253	1.169
DUM12	1.000	0.814	1.000	1.000	0.814	1.000	2.609	1.000	1.000	2.609
DUM13	4.563	0.422	3.186	1.432	1.925	24.779	0.079	10.298	2.406	1.953
DUM14	2.413	0.523	2.762	0.873	1.261	18.308	0.045	11.506	1.591	0.829
DUM15	1.150	0.662	0.071	16.156	0.761	14.387	0.045	14.052	1.024	0.642
DUM16	2.228	0.424	2.792	0.798	0.944	21.235	0.042	12.646	1.679	0.893
DUM17	0.614	0.843	0.124	4.953	0.517	13.783	0.034	8.073	1.707	0.467
DUM18	1.657	0.665	0.168	9.853	1.102	13.833	0.053	13.398	1.032	0.731
DUM19	1.000	0.983	1.000	1.000	0.983	1.000	0.866	1.000	1.000	0.866
DUM20	1.000	1.110	1.000	1.000	1.110	0.915	0.185	0.964	0.949	0.169
DUM21	3.228	0.532	2.838	1.137	1.717	9.965	0.127	6.852	1.454	1.264
DUM22	1.569	0.664	1.163	1.349	1.042	10.143	0.090	1.000	10.143	0.908
DUM23	1.060	0.593	2.810	0.377	0.629	22.996	0.036	10.207	2.253	0.830
DUM24	1.337	0.713	2.418	0.553	0.954	15.441	0.056	7.444	2.074	0.859
DUM25	9.231	0.428	2.721	3.392	3.955	9.260	0.150	6.722	1.378	1.385
DUM26	1.252	0.666	1.412	0.886	0.834	20.410	0.060	10.378	1.967	1.226
DUM27	1.076	1.036	1.000	1.076	1.114	1.000	1.079	1.000	1.000	1.079

Table 4.6 Malmquist Analyze of 27 university (2020-2022)

DUM	2020-2021					2021-2022				
	effch	**techch**	**pech**	**sech**	**tfpch**	**effch**	**techch**	**pech**	**sech**	**tfpch**
DUM1	0.871	6.162	1.000	0.871	5.369	1.148	1.713	1.000	1.148	1.966
DUM2	1.000	1.519	1.000	1.000	1.519	1.000	0.953	1.000	1.000	0.953
DUM3	1.000	1.260	1.000	1.000	1.260	1.000	0.939	1.000	1.000	0.939
DUM4	1.054	11.912	1.000	1.054	12.559	0.966	0.260	1.000	0.966	0.251
DUM5	0.947	1.337	1.000	0.947	1.266	1.057	0.994	1.000	1.057	1.051
DUM6	1.100	2.111	1.000	1.100	2.322	1.000	0.969	1.000	1.000	0.969
DUM7	0.849	1.804	1.000	0.849	1.531	1.067	0.941	1.000	1.067	1.005
DUM8	0.989	1.652	1.000	0.989	1.633	1.056	0.953	1.000	1.056	1.006
DUM9	1.000	1.211	1.000	1.000	1.211	1.000	12.285	1.000	1.000	12.285
DUM10	0.912	1.639	1.000	0.912	1.494	0.864	0.942	1.000	0.864	0.814
DUM11	1.060	2.018	1.000	1.060	2.141	1.000	1.058	1.000	1.000	1.058
DUM12	0.810	5.457	1.000	0.810	4.421	1.192	0.491	1.000	1.192	0.585
DUM13	0.247	3.685	0.247	0.999	0.909	0.244	3.030	0.396	0.616	0.739
DUM14	1.124	2.345	1.124	1.000	2.635	0.139	2.535	0.181	0.765	0.351
DUM15	1.000	9.621	1.000	1.000	9.621	0.081	1.026	0.090	0.897	0.083
DUM16	0.706	2.241	0.713	0.990	1.582	0.162	7.895	0.175	0.924	1.277
DUM17	1.000	4.582	1.000	1.000	4.582	0.078	1.787	0.187	0.419	0.140
DUM18	1.116	1.554	1.073	1.041	1.734	1.000	4.150	1.000	1.000	4.150
DUM19	1.000	2.593	1.000	1.000	2.593	1.000	0.932	1.000	1.000	0.932
DUM20	0.778	3.873	1.037	0.750	3.013	1.406	1.601	1.000	1.406	2.251
DUM21	0.654	1.812	0.717	0.912	1.185	0.600	1.852	0.795	0.754	1.111
DUM22	0.683	2.956	1.000	0.683	2.019	1.464	1.965	1.000	1.464	2.877
DUM23	1.001	3.315	1.134	0.883	3.319	0.425	2.225	1.044	0.407	0.945
DUM24	1.000	4.552	1.000	1.000	4.552	0.607	2.864	1.000	0.607	1.738
DUM25	0.388	3.024	0.495	0.783	1.173	0.946	2.103	0.965	0.980	1.988
DUM26	0.726	2.629	1.000	0.726	1.909	0.408	2.164	0.549	0.743	0.883
DUM27	1.000	2.573	1.000	1.000	2.573	1.000	1.035	1.000	1.000	1.035

These Malmquist analysis results indicate that most universities have improved productivity over the past year. This is an essential reference for university administrators and policymakers as it helps them better understand the performance of each university. They can use this information to develop targeted measures to enhance efficiency and performance.

4.2 Descriptive Statistics of Variables

We used the BCC mean and Malmquist index analysis results for descriptive statistics.

4.2.1 Frequency Analysis

(1) Frequency Analysis of BCC Mean Scores The data was divided into four groups based on '(maximum value - minimum value)/4'; the results are shown in Table 4.7.

Table 4.7 Frequency Analysis Results

Name	Option Frequency	Frequency	Percentage(%)	Cumulative Percentage (%)
crste	[0.271,0.453)	9	33.333	33.333
	[0.453,0.636)	3	11.111	44.444
	[0.818,1.0]	15	55.556	100
vrste	[0.294,0.471)	4	14.815	14.815
	[0.471,0.647)	5	18.519	33.333
	[0.647,0.824)	2	7.407	40.741
	[0.824,1.0]	16	59.259	100
scale	[0.571,0.678)	5	18.519	18.519
	[0.678,0.785)	4	14.815	33.333
	[0.785,0.893)	3	11.111	44.444
	[0.893,1.0]	15	55.556	100
Total		27	100.000	100.000

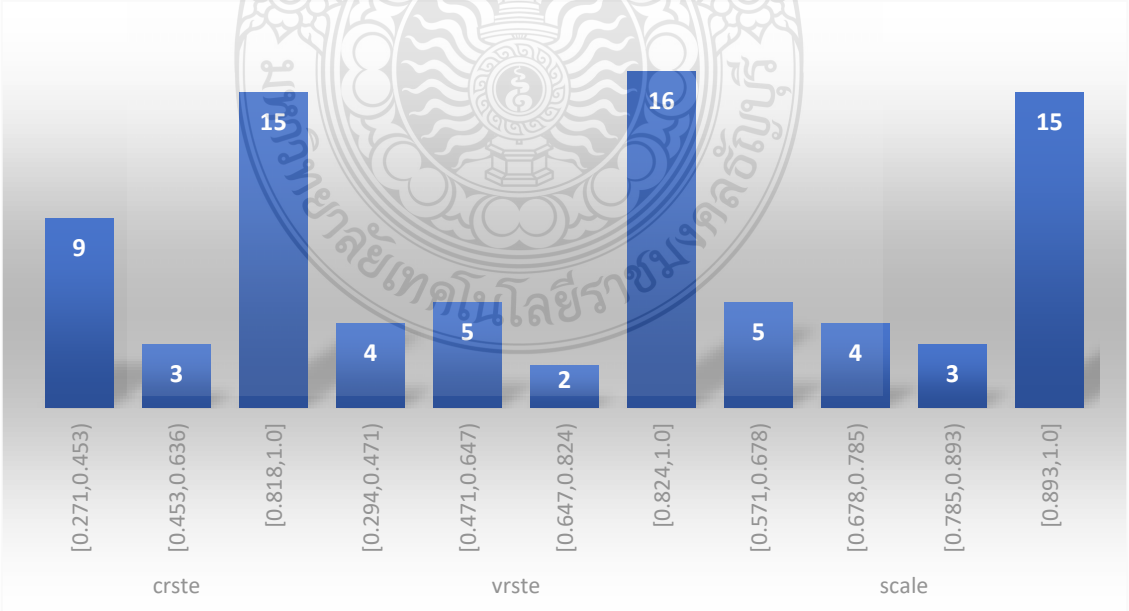

Figure 4.2 Frequency Analysis Results

（2）Variable Descriptive Analysis

Descriptive statistics are generated based on data summarization to provide an overall descriptive analysis of various statistical indicators of the population. It involves analyzing exceptional or prominently displayed indicators.

Table 4.8 Overall Descriptive Results.

Variable	Sample	Maximum	Minimum	Mean andard	Deviation	Median	Variance	Kurtosis	Skewness	Coefficient of Variation (CV)
crste	27	1	0.271	0.728	0.276	0.933	0.076	-1.829	-0.357	0.379
vrste	27	1	0.294	0.805	0.249	1	0.062	-1.161	-0.715	0.31
scale	27	1	0.571	0.855	0.139	0.933	0.019	-1.028	-0.662	0.162

Output 2: Scatter Plot

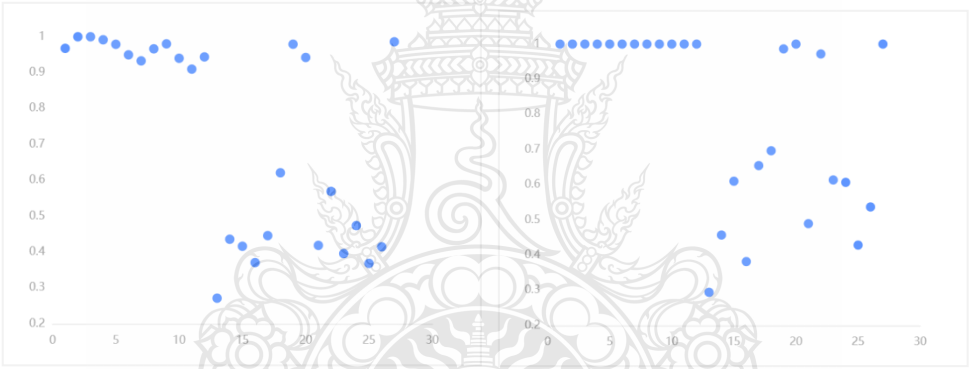

Figure 4.3 Crste Scatter Plot

Figure4.4 vrste Scatter Plot

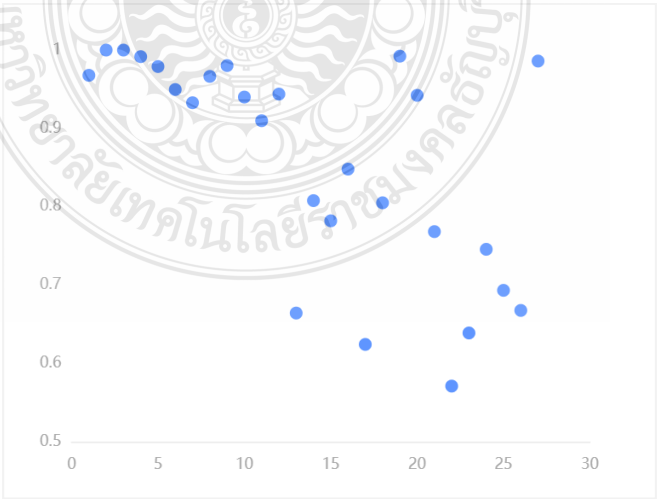

Figure 4.5 Scale Scatter Plot

Based on the coefficient of variation (CV) of 0.379 for crste, vrste, and scale, which is greater than 0.15, there may be outliers in the current data. The next step should involve analyzing the exceptional or prominently displayed indicators.

Table 4.9 overall description of the results

Variable	Sample	Maximum	Minimum	Mean	Standard Deviation		Median	Variance	Kurtosis	Skewness
crste	27	1	0.271	0.728	0.276	0.933	0.076	-1.829	-0.357	0.379
vrste	27	1	0.294	0.805	0.249	1	0.062	-1.161	-0.715	0.31
scale	27	1	0.571	0.855	0.139	0.933	0.019	-1.028	-0.662	0.162

4.3 Preliminary Analysis

4.3.1 Analysis of DEA Measurement Results

Crste Analysis: The average comprehensive efficiency score of the sampled universities is 0.728412963. The data indicates that although only two universities have a score of 1, the majority of the universities have comprehensive efficiency values close to 1, suggesting that these universities have achieved high overall performance with minimal efficiency losses when considering all input and output indicators. However, a few universities with slightly lower comprehensive efficiency values, such as DUM13, DUM15, DUM16, DUM17, and DUM21, may imply that these institutions have some degree of efficiency loss and require further optimization of resource allocation and management.

Vrste Analysis: The technical efficiency indicator evaluates the pure technical efficiency performance of universities when considering scale returns. The average score for the sampled universities is 0.855442593, with 12 universities obtaining a score of 1, indicating total efficiency. Some universities have technical efficiency values close to 1, suggesting that these institutions have achieved high technical efficiency performance without significant waste under scale return conditions. This also indicates a significant relationship between scale and efficiency in Sichuan Province's universities. However, there are a few universities with technical efficiency values slightly below 1, such as DUM13, DUM14, DUM16, DUM21, and DUM25, which implies some technical efficiency losses under scale return conditions, necessitating further optimization of production processes and resource utilization.

Scale Analysis: The scale efficiency indicator evaluates the performance of universities under scale return conditions. The data shows that the majority of universities have scale efficiency values close to 1, with an average value of 0.804792593, indicating that these institutions have achieved high performance under scale return conditions with minimal scale efficiency losses. There are no universities with scale efficiency below 0.5 in the entire sample, which indicates a relatively stable scale efficiency among the sampled universities. The average efficiency scores for technical efficiency and pure technical efficiency are 0.804792593 and 0.855442593, respectively. Overall, the differences in various indicators over the period from 2018 to 2022 remain relatively small, suggesting that the sampled universities' efficiency based on the selected measures has remained stable during this period.

From an annual perspective, after averaging various efficiency indicators, we observe the overall efficiency of universities in Sichuan Province. The data is as follows:

Table 4.10 Overall efficiency of 27 University

year	efficiency	score
	crste	0.702
2022	vrste	0.78737037
	scale	0.852925926
	crste	0.850925926
2021	vrste	0.929185185
	scale	0.915814815
	crste	0.961111111
2020	vrste	0.983888889
	scale	0.97562963
	crste	0.570703704
2019	vrste	0.634037037
	scale	0.799185185
	crste	0.558518519
2018	vrste	0.689481481
	scale	0.734851852

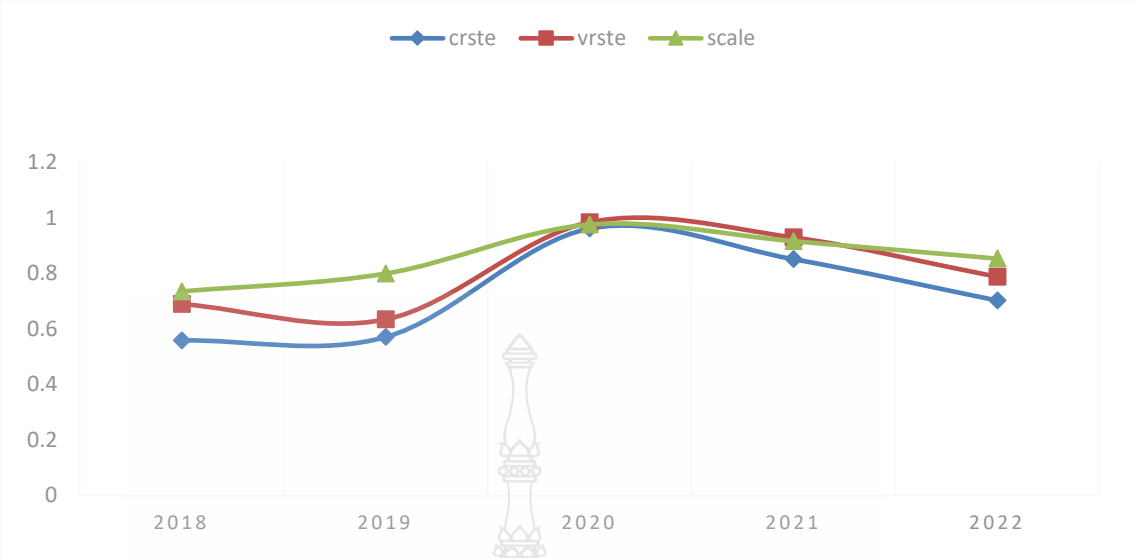

Figure 4.6 Annual average efficiency

From the data, shows that the efficiency scores vary across the years and different types of efficiency. In 2020, the universities achieved relatively high efficiency scores in all three categories, with comprehensive efficiency reaching 0.961, technical efficiency with scale returns reaching 0.984, and scale efficiency reaching 0.976. This indicates that in 2020, the universities performed well in converting inputs to outputs and efficiently utilizing their resources.

However, in 2018 and 2019, the universities' efficiency scores were relatively lower, with comprehensive efficiency at 0.559 and 0.571 and technical efficiency with scale returns at 0.689 and 0.634, respectively. These scores suggest that there might have been inefficiencies in resource allocation and utilization during those years, resulting in suboptimal performance.

4.3.2 Analysis of Malmquist Measurement Results

Wise data for each indicator, it is observed that Technological Change Efficiency (TECHCH) reached its lowest level in efficiency from 2018 to 2022, indicating significant room for improvement and enhancement in technological progress for the sampled universities. The change rate of Pure Technical Efficiency (PECH) is also decreasing year by year, indicating a specific deficiency in the management level and policy implementation efficiency of the universities.

By averaging the analysis rBased on the DEA-Malmquist index calculations (as shown in Table 4-3), the average Total Factor Productivity Change (TFPCH) for the sampled universities from 2018 to 2022 is 0.9949, indicating a decreasing trend in the average growth rate. The change rate of Technical Efficiency (EFFCH) is 1, implying that it is not the primary factor influencing the Change in Total Factor Productivity. The average growth rates of Technological Change Efficiency (TECHCH) and Pure Technical Efficiency (PECH) are 0.9929 and 1.007, respectively, showing a declining trend. The average efficiency value of Scale Efficiency (SECH) from 2010 to 2016 is 1.0012, indicating a slightly decreasing trend overall.

Analyzing the year-esults annually, we can observe the overall efficiency changes in public undergraduate universities in Sichuan Province, as shown in the table below:

Table 4.11 Malmquist overall efficiency

	2018-2019	2019-2020	2020-2021	20210-2022
effch	1.678777778	7.762925926	0.889444444	0.811481481
techch	0.827740741	0.573259259	3.312481481	2.209703704
pech	1.387592593	4.723703704	0.945925926	0.828962963
sech	2.103111111	1.622259259	0.939222222	0.938222222
tfpch	1.143740741	0.991407407	2.967592593	1.606740741

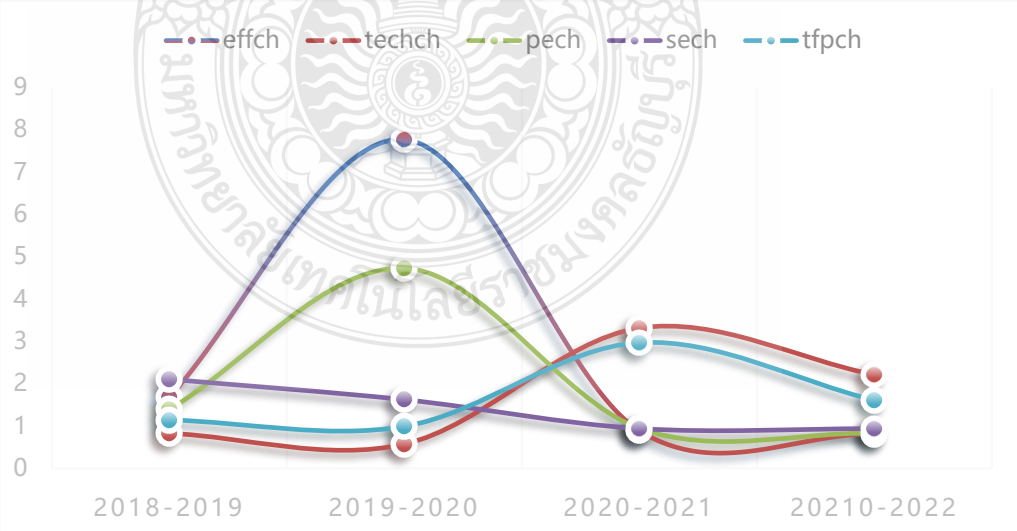

Figure 4.7 Malmquist Annual average efficiency

The Malmquist analysis results show the changes in efficiency and productivity of the public general undergraduate universities in Sichuan Province over four consecutive periods from 2018 to 2022. The analysis is based on the average values of the efficiency change (effch), technical change (techch), pure efficiency change (pech), scale efficiency change (sech), and total factor productivity change (tfpch) for the group of universities represented by "DUM."

Efficiency Change (effch):

Efficiency change measures the overall Change in efficiency from one period to another. A value greater than 1 indicates an improvement in efficiency, while a value less than 1 indicates a decline. In this analysis, we observe significant fluctuations in efficiency change. For example, in 2018-2019, there was a remarkable increase in efficiency (1.68 times), but in 2020-2021 and 2021-2022, the efficiency changes were relatively small (0.89 and 0.81, respectively), suggesting stability or slight fluctuations in overall efficiency during those periods.

Technical Change (techch):

Technical Change refers to the Change in technology or production methods over time. A value greater than 1 indicates technological progress, while a value less than 1 suggests a technological decrease. The results show fluctuations in technical Change, with significant improvements in 2019-2020 (0.57 times) and 2020-2021 (3.31 times) but a relatively smaller increase in 2021-2022 (2.21 times).

Pure Efficiency Change (pech):

Pure efficiency change focuses on changes in productive efficiency, excluding the impact of changes in technology. Similar to overall efficiency change, there are fluctuations in pure efficiency change, with notable improvements in 2018-2019 (1.39 times) and 2019-2020 (4.72 times).

Scale Efficiency Change (sech):

Scale efficiency change represents the Change in efficiency due to the Change in the scale of production. Fluctuations in scale efficiency are observed, with significant improvements in 2018-2019 (2.10 times) and 2019-2020 (1.62 times).

Total Factor Productivity Change (tfpch):

Total factor productivity change is a comprehensive measure of efficiency

change, taking into account both technological and pure efficiency changes. The results indicate fluctuations in total factor productivity change, with substantial improvements in 2018-2019 (1.14 times) and 2020-2021 (2.97 times).

CHAPTER 5
CONCLUSION, DISCUSSION AND RECOMMENDATIONS

In this study, the efficiency of public undergraduate colleges and universities in Sichuan Province from 2018 to 2022 is measured using DEA and Malmqust index. Chapter 4 presents the research results, and this chapter provides a summary of the conclusions drawn and suggestions for improving the efficiency of public undergraduate colleges and universities in Sichuan Province as follows:.

5.1 Discussion and Recommendation

5.2 Implications for practice and future research

5.1 Discussion and Recommendation

The study conducted efficiency analysis on 27 public undergraduate colleges and universities in Sichuan Province for the years 2018-2022 using the DEA method, considering unbalanced panel data to reveal the characteristics of delayed effects in education input. The Malmquist index was used to decompose the total factor productivity of these universities over the 5-year period. The following conclusions and recommendations were drawn from the study:

1）There is significant room for improvement in the efficiency of public undergraduate colleges and universities in Sichuan Province.

The research showed that external factors, such as economic development, have an impact on educational performance. Higher economic development levels are conducive to reducing slack variables in faculty, input funds, and campus area, thus enhancing educational efficiency. Education levels of residents also play a role in affecting faculty slack variables, but the impact on input funds and campus area is not significant. The DEA analysis results indicated that the average pure technical efficiency and scale efficiency of the 27 universities were 0.805 and 0.88, respectively, with an average overall efficiency of 0.728. Although the overall operation was stable, there is still a significant gap compared to other regions in China. Therefore, there is considerable

room for improving the efficiency of public undergraduate colleges and universities in Sichuan Province, as supported by findings from other studies conducted in different regions.

2）There exists an asymmetry between the allocation efficiency of educational resources and the development levels of public undergraduate colleges and universities in Sichuan Province.

Despite significant differences in development foundations, actual levels, and overall scale among different universities, the efficiency of resource allocation does not show proportionate changes. This suggests that more attention should be paid to both the quantity and efficiency of input and output for different universities. Universities with lower outputs should analyze their needs in detail and increase investment accordingly. This phenomenon aligns with the findings from studies at the provincial level, where economically developed provinces have an advantage in resource investment and lead in high-quality, connotative development of higher education compared to provinces with insufficient education funding, resulting in insufficient and unbalanced development in regional higher education.

3）Universities located in the provincial capital, Chengdu, do not show significant efficiency advantages.

Among the 27 universities, 13 are located in Chengdu, while the remaining 14 are located outside of Chengdu. DEA analysis results indicate that the average technical efficiency, pure technical efficiency, and scale efficiency of universities in Chengdu are 0.750, 0.834, and 0.844, respectively, while those outside of Chengdu are 0.686, 0.760, and 0.856, respectively. While universities in the provincial capital should theoretically show higher efficiency due to better resources and environment, the results reveal that these universities have not fully matched their outputs with the optimal scale of resources, suggesting room for improvement in management to avoid resource waste.

4) The overall efficiency of public undergraduate colleges and universities in

Sichuan Province has improved significantly over the past five years

With a Malmquist index average result of 1.6773. However, certain individual universities experienced non-efficiency progress. Two universities, Sichuan University of Science & Engineering and Sichuan Agricultural University, showed Malmquist index results below 1, indicating inefficiency progress. Interestingly, in cross-sectional data analysis, these two universities demonstrated higher efficiency. These universities are large-scale institutions in Sichuan Province, but their efficiency progress needs further attention and research.

5.2 Implications for practice and future research

1) Strengthen and improve the guiding policies of local governments, insisting on government leadership in conjunction with social forces to continuously enhance the efficiency of public undergraduate universities in Sichuan Province.

2) Address the imbalanced status of provincial universities and further study policies of classification guidance and support, developing targeted and differentiated educational investment policies.

3) Focus on Sichuan Province's education planning and output situation, providing theoretical support for the formulation of a more scientific and reasonable assessment system for universities.

The research provides valuable implications for the practice of higher education management in Sichuan Province. It suggests avenues for future research in educational resource allocation and efficiency improvement in the region.

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APPENDICES

APPENDIX A

- List of experts review research instruments
- Invitation letter to experts to examine research instruments

List of experts reviewing research instruments

Content Specialists

1. Prof. Qian wang.
   Sichuan Academy of Social Sciences
2. Prof. Yijun Ye
   GuiZhou university
3. Prof. Zixi Chen
   Sichuan university of science and engineering

Media Specialists

1. Prof. Chuanjiang Yu
   Sichuan university
2. Prof. Lilong He
   Sichuan university
3. Prof. Chuanjiang Yu
   Sichuan university

Assessment Specialists

1. Asst.Prof.Direk Akkahart
   Bansomdejchaopraya Rajabhat University
2. Asst.Prof,Dr.Nattakorn Papan
   Chandrakasem Rajabhat University
3. Minghua Lin
   Xiangtan university

MHESI 0962.36/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof. Qian wang.
Sichuan Academy of Social Sciences

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

If you have any questions or need further information, please feel free to contact Mr.Zhipei Xu, on the e-mail: zhipei_x@mail.rmutt.ac.th

Yours sincerely,

(Assistant Professor Arnon Niyomphol)
Dean of Faculty of Technical Education

MHESI 0962.37/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof. Yijun Ye
GuiZhou university

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

If you have any questions or need further information, please feel free to contact Mr.Zhipei Xu, on the e-mail: zhipei_x@mail.rmutt.ac.th

Yours sincerely,

(Assistant Professor Arnon Niyomphol)
Dean of Faculty of Technical Education

MHESI 0962.38/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof. Zixi Chen
Sichuan university of science and engineering

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

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Yours sincerely,

(Assistant Professor Arnon Niyomphol)
Dean of Faculty of Technical Education

MHESI 0962.41/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof. Chuanjiang Yu
Sichuan university

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

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Yours sincerely,

(Assistant Professor Arnon Niyomphol)
Dean of Faculty of Technical Education

MHESI 0962.43/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof. Lilong He
Sichuan university

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

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Dean of Faculty of Technical Education

MHESI 0962.41/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof. Chuanjiang Yu
Sichuan university

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

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Yours sincerely,

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Dean of Faculty of Technical Education

MHESI 0962.39/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Asst.Prof.Direk Akkahart
Bansomdejchaopraya Rajabhat University

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

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Yours sincerely,

(Assistant Professor Arnon Niyomphol)
Dean of Faculty of Technical Education

MHESI 0962.40/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Asst.Prof,Dr.Nattakorn Papan
Chandrakasem Rajabhat University

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

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Yours sincerely,

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Dean of Faculty of Technical Education

MHESI 0962.44/2023

Office of the Dean, Faculty of Technical Education
Rajamangala University of Technology Thanyaburi
Klong Luang, Pathum Thani 12110 Thailand
Tel:+66-2-549-4710 Fax:+66-2-577-5049

27 July, 2023

Dear Prof.Minghua Lin
Xiangtan university

Subject: Respectfully requesting a letter of invitation of experts for Ph.D. Dissertation

I am writing to request your assistance as an honorary external research reviewer in evaluating the research instruments of Mr.Zhipei Xu, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled "Measuring efficiency of public higher education using DEA model for Sichuan in China". under the supervision of Assistant Professor Dr. Tiamyod Pasawano. In this regard, I would like to request your valuable time to evaluate the research instruments as I strongly believe that your expertise will be of great value in improving the research instruments.

If you have any questions or need further information, please feel free to contact Mr.Zhipei Xu, on the e-mail: zhipei_x@mail.rmutt.ac.th

Yours sincerely,

(Assistant Professor Arnon Niyomphol)
Dean of Faculty of Technical Education

APPENDIX B

DEAP2.1 Software running result（BCC)

Results from DEAP Version 2.1 (BCC 2018)

Instruction file = 123.ins Data file = 123.dta

Input orientated DEA Scale assumption: VRS

Single-stage DEA - residual slacks presented

EFFICIENCY SUMMARY:

firm	crste	vrste	scale		firm	crste	vrste	scale	
1	0.368	1.000	0.368	drs	15	0.518	0.885	0.585	drs
2	0.412	1.000	0.412	drs	16	0.383	1.000	0.383	drs
3	0.355	0.997	0.356	drs	17	0.472	0.658	0.717	drs
4	0.338	1.000	0.338	drs	18	0.443	0.949	0.467	drs
5	0.437	1.000	0.437	drs	19	0.370	0.807	0.458	drs
6	0.504	1.000	0.504	drs	20	0.349	0.979	0.356	drs
7	0.323	0.793	0.408	drs	21	1.000	1.000	1.000	-
8	0.318	0.962	0.330	drs	22	0.432	0.728	0.594	drs
9	0.385	0.907	0.424	drs	23	0.246	0.536	0.459	drs
10	0.344	0.795	0.433	drs	24	0.177	0.661	0.268	irs
11	0.506	1.000	0.506	drs	25	1.000	1.000	1.000	-
12	0.352	0.777	0.453	drs	26	0.475	0.753	0.631	drs
13	0.388	0.851	0.456	drs	27	0.222	0.382	0.581	drs
14	0.589	1.000	0.589	drs					
mean	0.434	0.867	0.501						

Note: crste = technical efficiency from CRS DEA

vrste = technical efficiency from VRS DEA

scale = scale efficiency = crste/vrste

Note also that all subsequent tables refer to VRS results

SUMMARY OF OUTPUT SLACKS:

firm	output:	1	2
1		0.000	0.000
2		0.000	0.000
3		0.000	0.000
4		0.000	0.000
5		0.000	0.000
6		0.000	0.000
7		0.000	0.070
8		0.000	0.000
9		0.040	0.000
10		0.000	0.000
11		0.000	0.000
12		0.000	0.000
13		0.000	0.000
14		0.000	0.000
15		0.000	0.020
16		0.000	0.000
17		0.000	0.037
18		0.000	0.018
19		0.000	0.000
20		0.000	0.000
21		0.000	0.000
22		0.000	0.000
23		0.000	0.000
24		0.033	0.035
25		0.000	0.000
26		0.000	0.013
27		0.000	0.000
mean		0.003	0.007

SUMMARY OF INPUT SLACKS:

firm	input:	1	2
1		0.000	0.000
2		0.000	0.000
3		0.133	0.000
4		0.000	0.000
5		0.000	0.000
6		0.000	0.000
7		0.000	0.000
8		0.202	0.000
9		0.000	0.000
10		0.000	0.000
11		0.000	0.000
12		0.000	0.000
13		0.000	0.000
14		0.000	0.000
15		0.000	0.010
16		0.000	0.000
17		0.000	0.000
18		0.055	0.000
19		0.069	0.000
20		0.144	0.000
21		0.000	0.000
22		0.000	0.000
23		0.000	0.000
24		0.000	0.000
25		0.000	0.000
26		0.000	0.000
27		0.000	0.000
mean		0.022	0.000

SUMMARY OF PEERS:

firm	peers:
1	1
2	2
3	2 4 14
4	4
5	5
6	6
7	2 14 5
8	14 2 4
9	1 5 6
10	4 11 5 14
11	11
12	25 14 5 11
13	21 11 14 25
14	14
15	14 25
16	16
17	14 25 21
18	14 16
19	14 2 4
20	14 4 16
21	21
22	14 11 25 21
23	14 16 11 21
24	21 25
25	25
26	14 21 25
27	14 16 11 21

SUMMARY OF PEER WEIGHTS:

(in same order as above)

firm peer weights:

1 1.000
2 1.000
3 0.826 0.038 0.136
4 1.000
5 1.000
6 1.000
7 0.537 0.044 0.419
8 0.350 0.617 0.033
9 0.281 0.423 0.296
10 0.252 0.037 0.036 0.675
11 1.000
12 0.158 0.569 0.034 0.240
13 0.409 0.252 0.170 0.169
14 1.000
15 0.863 0.137
16 1.000
17 0.131 0.076 0.792
18 0.902 0.098
19 0.989 0.009 0.002
20 0.899 0.065 0.036
21 1.000
22 0.425 0.036 0.322 0.217
23 0.139 0.112 0.089 0.660
24 0.805 0.195
25 1.000
26 0.450 0.355 0.195
27 0.589 0.071 0.001 0.339

PEER COUNT SUMMARY:

(i.e., no. times each firm is a peer for another)

firm	peer count:	firm	peer count:
1	1	15	0
2	4	16	4
3	0	17	0
4	5	18	0
5	4	19	0
6	1	20	0
7	0	21	7
8	0	22	0
9	0	23	0
10	0	24	0
11	6	25	7
12	0	26	0
13	0	27	0
14	15		

SUMMARY OF OUTPUT TARGETS:

firm	output:	1	2
1		0.708	0.963
2		0.832	0.347
3		0.762	0.320
4		0.733	0.641
5		0.926	0.929
6		0.420	0.634
7		0.850	0.579

8	0.657	0.260
9	0.715	0.851
10	0.459	0.262
11	0.335	0.533
12	0.317	0.212
13	0.171	0.173
14	0.339	0.070
15	0.304	0.072
16	0.204	0.078
17	0.079	0.039
18	0.325	0.071
19	0.344	0.073
20	0.360	0.107
21	0.035	0.029
22	0.191	0.083
23	0.123	0.085
24	0.045	0.040
25	0.085	0.085
26	0.181	0.058
27	0.226	0.057

SUMMARY OF INPUT TARGETS:

firm	input:	1	2
1		1.000	0.550
2		0.671	0.411
3		0.609	0.370
4		0.722	0.436
5		0.671	0.676
6		0.439	0.330

7	0.650	0.508
8	0.507	0.303
9	0.695	0.538
10	0.355	0.211
11	0.391	0.240
12	0.231	0.147
13	0.140	0.088
14	0.199	0.101
15	0.172	0.095
16	0.211	0.038
17	0.039	0.018
18	0.200	0.095
19	0.204	0.104
20	0.233	0.121
21	0.015	0.000
22	0.104	0.070
23	0.096	0.040
24	0.014	0.011
25	0.008	0.058
26	0.096	0.057
27	0.137	0.062

FIRM BY FIRM RESULTS:

Results for firm: 1

Technical efficiency = 1.000

Scale efficiency = 0.368 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.708	0.000	0.000	0.708
output	2	0.963	0.000	0.000	0.963
input	1	1.000	0.000	0.000	1.000
input	2	0.550	0.000	0.000	0.550

LISTING OF PEERS:

peer	lambda weight
1	1.000

Results for firm: 2

Technical efficiency = 1.000

Scale efficiency = 0.412 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.832	0.000	0.000	0.832
output	2	0.347	0.000	0.000	0.347
input	1	0.671	0.000	0.000	0.671
input	2	0.411	0.000	0.000	0.411

LISTING OF PEERS:

peer	lambda weight
2	1.000

Results for firm: 3

Technical efficiency = 0.997

Scale efficiency = 0.356 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.762	0.000	0.000	0.762
output	2	0.320	0.000	0.000	0.320
input	1	0.744	-0.002	-0.133	0.609
input	2	0.371	-0.001	0.000	0.370

LISTING OF PEERS:

peer	lambda weight
2	0.826
4	0.038
14	0.136

Results for firm: 4

Technical efficiency = 1.000

Scale efficiency = 0.338 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.733	0.000	0.000	0.733
output	2	0.641	0.000	0.000	0.641
input	1	0.722	0.000	0.000	0.722
input	2	0.436	0.000	0.000	0.436

LISTING OF PEERS:

peer	lambda weight
4	1.000

Results for firm: 5

Technical efficiency = 1.000

Scale efficiency = 0.437 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.926	0.000	0.000	0.926
output	2	0.929	0.000	0.000	0.929
input	1	0.671	0.000	0.000	0.671
input	2	0.676	0.000	0.000	0.676

LISTING OF PEERS:

peer	lambda weight
5	1.000

Results for firm: 6

Technical efficiency = 1.000

Scale efficiency = 0.504 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.420	0.000	0.000	0.420
output	2	0.634	0.000	0.000	0.634
input	1	0.439	0.000	0.000	0.439
input	2	0.330	0.000	0.000	0.330

LISTING OF PEERS:

peer	lambda weight
6	1.000

Results for firm: 7

Technical efficiency = 0.793

Scale efficiency = 0.408 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.850	0.000	0.000	0.850
output	2	0.509	0.000	0.070	0.579
input	1	0.820	-0.170	0.000	0.650
input	2	0.641	-0.133	0.000	0.508

LISTING OF PEERS:

peer	lambda weight
2	0.537
14	0.044
5	0.419

Results for firm: 8

Technical efficiency = 0.962

Scale efficiency = 0.330 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.657	0.000	0.000	0.657
output	2	0.260	0.000	0.000	0.260
input	1	0.738	-0.028	-0.202	0.507
input	2	0.315	-0.012	0.000	0.303

LISTING OF PEERS:

peer	lambda weight
14	0.350
2	0.617
4	0.033

Results for firm: 9

Technical efficiency = 0.907

Scale efficiency = 0.424 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.675	0.000	0.040	0.715
output	2	0.851	0.000	0.000	0.851
input	1	0.766	-0.071	0.000	0.695
input	2	0.593	-0.055	0.000	0.538

LISTING OF PEERS:

peer	lambda weight
1	0.281
5	0.423
6	0.296

Results for firm: 10

Technical efficiency = 0.795

Scale efficiency = 0.433 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.459	0.000	0.000	0.459
output	2	0.262	0.000	0.000	0.262
input	1	0.446	-0.091	0.000	0.355
input	2	0.266	-0.054	0.000	0.211

LISTING OF PEERS:

peer	lambda weight
4	0.252
11	0.037
5	0.036
14	0.675

Results for firm: 11

Technical efficiency = 1.000

Scale efficiency = 0.506 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.335	0.000	0.000	0.335
output	2	0.533	0.000	0.000	0.533
input	1	0.391	0.000	0.000	0.391
input	2	0.240	0.000	0.000	0.240

LISTING OF PEERS:

peer	lambda weight
11	1.000

Results for firm: 12

Technical efficiency = 0.777

Scale efficiency = 0.453 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.317	0.000	0.000	0.317
output	2	0.212	0.000	0.000	0.212
input	1	0.297	-0.066	0.000	0.231
input	2	0.189	-0.042	0.000	0.147

LISTING OF PEERS:

peer	lambda weight
25	0.158
14	0.569
5	0.034
11	0.240

Results for firm: 13

Technical efficiency = 0.851

Scale efficiency = 0.456 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.171	0.000	0.000	0.171
output	2	0.173	0.000	0.000	0.173
input	1	0.164	-0.024	0.000	0.140
input	2	0.103	-0.015	0.000	0.088

LISTING OF PEERS:

peer	lambda weight
21	0.409
11	0.252
14	0.170
25	0.169

Results for firm: 14

Technical efficiency = 1.000

Scale efficiency = 0.589 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.339	0.000	0.000	0.339
output	2	0.070	0.000	0.000	0.070
input	1	0.199	0.000	0.000	0.199
input	2	0.101	0.000	0.000	0.101

LISTING OF PEERS:

peer	lambda weight
14	1.000

Results for firm: 15

Technical efficiency = 0.885

Scale efficiency = 0.585 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.304	0.000	0.000	0.304
output	2	0.052	0.000	0.020	0.072
input	1	0.195	-0.022	0.000	0.172
input	2	0.119	-0.014	-0.010	0.095

LISTING OF PEERS:

peer	lambda weight
14	0.863
25	0.137

Results for firm: 16

Technical efficiency = 1.000

Scale efficiency = 0.383 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.204	0.000	0.000	0.204
output	2	0.078	0.000	0.000	0.078
input	1	0.211	0.000	0.000	0.211
input	2	0.038	0.000	0.000	0.038

LISTING OF PEERS:

peer	lambda weight
16	1.000

Results for firm: 17

Technical efficiency = 0.658

Scale efficiency = 0.717 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.079	0.000	0.000	0.079
output	2	0.002	0.000	0.037	0.039
input	1	0.059	-0.020	0.000	0.039
input	2	0.027	-0.009	0.000	0.018

LISTING OF PEERS:

peer	lambda weight
14	0.131
25	0.076
21	0.792

Results for firm: 18

Technical efficiency = 0.949

Scale efficiency = 0.467 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.325	0.000	0.000	0.325
output	2	0.052	0.000	0.018	0.071
input	1	0.268	-0.014	-0.055	0.200
input	2	0.100	-0.005	0.000	0.095

LISTING OF PEERS:

peer	lambda weight
14	0.902
16	0.098

Results for firm: 19

Technical efficiency = 0.807

Scale efficiency = 0.458 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.344	0.000	0.000	0.344
output	2	0.073	0.000	0.000	0.073
input	1	0.338	-0.065	-0.069	0.204
input	2	0.129	-0.025	0.000	0.104

LISTING OF PEERS:

peer	lambda weight
14	0.989
2	0.009
4	0.002

Results for firm: 20

Technical efficiency = 0.979

Scale efficiency = 0.356 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.360	0.000	0.000	0.360
output	2	0.107	0.000	0.000	0.107
input	1	0.385	-0.008	-0.144	0.233
input	2	0.123	-0.003	0.000	0.121

LISTING OF PEERS:

peer	lambda weight
14	0.899
4	0.065
16	0.036

Results for firm: 21

Technical efficiency = 1.000

Scale efficiency = 1.000 (crs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.035	0.000	0.000	0.035
output	2	0.029	0.000	0.000	0.029
input	1	0.015	0.000	0.000	0.015
input	2	0.000	0.000	0.000	0.000

LISTING OF PEERS:

peer	lambda weight
21	1.000

Results for firm: 22

Technical efficiency = 0.728

Scale efficiency = 0.594 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.191	0.000	0.000	0.191
output	2	0.083	0.000	0.000	0.083
input	1	0.143	-0.039	0.000	0.104
input	2	0.096	-0.026	0.000	0.070

LISTING OF PEERS:

peer	lambda weight
14	0.425
11	0.036
25	0.322
21	0.217

Results for firm: 23

Technical efficiency = 0.536

Scale efficiency = 0.459 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.123	0.000	0.000	0.123
output	2	0.085	0.000	0.000	0.085
input	1	0.179	-0.083	0.000	0.096
input	2	0.074	-0.034	0.000	0.040

LISTING OF PEERS:

peer	lambda weight
14	0.139
16	0.112
11	0.089
21	0.660

Results for firm: 24

Technical efficiency = 0.661

Scale efficiency = 0.268 (irs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.012	0.000	0.033	0.045
output	2	0.006	0.000	0.035	0.040
input	1	0.021	-0.007	0.000	0.014
input	2	0.017	-0.006	0.000	0.011

LISTING OF PEERS:

peer	lambda weight
21	0.805
25	0.195

Results for firm: 25

Technical efficiency = 1.000

Scale efficiency = 1.000 (crs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.085	0.000	0.000	0.085
output	2	0.085	0.000	0.000	0.085
input	1	0.008	0.000	0.000	0.008
input	2	0.058	0.000	0.000	0.058

LISTING OF PEERS:

peer	lambda weight
25	1.000

Results for firm: 26

Technical efficiency = 0.753

Scale efficiency = 0.631 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.181	0.000	0.000	0.181
output	2	0.046	0.000	0.013	0.058
input	1	0.128	-0.031	0.000	0.096
input	2	0.075	-0.019	0.000	0.057

LISTING OF PEERS:

peer	lambda weight
14	0.450
21	0.355
25	0.195

Results for firm: 27

Technical efficiency = 0.382

Scale efficiency = 0.581 (drs)

PROJECTION SUMMARY:

variable		original value	radial movement	slack movement	projected value
output	1	0.226	0.000	0.000	0.226
output	2	0.057	0.000	0.000	0.057
input	1	0.360	-0.223	0.000	0.137
input	2	0.163	-0.101	0.000	0.062

LISTING OF PEERS:

peer	lambda weight
14	0.589
16	0.071
11	0.001
21	0.339

APPENDIX C

DEAP2.1 Software running result（Malmquist)

Results from DEAP Version 2.1

Instruction file = 123.ins

Data file = 123.dta

Input orientated Malmquist DEA

DISTANCES SUMMARY

year = 1

firm	crs te rel to tech in yr			vrs
no.	**********			te
	t-1	t	t+1	
1	0.000	1.000	1.331	1.000
2	0.000	1.000	1.011	1.000
3	0.000	1.000	6.794	1.000
4	0.000	1.000	0.981	1.000
5	0.000	1.000	3.720	1.000
6	0.000	0.869	0.819	1.000
7	0.000	1.000	1.112	1.000
8	0.000	1.000	1.076	1.000
9	0.000	1.000	1.308	1.000
10	0.000	1.000	1.164	1.000
11	0.000	0.796	0.766	1.000
12	0.000	1.000	1.517	1.000
13	0.000	0.009	0.032	0.030
14	0.000	0.020	0.048	0.028
15	0.000	0.060	0.091	1.000
16	0.000	0.020	0.047	0.027
17	0.000	0.118	0.119	1.000
18	0.000	0.039	0.059	0.414

19	0.000	1.000	1.153	1.000
20	0.000	1.000	0.993	1.000
21	0.000	0.031	0.075	0.051
22	0.000	0.063	0.095	0.860
23	0.000	0.027	0.040	0.029
24	0.000	0.048	0.068	0.056
25	0.000	0.011	0.041	0.053
26	0.000	0.039	0.059	0.068
27	0.000	0.930	0.879	1.000
mean	0.000	0.559	0.941	0.690

year = 2

firm	crs te rel to tech in yr			vrs
no.	**********			te
	t-1	t	t+1	
1	1.597	1.000	128.119	1.000
2	1.154	1.000	0.949	1.000
3	1.290	1.000	1.047	1.000
4	1.012	0.992	0.838	1.000
5	1.394	1.000	1.225	1.000
6	0.984	0.879	0.872	1.000
7	1.053	1.000	0.992	1.000
8	1.377	1.000	1.628	1.000
9	4.512	1.000	45.785	1.000
10	1.048	1.000	0.958	1.000
11	0.785	0.753	0.709	1.000
12	1.004	1.000	1.040	1.000
13	0.026	0.040	0.635	0.097
14	0.031	0.047	1.257	0.077

15	0.046	0.070	1.710	0.071
16	0.019	0.045	1.250	0.076
17	0.052	0.073	4.375	0.124
18	0.043	0.065	1.176	0.070
19	1.114	1.000	1.723	1.000
20	1.223	1.000	1.545	1.000
21	0.068	0.100	1.009	0.146
22	0.066	0.099	1.100	1.000
23	0.015	0.028	0.862	0.083
24	0.046	0.065	1.251	0.134
25	0.069	0.104	0.692	0.145
26	0.033	0.049	0.915	0.096
27	1.015	1.000	0.873	1.000
mean	0.781	0.571	7.575	0.634

year = 3

firm no.	crs te rel to tech in yr ********** t-1	t	t+1	vrs te
1	1.772	1.000	0.793	1.000
2	1.206	1.000	0.967	1.000
3	1.168	1.000	1.034	1.000
4	1.134	0.948	0.821	1.000
5	1.326	1.000	0.949	1.000
6	0.930	0.909	0.768	1.000
7	1.479	1.000	0.783	1.000
8	0.974	0.901	0.718	1.000
9	2.994	1.000	1.487	1.000
10	1.266	1.000	0.788	1.000
11	0.773	0.943	0.829	1.000

12	7.083	1.000	0.799	1.000
13	0.098	1.000	0.450	1.000
14	0.047	0.869	0.729	0.890
15	0.049	1.000	0.977	1.000
16	0.047	0.959	0.683	0.962
17	0.069	1.000	1.112	1.000
18	0.045	0.896	0.817	0.932
19	1.291	1.000	0.917	1.000
20	0.048	0.915	0.509	0.964
21	0.162	1.000	0.658	1.000
22	0.090	1.000	0.576	1.000
23	0.026	0.648	0.303	0.845
24	0.060	1.000	0.586	1.000
25	0.143	0.962	0.455	0.972
26	0.067	1.000	0.512	1.000
27	1.016	1.000	0.874	1.000
mean	0.939	0.961	0.774	0.984

year = 4

firm	crs te rel to tech in yr			vrs
no.	**********			te
	t-1	t	t+1	
1	26.245	0.871	1.572	1.000
2	2.233	1.000	1.176	1.000
3	1.642	1.000	1.208	1.000
4	122.749	1.000	11.854	1.000
5	1.606	0.947	0.982	1.000
6	3.767	1.000	1.066	1.000
7	2.163	0.849	0.911	1.000
8	1.937	0.891	1.019	1.000
9	2.181	1.000	6.015	1.000

10	1.929	0.912	0.963	1.000
11	3.583	1.000	1.040	1.000
12	19.286	0.810	2.754	1.000
13	1.508	0.247	0.112	0.247
14	4.505	0.976	0.997	1.000
15	90.396	1.000	12.115	1.000
16	2.420	0.677	0.109	0.686
17	23.339	1.000	4.479	1.000
18	2.201	1.000	0.072	1.000
19	6.163	1.000	1.233	1.000
20	5.935	0.711	0.301	1.000
21	1.412	0.654	0.275	0.717
22	3.434	0.683	0.261	1.000
23	3.337	0.648	0.280	0.957
24	12.151	1.000	0.259	1.000
25	1.613	0.373	0.140	0.481
26	2.570	0.726	0.345	1.000
27	5.785	1.000	1.045	1.000
mean	13.188	0.851	1.948	0.929

year = 5

firm	crs te rel to tech in yr			vrs
no.	**********			te
	t-1	t	t+1	
1	5.292	1.000	0.000	1.000
2	1.068	1.000	0.000	1.000
3	1.065	1.000	0.000	1.000
4	0.776	0.966	0.000	1.000
5	1.026	1.000	0.000	1.000

6	1.000	1.000	0.000	1.000
7	0.861	0.906	0.000	1.000
8	0.977	0.941	0.000	1.000
9	907.755	1.000	0.000	1.000
10	0.738	0.788	0.000	1.000
11	1.165	1.000	0.000	1.000
12	0.791	0.966	0.000	1.000
13	0.252	0.060	0.000	0.098
14	0.888	0.135	0.000	0.181
15	1.031	0.081	0.000	0.090
16	1.100	0.110	0.000	0.120
17	1.118	0.078	0.000	0.187
18	1.248	1.000	0.000	1.000
19	1.072	1.000	0.000	1.000
20	1.086	1.000	0.000	1.000
21	0.567	0.392	0.000	0.570
22	1.472	1.000	0.000	1.000
23	0.588	0.275	0.000	1.000
24	1.291	0.607	0.000	1.000
25	0.587	0.353	0.000	0.464
26	0.659	0.296	0.000	0.549
27	1.121	1.000	0.000	1.000
mean	34.689	0.702	0.000	0.787

[Note that t-1 in year 1 and t+1 in the final year are not defined]

MALMQUIST INDEX SUMMARY

year = 2

firm	effch	techch	pech	sech	tfpch
1	1.000	1.095	1.000	1.000	1.095
2	1.000	1.068	1.000	1.000	1.068
3	1.000	0.436	1.000	1.000	0.436
4	0.992	1.020	1.000	0.992	1.012
5	1.000	0.612	1.000	1.000	0.612
6	1.011	1.090	1.000	1.011	1.102
7	1.000	0.973	1.000	1.000	0.973
8	1.000	1.131	1.000	1.000	1.131
9	1.000	1.857	1.000	1.000	1.857
10	1.000	0.949	1.000	1.000	0.949
11	0.946	1.040	1.000	0.946	0.984
12	1.000	0.814	1.000	1.000	0.814
13	4.563	0.422	3.186	1.432	1.925
14	2.413	0.523	2.762	0.873	1.261
15	1.150	0.662	0.071	16.156	0.761
16	2.228	0.424	2.792	0.798	0.944
17	0.614	0.843	0.124	4.953	0.517
18	1.657	0.665	0.168	9.853	1.102
19	1.000	0.983	1.000	1.000	0.983
20	1.000	1.110	1.000	1.000	1.110
21	3.228	0.532	2.838	1.137	1.717
22	1.569	0.664	1.163	1.349	1.042
23	1.060	0.593	2.810	0.377	0.629
24	1.337	0.713	2.418	0.553	0.954
25	9.231	0.428	2.721	3.392	3.955
26	1.252	0.666	1.412	0.886	0.834
27	1.076	1.036	1.000	1.076	1.114
mean	1.335	0.773	1.043	1.279	1.032

year = 3

firm	effch	techch	pech	sech	tfpch
1	1.000	0.118	1.000	1.000	0.118
2	1.000	1.127	1.000	1.000	1.127
3	1.000	1.056	1.000	1.000	1.056
4	0.956	1.190	1.000	0.956	1.137
5	1.000	1.040	1.000	1.000	1.040
6	1.034	1.016	1.000	1.034	1.050
7	1.000	1.221	1.000	1.000	1.221
8	0.901	0.815	1.000	0.901	0.734
9	1.000	0.256	1.000	1.000	0.256
10	1.000	1.150	1.000	1.000	1.150
11	1.253	0.933	1.000	1.253	1.169
12	1.000	2.609	1.000	1.000	2.609
13	24.779	0.079	10.298	2.406	1.953
14	18.308	0.045	11.506	1.591	0.829
15	14.387	0.045	14.052	1.024	0.642
16	21.235	0.042	12.646	1.679	0.893
17	13.783	0.034	8.073	1.707	0.467
18	13.833	0.053	13.398	1.032	0.731
19	1.000	0.866	1.000	1.000	0.866
20	0.915	0.185	0.964	0.949	0.169
21	9.965	0.127	6.852	1.454	1.264
22	10.143	0.090	1.000	10.143	0.908
23	22.996	0.036	10.207	2.253	0.830
24	15.441	0.056	7.444	2.074	0.859
25	9.260	0.150	6.722	1.378	1.385
26	20.410	0.060	10.378	1.967	1.226
27	1.000	1.079	1.000	1.000	1.079
mean	3.375	0.250	2.534	1.332	0.842

year = 4

firm	effch	techch	pech	sech	tfpch
1	0.871	6.162	1.000	0.871	5.369
2	1.000	1.519	1.000	1.000	1.519
3	1.000	1.260	1.000	1.000	1.260
4	1.054	11.912	1.000	1.054	12.559
5	0.947	1.337	1.000	0.947	1.266
6	1.100	2.111	1.000	1.100	2.322
7	0.849	1.804	1.000	0.849	1.531
8	0.989	1.652	1.000	0.989	1.633
9	1.000	1.211	1.000	1.000	1.211
10	0.912	1.639	1.000	0.912	1.494
11	1.060	2.018	1.000	1.060	2.141
12	0.810	5.457	1.000	0.810	4.421
13	0.247	3.685	0.247	0.999	0.909
14	1.124	2.345	1.124	1.000	2.635
15	1.000	9.621	1.000	1.000	9.621
16	0.706	2.241	0.713	0.990	1.582
17	1.000	4.582	1.000	1.000	4.582
18	1.116	1.554	1.073	1.041	1.734
19	1.000	2.593	1.000	1.000	2.593
20	0.778	3.873	1.037	0.750	3.013
21	0.654	1.812	0.717	0.912	1.185
22	0.683	2.956	1.000	0.683	2.019
23	1.001	3.315	1.134	0.883	3.319
24	1.000	4.552	1.000	1.000	4.552
25	0.388	3.024	0.495	0.783	1.173
26	0.726	2.629	1.000	0.726	1.909
27	1.000	2.573	1.000	1.000	2.573
mean	0.853	2.725	0.914	0.933	2.323

year = 5

firm	effch	techch	pech	sech	tfpch
1	1.148	1.713	1.000	1.148	1.966
2	1.000	0.953	1.000	1.000	0.953
3	1.000	0.939	1.000	1.000	0.939
4	0.966	0.260	1.000	0.966	0.251
5	1.057	0.994	1.000	1.057	1.051
6	1.000	0.969	1.000	1.000	0.969
7	1.067	0.941	1.000	1.067	1.005
8	1.056	0.953	1.000	1.056	1.006
9	1.000	12.285	1.000	1.000	12.285
10	0.864	0.942	1.000	0.864	0.814
11	1.000	1.058	1.000	1.000	1.058
12	1.192	0.491	1.000	1.192	0.585
13	0.244	3.030	0.396	0.616	0.739
14	0.139	2.535	0.181	0.765	0.351
15	0.081	1.026	0.090	0.897	0.083
16	0.162	7.895	0.175	0.924	1.277
17	0.078	1.787	0.187	0.419	0.140
18	1.000	4.150	1.000	1.000	4.150
19	1.000	0.932	1.000	1.000	0.932
20	1.406	1.601	1.000	1.406	2.251
21	0.600	1.852	0.795	0.754	1.111
22	1.464	1.965	1.000	1.464	2.877
23	0.425	2.225	1.044	0.407	0.945
24	0.607	2.864	1.000	0.607	1.738
25	0.946	2.103	0.965	0.980	1.988
26	0.408	2.164	0.549	0.743	0.883
27	1.000	1.035	1.000	1.000	1.035
mean	0.640	1.557	0.709	0.902	0.996

MALMQUIST INDEX SUMMARY OF ANNUAL MEANS

year	effch	techch	pech	sech	tfpch
2	1.335	0.773	1.043	1.279	1.032
3	3.375	0.250	2.534	1.332	0.842
4	0.853	2.725	0.914	0.933	2.323
5	0.640	1.557	0.709	0.902	0.996
mean	1.252	0.951	1.144	1.094	1.191

MALMQUIST INDEX SUMMARY OF FIRM MEANS

firm	effch	techch	pech	sech	tfpch
1	1.000	1.080	1.000	1.000	1.080
2	1.000	1.149	1.000	1.000	1.149
3	1.000	0.859	1.000	1.000	0.859
4	0.991	1.393	1.000	0.991	1.381
5	1.000	0.959	1.000	1.000	0.959
6	1.036	1.227	1.000	1.036	1.270
7	0.976	1.192	1.000	0.976	1.163
8	0.985	1.098	1.000	0.985	1.081
9	1.000	1.630	1.000	1.000	1.630
10	0.942	1.139	1.000	0.942	1.073
11	1.059	1.200	1.000	1.059	1.271
12	0.991	1.544	1.000	0.991	1.531
13	1.615	0.781	1.338	1.207	1.261
14	1.619	0.613	1.595	1.016	0.992
15	1.075	0.735	0.548	1.963	0.790
16	1.525	0.749	1.449	1.052	1.142
17	0.902	0.695	0.657	1.372	0.627
18	2.249	0.690	1.247	1.804	1.552
19	1.000	1.198	1.000	1.000	1.198

20	1.000	1.062	1.000	1.000	1.062
21	1.885	0.690	1.825	1.033	1.300
22	1.997	0.767	1.038	1.923	1.531
23	1.794	0.630	2.414	0.743	1.131
24	1.882	0.848	2.060	0.913	1.595
25	2.366	0.799	1.719	1.376	1.890
26	1.659	0.691	1.684	0.985	1.146
27	1.018	1.314	1.000	1.018	1.338
mean	1.252	0.951	1.144	1.094	1.191

[Note that all Malmquist index averages are geometric means]

Biography

Name-Surname	Mr. Zhipei Xu
Date of Birth	September 8, 1976
Address	519,Huixing Stree , Administration Building of Sichuan University of Science and Engineering, Sichuan China, 64300
Education	Master of Accounting,School of Accounting Southwestern University of Finance and Economics Chengdu City, Sichuan, China
Work Experience	
2020-Present	Director of Finance of Sichuan University of Science and Engineering
2016-2020	Deputy Director of Finance of Sichuan University of Science and Engineering 519 Huixing, Street, Huidong, Zigong, China
2000-2016	Accounting Teacher, Sichuan University of Science and Engineering 519 Huixing, Street, Huidong, Zigong, China
Telephone	+8613990076815
e-mails	zhipei_x@mail.rmutt.ac.th or 1013768222@qq.com

วิทยานิพนธ์ฉบับนี้เป็นงานวิจัยที่เกิดจากการค้นคว้าและวิจัย ขณะที่ข้าพเจ้าศึกษาอยู่ในคณะครุศาสตร์อุตสาหกรรม มหาวิทยาลัยเทคโนโลยีราชมงคลธัญบุรี ดังนั้น งานวิจัยในวิทยานิพนธ์ฉบับนี้ถือเป็นลิขสิทธิ์ของมหาวิทยาลัยเทคโนโลยีราชมงคลธัญบุรี และข้อความต่าง ๆ ในวิทยานิพนธ์ฉบับนี้ ข้าพเจ้าขอรับรองว่าไม่มีการคัดลอกหรือนำงานวิจัยของผู้อื่นมานำเสนอในชื่อของข้าพเจ้า

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(Mr.Zhipei Xu)