ANALYSIS AND COUNTERMEASURES OF SCIENTIFIC RESEARCH PERFORMANCE OF HIGHER VOCATIONAL COLLEGES IN SICHUAN PROVINCE USING THE DEA-BCC MODEL

LIN ZHOU

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF SCIENCE IN TECHNICAL EDUCATION PROGRAM IN VOCATIONAL EDUCATION
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RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI
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Program	Vocational Education
Dissertation Advisor	Associate Professor Suthiporn Boonsong, Ed.D.
Dissertation Co-Advisor	Assistant Professor Issara Siramanecrat, Ph.D.
Academic Year	2023

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20 February 2024

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ABSTRACT

This study aimed to: 1) analyze and evaluate the scientific research performance of higher vocational colleges in Sichuan province, China, 2) analyze the impact and importance of research input indicators on the research performance of higher education colleges and 3) establish a comprehensive evaluation model for analyzing the scientific research performance of higher vocational colleges in Sichuan province. The study samples included research performance input and output data from 30 higher vocational colleges in Sichuan province from 2019 to 2021. Correlation analysis between research input and output was conducted using the DEA-BCC model, the Malmquist index model, and the Rough Set theory. The computation of the DEA-BCC model and the Malmquist index model was performed using DEAP2.1 software, while the Rough Set theory was analyzed using the Python programming language.

The results showed that: 1) five colleges demonstrated good scientific research performance as analyzed by DEA-BCC and Malmquist index models. Despite an overall upward trend in scientific research performance among higher vocational colleges in Sichuan, the levels remain relatively modest, 2) internal expenditure for scientific research funds and senior and above professional teachers were found to have a significant impact on scientific research efficiency according to the Rough Set analysis and 3) the integrated use of the DEA-BCC model, Malmquist index model, and Rough Set theory can scientifically and effectively evaluate the research performance of higher vocational colleges.

It can be concluded that improving research management, resource utilization, and technological innovation can enhance efficiency and bridge gaps among higher vocational colleges in Sichuan province.

Keywords: scientific research performance, data envelopment analysis, DEA-BCC model, Malmquist index model, rough set theory

Acknowledgement

I would like to express my deepest gratitude to Associate Professor Sutthiporn Boonsong, Assistant Professor Issara Siramaneerat, and Assistant Professor Pakornkiat Sawetmethikul for their invaluable guidance and unwavering support throughout my Ed.D. Special thanks also go to the members of my dissertation committee: Associate Professor Wisuit Sunthonkanokpong, Associate Professor Yothin Sawangdee, Associate Professor Kumron Sirathanakul, Assistant Professor Sukanya boonsri, Assistant Professor Tiamyod Pasawano, for their valuable recommendations.

Secondly, I am sincerely grateful to Rajamangala University of Technology Thanyaburi and Sichuan University of Science and Engineering for providing me with this incredible opportunity to pursue my studies. Their generous financial assistance and academic and professional support have been instrumental in shaping my research journey.

Furthermore, I want to express my gratitude to my parents for their nurturing care and upbringing. Their support has been instrumental in shaping my resilient character, a treasure that I hold dear. They have played a crucial role in my academic success. Additionally, I am thankful to my husband and son for their unwavering love and trust during my studies abroad. Their support allowed me to focus on my studies without any worries, bringing happiness into our lives.

Lastly, I would like to express my heartfelt gratitude to all of my relatives, friends, supervisors, and colleagues for their unwavering support and invaluable companionship throughout completing my studies. Their encouragement and advice have greatly contributed to this journey.

Lin Zhou

Table of Contents

List of Tables

Page

List of Figures

CHAPTER 1
INTRODUCTION

1.1 Background and Statement of The Problem

The National Vocational Education Reform Implementation Plan was issued by the State Council of China in January 2019. The plan emphasized that vocational education and general education are distinct but equally significant. It was recommended that vocational education be given greater prominence in educational reform and innovation, as well as in economic and social development.

In October 2021, the Opinions on Promoting the High-quality Development of Modern Vocational Education were issued by the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council. The document emphasized that vocational education plays a vital role in the national education system and human resources development. It carries the significant responsibility of nurturing diverse talents, preserving technical skills, and fostering employment and entrepreneurship.

In the pursuit of building a socialist modernization country comprehensively, vocational education holds immense prospects and untapped potential. The Twentieth National Congress of the Communist Party of China explicitly stated the need to harmonize vocational education, higher education, and continuing education. This coordination aims to foster innovation, promote the integration of vocational education with various sectors, such as industry and science, and optimize the focus and direction of vocational education.

The revised Vocational Education Law of the People's Republic of China was officially implemented on May 1, 2022. It explicitly acknowledges vocational education as an educational category of equal importance to general education. It recognizes vocational education as a crucial component of the national education system and human resources development. Additionally, the law highlights vocational education as a significant means to nurture diverse talents, preserve technical skills, and stimulate employment and entrepreneurship.

In August 2022, the Ministry of Education of China released a document titled

"Several Opinions on Enhancing Organized Scientific Research in Colleges and Universities to Foster High-level Self-reliance and Advancement". The document emphasized that universities play a crucial role in China's scientific and technological prowess, serving as a vital component of the nation's overall strength in these fields.

The introduction of these policies underscores the acknowledgment and importance given to vocational education in China's educational reform and development. The Chinese government recognizes vocational education as a vital element within the national education system and human resources development. It is regarded as a critical avenue for cultivating a diverse talent pool, fostering employment and entrepreneurship, and adapting to the evolving requirements of the contemporary workforce. Consequently, prioritizing and investing in vocational education is imperative to meet the demands of a dynamic job market and contribute to the overall progress and advancement of the nation.

The strength of a country is closely tied to the strength of its science and technology. The competition between nations ultimately boils down to their scientific and technological capabilities. Currently, China's economy has transitioned from rapid growth to high-quality development. Scientific and technological innovation serves as the core driver for this development, offering new opportunities for growth and serving as a vital support system. Therefore, it is crucial that we prioritize scientific and technological innovation as the focal point and starting point for all our endeavors (Wang, 2019).

In terms of policy direction, the development of scientific research and technological innovation is a crucial aspect of enhancing the overall quality of higher vocational colleges. Strengthening the capacity for scientific research and technological innovation has consistently been a national-level expectation for higher vocational colleges. The significance of scientific research and technological innovation within higher vocational colleges is continuously emphasized, making it an integral component of their core competitiveness. By prioritizing and investing in scientific research and technological innovation, higher vocational colleges can further enhance their standing and contribute to the advancement of vocational education(Wu, 2023).

Scientific research serves as a significant catalyst for the advancement of higher vocational colleges, playing a crucial role in enhancing the quality of education and teaching, strengthening faculty development, and improving their ability to serve society. As national investment in scientific research within universities continues to grow, there is a shared concern among the government, universities, and society regarding the evaluation of scientific research performance and the optimization of scientific and technological resource allocation in universities. Finding effective methods to assess scientific research outcomes in universities and optimizing the allocation of resources has become a common focus, ensuring that research efforts align with national priorities and contribute to societal needs(Zhong & Liu, 2017).

Scientific research within vocational colleges holds significant importance in the advancement of vocational education. It serves as a fundamental component that distinguishes vocational education and contributes to its unique characteristics. Enhancing the quality of education and expanding the service function are achievable only through the integration of scientific research. The role of scientific research in the development of higher vocational colleges has become increasingly crucial(Liu & Kuang,2019).

The performance of scientific research is a crucial indicator for assessing the level of scientific and technological research and the overall competitiveness of higher vocational colleges. It serves as a reflection of the ability of these institutions to contribute to national strategies and regional economic and social development. By evaluating scientific research performance, higher vocational colleges can gauge their effectiveness in generating knowledge, innovation, and practical solutions that align with the needs of the nation and the local community(Yu, 2023). The pursuit of research breakthroughs is essential for achieving high-quality development in higher vocational colleges(Sun, 2020).

However, compared with the clear research orientation and development mode of undergraduate colleges, there are still many weak links in the research work of higher vocational colleges in China, including unclear orientation, weak management, and insufficient investment in human and material resources(Ma et al., 2021). There is a tendency to prioritize the number of research achievements over their quality, leading to a generally low standard of scientific research accomplishments(Qiao, 2020). The current higher vocational education in China is busy with keeping up with the pace of industry and enterprises, trying to meet the current labor demand, not paying attention to the formation of technical skills, not paying attention to research and development and iteration of new technologies and new skills. Fundamentally speaking, it has not yet formed the academic research atmosphere that universities should have, so some people think that academic is not or should not be the connotation of higher vocational education, so it is difficult to form the academic ecology and vitality of sustainable development of higher vocational education (Kuang Ying, 2020). Compared with ordinary undergraduate colleges and universities, the construction of scientific research platforms in higher vocational colleges started late, made slow progress, achieved limited results, and even did not build a clear cognitive system and action framework(Wu, 2023).

In conclusion, it is crucial to address the challenges and limitations faced by higher vocational colleges in China. These issues include a lack of clear research direction, weak management practices, insufficient resource allocation, prioritization of quantity over quality in research achievements, inadequate focus on technical skills and innovation, absence of an academic research environment, slow progress in establishing effective scientific research platforms, and a lack of well-defined cognitive systems and action frameworks. Overcoming these obstacles is essential for the progress of vocational education and will enable higher vocational colleges to make significant contributions to scientific research and innovation. Therefore, it is important to establish clear research directions, improve management practices, allocate enough resources, prioritize quality over quantity to achieve good results, nurture technical abilities, encourage innovation development, and foster an academic atmosphere within these colleges(Feng et al., 2022)

The emergence of higher vocational education on a large scale took place around the 1960s, with several countries embarking on its development. In China, the expansion of higher education enrollment has played a significant role in facilitating the extensive growth of higher vocational education. This move was further reinforced in 1999 when the Ministry of Education decided to integrate higher vocational education, higher vocational education, and adult higher education. This integration marked the birth of what is now referred to as higher vocational education in China(Chen et al., 2018).

Today, higher vocational education in China is a vital component of the country's educational system, serving as a bridge between theoretical knowledge and practical skills required in various industries. In response to the increasing demand for a skilled workforce, China has greatly expanded opportunities for vocational high schools and college programs in recent years (Kim et al., 2016). The expansion of higher vocational education in China has not only increased opportunities for students but also played a crucial role in the overall development of the country's economy. With China's economy growing and becoming more diverse, there is an increasing demand for highly skilled professionals. Higher vocational education addresses this demand by offering specialized training in specific industries, equipping students with the necessary skills and knowledge to excel in their chosen careers. Thus, the expansion of higher vocational education is both essential and advantageous for individuals as well as the nation as a whole. It has not only broadened students' opportunities but has also contributed to the overall economic development of the nation(Li, 2023). Hence, the growth and advancement of higher vocational education in China not only addresses the demands of the contemporary labor market but also makes a substantial contribution to the overall economic progress and long-term viability of the nation.

The China Vocational Education Development Report (2012-2022) highlights significant progress made in vocational education reforms in China. One of the key reforms explored is the establishment of a college entrance examination system for vocational education. Additionally, cultural quality and vocational skills classification for enrollment have been implemented. To standardize the process of characteristic training, specific requirements for formulating professional personnel training programs in vocational schools have been established. These requirements include training objectives, curriculum setting, class hour arrangement, practical teaching, and graduation requirements. These measures provide a solid foundation for professional personnel training and quality evaluation. Vocational schools have also implemented a practice management system to clarify the concept and scope of practice and to outline measures for practice management.

The report suggests incorporating vocational undergraduate education into the existing bachelor's degree system with a focus on strengthening vocational education's characteristics in terms of bachelor's degree authorization and degree award standards. These efforts aim to construct a set of vocational education systems with Chinese characteristics, running through students' entrance and exit, and creating a brighter future for vocational education in China(Hu, 2022).

As indicated in Table 1.1, China's higher education universities and colleges have seen remarkable growth in recent years, with over 3,000 operating in 2022. Of these, more than half were higher vocational colleges, providing students with the skills and knowledge needed to succeed in their chosen fields. Vocational education has become increasingly popular in China, with enrollment numbers consistently exceeding those of traditional undergraduate programs. Vocational education now offers over 1,300 majors and 120,000 professional points, covering a wide range of sectors. Despite being introduced relatively late compared to other educational models, vocational education has played a significant role in fostering economic and social development in China.

Overall, the growth of vocational education in China has been impressive, shaping the country's workforce and demonstrating the importance of this type of education in its development(Feng et al., 2022).

Table 1.1 Statistics of Higher Vocational Colleges in China（2018-2022）

Year	Number of university	Number of higher vocational colleges	Percentage of higher vocational colleges	Enrollment of the higher vocational colleges (million)	Enrollment of general undergraduate (million)
2022	3013	1521	50.4%	5.49	4.67
2021	3012	1486	49.3%	5.56	4.44
2020	2738	1468	53.6%	5.24	4.43
2019	2688	1423	52.9%	4.83	4.31
2018	2663	1418	53.2%	3.68	4.22

Source : China Education Development Statistical Bulletin（2018-2022）

The 2022 Annual Report on the Quality of Vocational Education in China delves deep into the comprehensive impact of higher vocational colleges on the Chinese economy. These colleges have strategically focused on key industries such as modern manufacturing, strategic emerging industries, and modern services, which has resulted in a substantial contribution to the actual economy. More than 70% of new employees in front-line sectors are graduates from higher vocational colleges. This demonstrates the valuable role that higher vocational colleges play in supplying skilled workers who directly contribute to the growth and success of these vital industries. This data highlights the essential role that these educational institutions play in nurturing and molding the country's workforce. The report also highlights the efforts made by higher vocational colleges to improve the quality of education by emphasizing practical skills and hands-on experience, which has resulted in a significant increase in the employability of their graduates. Additionally, the report suggests that the government should continue to support vocational education by investing in infrastructure and resources, and by collaborating with industry partners to ensure that the curriculum remains relevant and up-to-date(Liu, 2022).

The success of vocational colleges in China can be attributed to initiatives like the Double High Plan, which has been instrumental in driving service contributions. According to the report, the median amount of horizontal technical service funds for Double High Plan colleges is 7.39 million RMB, the median amount of funds from technology transactions is 1.61 million RMB, and the median amount of funds from non-degree training is 6.36 million RMB. These figures show respective increases of 26.3%, 43.3%, and 5.5% compared to the previous year.

The report also highlights the efforts of higher vocational colleges to work closely with industry enterprises to understand technical needs and establish platforms for product research and development, technological innovation, and outcome transformation, thereby facilitating corporate transformation and upgrading. This collaborative approach has resulted in significant progress in the field of technological innovation.

In 2021, Chinese vocational colleges collectively obtained authorization for

5,828 invention patents, an increase of 43.57% compared to the previous year. This figure is a testament to the dedication and hard work of the colleges in fostering a culture of innovation and creativity among their students and faculty. Overall, the report provides a comprehensive overview of the vital role played by higher vocational colleges in China in driving economic growth, innovation, and workforce development.

The scientific research level in higher vocational colleges serves as an indicator of their capacity to contribute to national strategies, and regional economic, and social development(Yu, 2023). Consequently, scientific research has increased its importance in developing higher vocational colleges(Liu & Kuang, 2019). Pursuing research breakthroughs is the key to achieving high-quality development for higher vocational colleges(Sun, 2020).

Despite some notable advancements, scientific research in higher vocational colleges still has a long way to go in terms of contributing to society. While higher vocational colleges have made progress in research, there are still significant disparities in the overall level of research.

Unfortunately, higher vocational colleges have not yet been able to establish themselves as leading platforms for transforming scientific and technological advancements. Consequently, they still face challenges, such as the separation between academia and industry, which limit their ability to drive innovation, facilitate the conversion of scientific achievements, and effectively serve national strategies for innovation-driven development. Therefore, it is necessary to further enhance both scientific research capabilities and social service contributions within higher vocational colleges. By doing so, they can maximize their potential to contribute to innovation-driven development and better serve society.(Gao et al., 2023;Lin & Xu, 2022)

Compared with the clear research orientation and development mode of undergraduate colleges, there are still many weak links in the research work of higher vocational colleges in China, including unclear orientation, weak management, and insufficient investment in human and material resources. Although many higher vocational colleges emphasize the importance of scientific research, they often overlook the evaluation of research work and its outputs. Examining the state of university research can be approached from various angles, including analyzing the evaluation system and positioning of the research within the university. Among these perspectives, evaluating a university's research level is most informative, especially when assessing input and output efficiency. Using appropriate evaluation methods makes it possible to assess the current performance of a university's research while identifying any issues in the process. With this analysis as a foundation, implementing performance-based governance strategies can foster hierarchical and holistic growth within universities and effectively enhance their research capabilities. Universities strive to be at the forefront of knowledge production and play a vital role in shaping the progress of society. By evaluating the research performance of universities, we can gauge their impact and effectiveness in contributing to the advancement of knowledge and society(Ma et al., 2021; Zong & Wang, 2017; Keshavarzi & Heidari, 2020).

According to the statistics presented in Table 1.2, Sichuan Province has a total of 82 higher vocational colleges in the year 2022, which places it in the fifth position among all provinces of China and first among those located in the western region of the country. This study aims to investigate the science performance of higher vocational colleges in Sichuan Province, to improve their scientific research efficiency and promote the development of higher vocational education in the region. Given that Sichuan is a major province for higher vocational education in China, this research can also serve as a reference for improving the science performance of similar colleges across China, holding practical significance.

Table 1.2 The Number of Higher Vocational Colleges in Each Province of China in 2022

Region	Bachelor's Degree Level	Associate Degree Level	Total	Rank
Henan	1	99	100	1
Guangdong	2	93	95	2
Jiangsu	1	89	90	3
Shandong	3	83	86	4
Sichuan	1	81	82	5
Hunan	1	76	77	6
Anhui	0	75	75	7
Hebei	3	62	65	8
Jiangxi	3	61	64	9
Hubei	0	62	62	10
Liaoning	1	51	52	11
Zhejiang	2	49	51	12
Fujian	1	50	51	13
Shanxi	2	48	50	14
Yunnan	0	50	50	15
Guangxi	2	47	49	16
Guizhou	1	46	47	17
Chongqing	1	43	44	18
Shaanxi	2	40	42	19
Heilongjiang	0	41	41	20
Inner Mongolia	0	37	37	21
Xinjiang	1	36	37	22

Jilin	0	29	29	23
Gansu	2	27	29	24
Tianjin	0	26	26	25
Beijing	0	25	25	26
Shanghai	1	24	25	27
Hainan	1	13	14	28
Ningxia	0	12	12	29
Qinghai	0	8	8	30
Tibet	0	3	3	31

Source : Think Tank on China Higher Vocational Education Development(2022)

In 1978, Charnes, Cooper, and Rhodes established the Data Envelopment Analysis(DEA) model together. This method is a mathematical programming technique that assesses the relative effectiveness of similar decision-making units. In 2011, Cooper, Seiford, and Zhu introduced a new definition for DEA in an article. Here they emphasized that DEA is a data-driven approach used to evaluate the efficiency of a group of homogeneous decision-making units. Overall, DEA serves as a robust mathematical programming tool to compare and assess the relative effectiveness or efficiency among similar decision-making units (Charnes, A., et al. 1978; Cooper, W. W., et al., 2011).

The Data Envelopment Analysis (DEA) method is a powerful data-driven approach that can be used to analyze the performance of operations across various domains. By evaluating a range of performance indicators and combining multidimensional data, DEA can provide comprehensive insights on improving overall performance. Unlike other methods, DEA does not rely heavily on assumptions, which makes it more widely applicable in practice. DEA is particularly useful in complex scenarios where there are multiple dimensions of performance and decision-makers lack trade-off information between these indicators. It can help identify inefficiencies and provide recommendations for optimal resource allocation to improve performance.

Moreover, DEA can handle complex relationships among multiple performance indicators, thereby enabling a more nuanced understanding of operational performance. Overall, DEA is a powerful tool for organizations seeking to optimize their performance across various domains. By utilizing the Data Envelopment Analysis method, decision-makers can gain valuable insights into the efficiency and effectiveness of various operations(Charnes, A., et al. 1978; Cooper, W. W., et al., 2011; Zhu, 2014).

Numerous techniques have been utilized by researchers to assess the efficacy of scientific research in higher vocational colleges over time. These methods encompass peer review, expert evaluation, Delphi method, case study approach, analytic hierarchy process, principal component analysis technique, factor analysis technique, and data envelopment analysis. Each approach possesses its advantages and constraints; henceforth it is crucial for researchers to meticulously deliberate which methodology or combination of methodologies best suits their research inquiry and setting. Through careful consideration of the strengths and limitations inherent in various evaluation approaches, researchers can ensure a comprehensive and meticulous appraisal of scientific research conducted in higher vocational colleges(Gao, et al., 2023).

DEA has become widely recognized and preferred in evaluating the performance of university research due to its unbiased and equitable nature. This method allows for a comprehensive assessment of efficiency by considering numerous inputs and outputs, eliminating the influence of subjective factors. Applying DEA analysis to evaluate scientific research at Sichuan higher vocational colleges holds practical importance in enhancing their research capabilities, while also serving as a valuable reference for advancing higher vocational education across other provinces. By utilizing the DEA analysis model, Sichuan higher vocational colleges can gain valuable insights into their research performance and identify areas for improvement(Wang & Tan, 2021). The use of DEA in evaluating the performance of universities and other educational institutions has proven to be effective and beneficial in various studies (Tan, 2016). It provides a comprehensive and objective assessment of the efficiency and performance of these institutions, allowing for targeted improvements and resource optimization. This not only benefits the institutions themselves, but also stakeholders such as students, faculty, and funding agencies.

In terms of research scope, scholars primarily focus on studying scientific research performance in specific types or regions within higher vocational colleges. This allows for a more detailed analysis of the effectiveness of scientific research in these particular areas. The use of various evaluation methods provides a comprehensive understanding of the strengths and weaknesses of scientific research performance in higher vocational colleges, allowing for improvements to be made where necessary. As a result, the use of DEA and other evaluation methods plays a vital role in improving scientific research performance in higher vocational colleges(Pang & Yi, 2023; Dou & Li, 2022).

Several key aspects have been identified by scholars that influence scientific research performance in higher vocational colleges. These include the scientific research management system, scientific research operation mechanism, scientific research environment, incentive rewards, scientific research team, and more. The scientific research management system refers to the regulatory framework, policies, and procedures that guide scientific research activities in higher vocational colleges. On the other hand, the scientific research operation mechanism encompasses the processes and practices that facilitate the execution of scientific research projects. The scientific research environment comprises the physical and intellectual infrastructure that supports scientific research activities in higher vocational colleges. Incentive rewards refer to the incentives that motivate researchers and scientists to engage in scientific research activities. Finally, the scientific research team includes a group of individuals, including researchers and scientists, who work together to conduct scientific research in higher vocational colleges(Gao et al.,2023; Shu, 2022).

1.2 Research Questions

1.2.1 What is the changing trend of scientific research performance in higher vocational colleges in Sichuan Province?

1.2.2 What is the importance of the major research input indicators on the impact of research performance in higher education colleges in Sichuan Province?

1.2.3 What is the effective model to evaluate the scientific research performance of higher vocational colleges in Sichuan Province?

1.3 Research Objectives

1.3.1 To analyze and evaluate the scientific research performance of higher vocational colleges in Sichuan province.

1.3.2 To analyze the importance of the impact of research input indicators on the research performance of higher education colleges.

1.3.3 To establish a comprehensive evaluation model to analyze the scientific research performance of higher vocational colleges in Sichuan Province.

1.4 Research Scope

1.4.1 Content Scope

Firstly, to assess the scientific research performance of higher vocational colleges in Sichuan using Data Envelopment Analysis (DEA) and Malmquist index models, and secondly, to investigate the influence of scientific research inputs on scientific research performance through Rough Set theory. Thirdly, to employ a comprehensive model to assess the scientific research performance of higher vocational colleges.

1.4.2 Sample Scope

This study's target population includes 82 higher vocational colleges within Sichuan Province, of which 30 were selected as the research sample. The sample for this study consists of research performance input and output data from 30 higher vocational colleges in Sichuan Province for the years 2019 to 2021. It is worth noting that some scholars have previously researched research activities in Sichuan's higher vocational colleges using sample sizes of fewer than 30 colleges(Xiao & Chen, 2022; Zhang, 2020). this study opted for a sample of 30 higher vocational colleges encompassing most types of higher vocational colleges in Sichuan Province, including comprehensive, engineering and technical, political and legal, agriculture and forestry, medical and pharmaceutical, and art colleges. Additionally, all eight higher vocational colleges participating in the

Double High Plan are included in the sample. These sample colleges are distributed across 18 out of the 21 prefecture-level cities in Sichuan Province.

The study covers relevant data from the sample colleges from 2019 to 2021. The sample data primarily comes from the publicly available annual quality reports, annual budgets, and final accounts reports of each higher vocational college, as well as the scientific and technological statistical data of each college.

1.4.3 Timing Scope

2019-2021

1.5 Definition of Terms

Higher vocational colleges: They are higher education institutions that specialize in providing targeted education and training in specific occupational or professional fields. Their programs are designed to prepare individuals for employment in industries or occupations that require practical skills and knowledge. Vocational colleges offer a diverse range of technical and vocational programs, including fields such as automotive technology, culinary arts, healthcare, business administration, and information technology.

Performance: It refers to the organization or individual in a certain situation and time to achieve their goals of work performance, efficiency, and effectiveness, there are two aspects of personal performance and organizational performance.

Scientific research performance: The performance of researchers engaged in scientific research-related work in a certain period of time. Its essence is a measure of the efficiency of input and output.

DEA(Date Envelopment Analysis): It is a comprehensive evaluation method for the efficiency of complex systems with multi-index inputs and multi-index outputs. There is no need to determine the functional relationship between input and output in advance, no need to standardize the data, and no need to determine the weight of each index, so the evaluation is more objective.

DEA-BCC (Data Envelopment Analysis-Banker, Charnes, Cooper) Model: It is a method employed for assessing the relative efficiency of units under conditions involving multiple inputs and outputs. This model, utilizing linear programming techniques, constructs an envelopment surface to determine whether units are efficient. Relative efficiency is ascertained by maximizing the ratio between inputs and minimizing the ratio between outputs. The model imposes constraints to ensure that each unit is at least as efficient as one other unit in terms of both inputs and outputs. By solving this linear programming problem, the model provides relative efficiency scores for each unit, facilitating the comparison and evaluation of their relative performance levels.

Malmquist Index Model: It is utilized in the field of economics to assess changes in production efficiency across different time periods. It evaluates overall variations by examining both technical change and efficiency change. By utilizing the production possibility frontier, a value greater than 1 on the Malmquist index indicates an improvement in efficiency, a value less than 1 suggests a decline in efficiency, and equality to 1 implies no change has occurred.

Rough Set Theory: Introduced by Zdzisław Pawlak, is a mathematical approach for handling uncertainty and vagueness in data analysis. It focuses on discernibility boundaries within sets, allowing classification in situations with incomplete or imprecise information. This theory is applied in fields like artificial intelligence, machine learning, and data mining.

1.6 Limitations of the Study

There are several limitations to consider in this study. Firstly,The scientific research performance indicators selected in this study have certain limitations. Additionally,this study lacked precise statistics on high-quality research outcomes. Moreover, The impact study of research input indicators in this research requires further optimization. Lastly,The policy recommendations in this study had limitations.

1.7 Expected Benefits

1.7.1 To assess the performance and trends in scientific research of higher vocational colleges in Sichuan Province. The findings will serve as a valuable resource for improving the efficiency of scientific research in these colleges, aiding decision-making processes.

1.7.2 To study the impact of input indicators on research performance and identify the main factors influencing the differences in research performance among higher vocational colleges.

1.7.3 To develop a scientific research performance evaluation model for higher vocational colleges in Sichuan province. The analysis will focus on the scientific research performance and its changing trends over time, aiming to provide valuable insights for decision-making processes to enhance scientific research performance in higher vocational colleges.

1.8 Research implementation

In recent times, higher vocational colleges in Sichuan Province have been under scrutiny for their relatively low scientific research performance. This study highlights the need for a more comprehensive analysis and research on the scientific research performance of these colleges. It is imperative to develop effective schemes to enhance the efficiency of scientific research in these colleges. To achieve this, it is crucial to establish a perfect scientific research performance evaluation and assessment model that can help to monitor and evaluate the performance of the colleges accurately. This model will provide useful insights into the areas where these colleges need improvement and help to develop targeted interventions to enhance their scientific research performance.

The findings from the analysis should be disseminated widely and applied in the higher vocational colleges in Sichuan Province to enhance scientific research performance and contribute to the region's overall development. This will require effective collaboration and cooperation between the relevant stakeholders, including the government, higher education colleges, and industry players. By improving the scientific research performance of these colleges, Sichuan Province can enhance its competitiveness, promote economic growth, and contribute to the country's development as a whole.

There is a lack of consistent standards and understanding for the evaluation of scientific research inputs in higher vocational colleges in Sichuan. The determination of these inputs often relies solely on the experience of college research departments, which lacks a systematic approach. Moreover, the performance levels achieved by these colleges in terms of scientific research differ greatly from those at central universities. Additionally, there is currently no comprehensive system to evaluate and assess the performance of scientific research in higher vocational colleges, including an inadequate adjustment mechanism for input based on phased output results. This situation hampers efforts to enhance performance in scientific research. Therefore, this study aims to investigate how input indicators affect research performance and proposes strategies to improve overall performance.

1.9 Research Framework

This study employs DEA-BCC models, Malmquist index models, and Rough Set theory. The research is divided into two phases: the first phase involves dynamic and static analysis of scientific research performance in higher vocational colleges in Sichuan Province using DEA-BCC and Malmquist index models to understand the overall status and trends. The second phase involves an analysis of input indicators for scientific research performance in higher vocational colleges using the Rough Set theory. Based on the comprehensive analysis from both phases, relevant recommendations are provided.

The research framework depicted in Figure 1.1 primarily emphasizes theoretical analysis, the construction of an evaluation model, and data analysis.

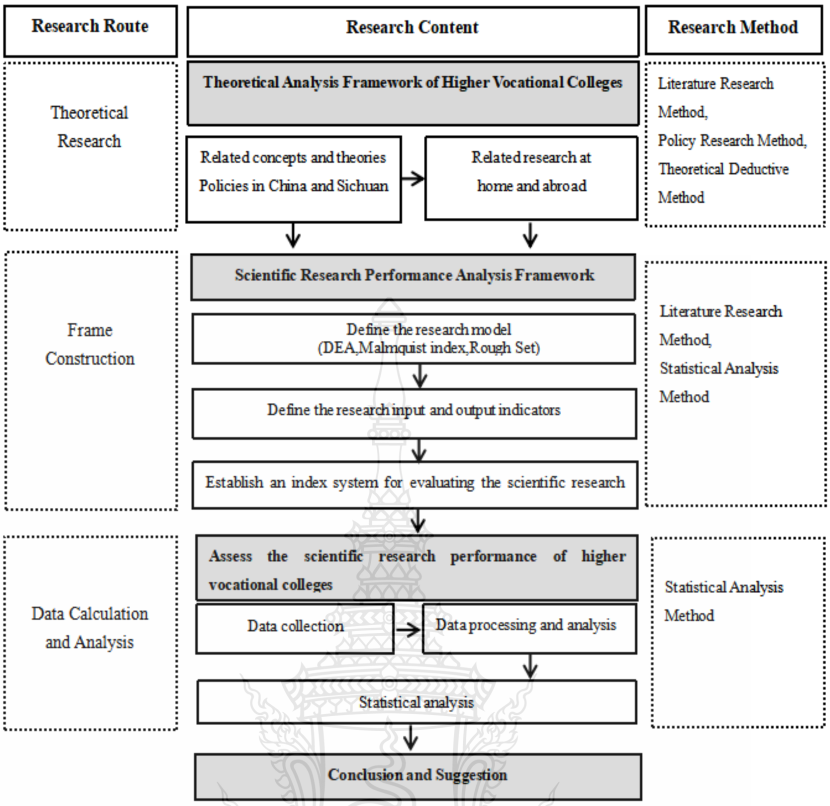

Figure 1.1 Research Framework

CHAPTER 2
REVIEW OF THE LITERATURE

2.1 Performance Theory

In the Oxford Modern Advanced English-Chinese Dictionary, performance is interpreted as execution and performance. In the ' Chinese dictionary ', performance is interpreted as achievement and effectiveness. Owen was the first to introduce performance evaluation into the Western industrial sector in Scotland, so the term performance came into being. In 1959, Bain and Scherer of Harvard University put forward the Structure, Conduct, Performance model (SCP) model in the Industrial Organization published in 1959, which became one of the earliest basic theoretical models of performance. In 1977, P.H.Hatry, a famous contemporary American performance management expert, put forward three evaluation contents, namely effectiveness, efficiency, and workload, when studying the evaluation criteria of government public services. From the perspective of this performance evaluation content, the three evaluation contents directly point to the results of government public services, and the performance also has typical results characteristics. Bernardin believed that performance is the result of work, and the overall strategic objectives, investment ratio, and customer satisfaction are closely related to performance. Kane believed that performance is the realization of employee outcomes, which exist simultaneously and are independent of each other(Zhang & Han, 2005; Bernardin, 1995; Kane,1996).

In 1990, Murphy defined performance as a set of behaviors that are interrelated with the goals of the organization or organizational unit. In 1991, Ilgen and Schneider viewed performance as the actions undertaken by individuals or systems. Expanding further, In 1993, Campbell and others defined performance as behavior itself, emphasizing that it is observable by others. These varying perspectives highlight the multifaceted nature of performance and its association with goal-oriented actions and behavior.

According to this definition, performance should include only those actions or behaviors that are related to the organizational goals and can be evaluated according to the individual's ability. Performance is not the consequence or result of behavior, it is the behavior itself (Hu, 2015). According to Gao Lei(2012), performance encompasses the level and impact of employees' individual or group abilities within a specific environment. It also encompasses the behaviors exhibited by individuals or groups in their pursuit of predetermined goals, as well as their accomplishments and contributions. This definition emphasizes the connection between performance and both individual and collective efforts in achieving desired outcomes.

Chen Fang and Lin Feng pointed out that performance is the work behavior, method, result, and possible influence within a specific time. In the organization, it is generally used to judge the completion of the work, the performance of the duties, and the growth of the members(Chen & Lin, 2020). Jia Mingxia believes that performance is the input and output of an enterprise or employee in a certain cycle. Specifically, input refers to the use of resources including human and material resources, as well as personal emotions, enthusiasm, and emotional input; output refers to the amount of work done, service quality, and effectiveness of all aspects of content, based on input and output and then a person's ability to work a comprehensive criticism (Jia, 2022).

The various definitions and perspectives on performance highlight its multifaceted nature and its close connection to organizational goals, individual behaviours, and outcomes. Performance is a complex concept that encompasses the behaviours, actions, and achievements of individuals or groups within an organization (Ofori et al., 2017). It involves the evaluation of work performance based on predetermined goals, the use of resources, and the overall effectiveness and efficiency of an organization or employee.

The concept of performance is multifaceted, encompassing behaviours, actions, achievements, and the evaluation of work performance about organizational goals. Through the interpretation, source and research analysis of performance in Chinese and English, this study believes that performance is the achievement and effect obtained through work. Performance is based on work, and performance is influenced by work environment, staff, work objectives, work methods and work process.

2.2 Scientific Research Performance Theory

Performance management emerged from the study of human resource management theory and practice by Western scholars in the late 1970s. It gained prominence in the field of scientific research management during the 1990s. From Zhou Wei's perspective, the evaluation of scientific research performance involves using specific methodologies to render impartial and comprehensive assessments of the scientific research input, output, and outcomes of an individual or organization engaged in scientific research activities during a specific period (Zhou, 2010). In simpler terms, the evaluation aims to determine the effectiveness and efficiency of a scientific research project by analyzing multiple factors such as the research methodology employed, the resources utilized, and the results obtained.

According to a study conducted by Wang Dongshan, The performance of university teachers in scientific research endeavors encompasses both the productivity and effectiveness of their scientific research activities and related work. This research emphasizes the importance of considering not only the quantity of output but also the efficiency with which research is conducted in evaluating the performance of university teachers in scientific endeavors(Wang, 2012).

According to the research conducted by Xu Chenlong, the evaluation of scientific research performance in universities encompasses multiple factors, including the quality and quantity of scientific output, as well as the level of research conducted. This suggests that the overall assessment of scientific research in universities is not solely based on the quantity of publications but also takes into account the level of research quality. The findings highlight the need for a comprehensive evaluation approach that considers various aspects of scientific research performance. Xu's perspective highlights the importance of a comprehensive evaluation system that takes into account multiple aspects of scientific research performance in universities(Xu, 2013).

Dong Jie found that evaluating the productivity of individuals involved in scientific research over a specific period typically relies on their scientific research performance. This performance is gauged by the output of scientific research results that are achieved during their work(Dong, 2017). In evaluating the scientific research performance of individuals involved in research activities, both the quantity and quality of research output are essential factors to consider. These factors play a crucial role in assessing the contributions and achievements of personnel in the realm of scientific research.

In a recent study carried out by Shang Fang in 2021, it was found that the scientific research performance of teachers can be defined as the actions and outcomes that align with the scientific research objectives demonstrated by teachers during their scientific research activities(Shang, 2021).

According to this definition, this includes factors such as the selection of research topics, the formulation of research plans, the execution of research methods, and the interpretation and communication of research findings. In essence, the scientific research performance of teachers is a comprehensive reflection of their proficiency in conducting research and their commitment to advancing knowledge in their respective fields.

Gu et al. believe that scientific research performance refers to the scientific research achievements produced by scientific researchers in a certain period, such as published papers. These achievements are considered as an important measure of the productivity and impact of scientific research. This definition aligns with the common understanding that scientific research performance is often measured by the output of published papers and other research achievements within a specific time frame(Gu et al., 2021).

Wang and Cai regard scientific research performance as a unity of results, behavior, process, and ability, including task-based performance and innovative performance. These components of scientific research performance are crucial in evaluating the effectiveness and impact of research conducted by individuals in academic institutions. By considering these components, universities and academic institutions can better assess the overall quality and contribution of their research activities(Wang & Cai, 2022; Shi et al., 2019).

Within the field of scientific research, measuring research performance is a critical indicator of the effectiveness of academic institutions' scientific and technological innovation systems(Gao & Qi, 2023). This belief serves as a driving force in implementing knowledge value-oriented distribution policies and demonstrates the significant value that scientific research personnel bring to the table. In essence, scientific research performance is a crucial factor in evaluating the success of colleges and universities in fostering innovation and progress in the science field.

Combining various views from the academic community, this study defines the scientific research performance of universities as the accomplishments and benefits achieved by scientific researchers. This includes papers, monographs, scientific research projects, patents, scientific research technology transfer income, and other related factors. These factors collectively evaluate the productivity and impact of a university's scientific research activities.

2.3 Performance Evaluation

The notion of evaluating performance emerged during the Scientific Management movement in the early 20th century, notably championed by Frederick Taylor and other influential figures. These pioneers emphasized the importance of scientifically assessing and enhancing work performance, subsequently paving the way for the evolution of performance evaluation as a crucial managerial tool (Taylor, F.W.,1911).

Over time, performance evaluation has evolved and been utilized in numerous countries, emerging as a vital instrument in the realms of organizational management and human resources. Performance evaluation is a crucial process that organizations use to assess the effectiveness and efficiency of their systems, strategies, and processes.

The evaluation of performance is an essential process employed by organizations to gauge the effectiveness and efficiency of their systems, strategies, and processes. Through this evaluation, organizations can evaluate if they are successfully meeting their objectives and goals. Furthermore, it enables them to identify areas where improvements can be made and make informed decisions regarding resource allocation and future strategic planning. This process provides valuable insights into how well organizations address customer needs while efficiently utilizing resources for achieving customer satisfaction. Moreover, performance evaluation serves as an essential tool for managers to exercise control over business activities by conducting regular assessments(Petry et al., 2020).

Performance evaluation is a complex and multifaceted concept, with different definitions and understandings depending on the disciplinary perspective of scholars. In academic circles, the definition of performance evaluation can be categorized into two main types: Human resource management, it focuses on employee promotion and salary determinations by assessing their work behavior and effectiveness. In the field of public utility management, performance evaluation aims to assess goal achievement and fund utilization through the establishment of goals, evaluation indicators, and methodologies(Wang, 2022).

Kaplan(1990)believes that performance evaluation involves the assessment of whether an organization has successfully attained its predetermined business objectives and outcomes, either through subjective judgment or by using quantitative criteria. Bacal(1999)believes that performance management is a continuous communication process where employees and their supervisors work together to establish clear expectations regarding essential job functions and how those functions contribute to the organization's goals. Qing et al. (2012) define performance evaluation as the process of making reasonably rational assessments of an organization's performance, efficiency, and effectiveness using standardized criteria, scientific methods, and rigorous procedures.

2.4 Research Performance Evaluation

Research performance evaluation can be defined as the objective, fair, and comprehensive assessment of the outputs of an institution or project within a certain period based on specific standards and scientific methods (Gong et al., 2022). This evaluation aims to measure the research performance and impact, taking into consideration factors such as publication records, citation counts, funding acquisition, collaborations, knowledge transfer, and other relevant indicators. Furthermore, research performance evaluation allows for the identification of strengths, weaknesses, and areas for improvement, ultimately guiding strategic decision-making and resource allocation within the research ecosystem(Mohebifar et al., 2016)

The practice of research evaluation involves investigating certain aspects of the quality of research practice to systematically and scientifically assess researchers (Daghistani et al, 2017). It is essential to use tangible and quantitative measures in research performance evaluation to ensure a systematic and objective assessment. These measures can include metrics such as the number of publications, citation counts, funding acquisition, patents filed, and awards received. By utilizing these quantitative measures, research performance evaluation enables the identification of high-performing researchers, facilitates bench-marking and comparison across different institutions or projects, and informs research management and policy decisions.

Based on a comprehensive analysis of research performance evaluation, this study defines research performance evaluation as the objective assessment of the efficiency in both input and output of a research organization during a specific period. It utilizes scientific methods to establish an evaluative system with rational indicators beyond merely quantifiable funding. In addition, it considers crucial resources such as personnel and material conditions necessary for conducting scientific activities. This study takes a holistic approach to evaluating the research activities of universities by providing a comprehensive and scientifically driven assessment. The aim is to facilitate the rational allocation of limited resources for future endeavors while considering various aspects of measuring research performance accurately.

2.5 Date Envelopment Analysis

Data Envelopment Analysis (DEA) is a comprehensive evaluation method that utilizes the concept of relative efficiency. It employs mathematical programming as its primary tool and optimization as its main approach. DEA evaluates the relative effectiveness or benefit of units, such as departments or enterprises, by analyzing multi-index input and output data. This approach allows for a comprehensive assessment of the performance of similar units, considering multiple factors simultaneously. Since

Charnes, Cooper, and Rhode first proposed the model and used it to evaluate the relative effectiveness between departments in 1978, the DEA method has been continuously improved and widely used in practice, especially in the evaluation of non-purely profitable public services, such as schools, hospitals, and certain cultural facilities. It is considered to be an effective method (Duan & Huo, 2007).

DEA is a powerful and widely used evaluation method that allows for the assessment of the relative efficiency and effectiveness of various organizational units Use the following sources if appropriate (Li et al., 2020). Utilizing the data-driven approach, Data Envelopment Analysis allows for a comprehensive examination of decision-making units' efficiency and performance, providing insightful and actionable information for improvement (Vintila et al., 2022). Moreover, its utilization across a broad spectrum of domains and industries underscores its adaptability as a reference for performance assessment and comparison.

By employing DEA, decision-making units can undergo a thorough evaluation of their efficiency and performance (Jomthanachai et al., 2021). Data Envelopment Analysis offers decision-making units a valuable method to identify areas of improvement and make comparisons among different units. By using objective measures of efficiency, DEA allows decision-makers to inform their decisions effectively regarding resource allocation and organizational management. As a result, it becomes an influential tool in evaluating the efficiency of decision-making units and driving overall organizational improvement(Kristiningrum, 2021).

Owing to its numerous advantages, Data Envelopment Analysis has gained traction as a tool for measuring performance. One significant advantage is that DEA does not rely on any prior knowledge or assumptions about the input-output indicators used. Unlike other methods, it doesn't require pre-specifying the production function parameters to estimate the efficient frontier, making it more flexible and adaptable. Furthermore, unlike partial efficiency measurement methods, DEA evaluates total factor efficiency by considering all input and output indicators simultaneously. This feature makes DEA particularly advantageous for evaluations involving multiple inputs and outputs in various contexts(Bangash et al., 2018).

Additionally, an important aspect to highlight is that the DEA methodology does not require the prior establishment of the importance or weight of inputs and outputs for efficiency analysis. Instead, decision-making units have the flexibility to select weights that will enhance their efficiency value(Mahapatra & Bhar, 2020). This is a substantial advantage as it allows for a more objective evaluation of performance levels, eliminating biases caused by human factors. At the same time, DEA is a technical method based on linear programming, which is very easy to solve and can deal with a large number of constraints and variables. Finally, the DEA method is not limited to efficiency evaluation. It can also find the limitations and shortcomings of the decision-making unit according to the evaluation results, and find the direction of improvement accordingly(Sun, 2014).

The notable DEA models encompass the CCR model contingent on constant returns to scale and the BCC model that takes into account variable returns to scale (Banker et al., 1984), the additive DEA model (Charnes et al., 1986), Russell measure model (Färe et al., 1992), cross-efficiency DEA model (Sexton et al.,1986; Doyle & Green, 1994), super-efficiency DEA model (Andersen & Petersen, 1993), Slacks-Based Measure (SBM) DEA model (Tone, 2001), and the network DEA model (Färe et al., 2007). Besides the extension of the basic DEA model, Simar and Wilson (2007) introduced a two-step regression model accounting for the effect of environmental variables on DEA efficiency (Banker & Natarajan, 2008).

The core principle of the DEA approach involves creating a linear programming model to thoroughly examine input and output data. This process generates an efficiency measure for each Decision Making Unit, which is then used to rank and categorize them based on their relative effectiveness. The DEA method also enables decision-makers to identify reasons why some DMUs are not efficient according to this measure, providing valuable managerial insights.

Extensive academic research has contributed to the evolution of the theoretical framework underlying the DEA method, incorporating various fundamental concepts that establish its principles.

2.5.1 Decision-Making Unit

The Decision-Making Unit plays a crucial role in the DEA method. It refers to a collective entity composed of multiple units or departments, each with its unique inputs and outputs. To qualify as homogeneous, these entities must exhibit three essential characteristics: they pursue common goals and tasks, operate within the same external environment, and display similar types of input and output indicators. If these conditions of homogeneity are not fully met, alternative methods may be utilized to establish an assumption of homogeneity(Huang et al., 2021).

The DEA method necessitates that inputs and outputs meet specific criteria, including disposability, dimensionlessness, input negativity, and output positivity. Outputs refer to outcomes while inputs refer to resources. Decision-making units encompass a wide range of entities, such as schools, hospitals, non-profit organizations in the public sector, enterprises banks even comparative national objects in the private sector. Additionally, the DEA method enables longitudinal studies by considering observations at different time points for a particular organizational entity as decision-making units for analysis(Civic, 2023).

2.5.2 Inputs and Outputs

In the Data Envelopment Analysis model, inputs and outputs are crucial concepts that are used to evaluate the efficiency level of Decision Making Units (Haziq et al., 2019). The definition of inputs and outputs holds deeper significance:

Inputs: Inputs refer to the resources, factors, and costs that are applied, involved, or controlled by Decision Making Units in the production or service process. These inputs can encompass a wide range of resources, such as labor, capital, raw materials, and even energy. In the DEA model, we consider them as different factors that Decision Units consume during their production activities or service provision(Masitoh, 2017).

Outputs: When Decision Making Units engage in production activities or service provision, the concept of outputs is emphasized in the field of economics. Outputs refer to the results, outcomes, or effects that are provided, created, or generated by Decision Making Units. These outputs can include products, services, income, and benefits. In the Data Envelopment Analysis model, inputs and outputs are crucial concepts used to evaluate the efficiency of Decision Making Units(Sinha et al., 2022).

2.5.3 Production Possibility Set

In DEA, the Production Possibility Set (PPS) is an important concept used to represent the diverse production or operational capabilities of Decision Making Units under given input and output conditions.

Specifically, the PPS describes a range of points that can be efficiently achieved by DMUs. These points represent different combinations of inputs and outputs that can be successfully achieved by DMUs under specific resource and technological levels. Those points that are located within the PPS are considered excellent because they represent the maximum output that can be achieved with a given set of resources or the minimum resource utilization for a given output. The main objective of DEA is to determine the relative position of a unit in a production set (Amirteimoori et al., 2004). For this purpose, the distance between each DMU and the PPS is measured to evaluate their relative efficiency. This allows us to identify which units can achieve optimal production efficiency under specific resource and technological conditions, and accurately assess their relative effectiveness compared to other decision-making units.

2.5.4 Production Frontier

Data Envelopment Analysis utilizes the notion of Production Frontier to describe the optimal efficiencies that can be achieved by Decision Making Units given specified input and output conditions. The Production Frontier represents an ideal target that is theoretically unattainable but holds significance. Its primary purpose is to assess the disparity between decision-making units and their potential for maximum output or minimal resource usage in an idealized scenario(Dong & Cai, 2020).

In practical applications, the Production Frontier acts as a benchmark, enabling comparisons between decision-making units and the theoretical state of perfection. This facilitates evaluation of their relative efficiency; with those closer to this frontier being deemed more aligned with the idealized state. To estimate the efficiency of decision-making units, Data Envelopment Analysis uses frontier methods such as the Production Frontier (Tavares & Meza, 2021).

Fundamentally, the Production Frontier concept within Data Envelopment Analysis is employed to gauge the relative efficiency of decision-making entities by contrasting their performance against an idealized situation signifying optimum efficiency. This standard operates as a benchmark for appraising the efficiency of these entities(Guo et al., 2021).

2.5.5 Return to Scale

DEA model employs the concept of Return to Scale to evaluate how changes in production scale impact the efficiency of Decision Making Units. It examines the proportional relationship between inputs and outputs, shedding light on how DMU efficiency fluctuates as the production scale expands, contracts, or remains constant. DEA recognizes three categories for return to scale: Increasing Returns to Scale indicates that efficiency improves when inputs and outputs expand proportionally; Constant Returns to Scale suggests that efficiency remains stable as inputs and outputs increase proportionally; Decreasing Returns to Scale indicate a decline in efficiency when inputs and outputs expand proportionally. By assessing return to scale status, DEA offers valuable insights into the influence of production scale on efficiency, enabling decision-makers to understand better and optimize opportunities for the production process(Ahmed et al., 2022; Chau & Ahamed, 2022).

2.5.6 Comprehensive Efficiency

Comprehensive Efficiency refers to the overall efficiency level achieved by a decision-making unit (such as a company or organization) in terms of production or input-output relations in DEA analysis.

It takes into account all outputs and inputs of production, as well as the contributions of both pure technical efficiency and scale efficiency. The comprehensive efficiency is calculated using the formula: Comprehensive Efficiency= Pure Technical Efficiency* Scale Efficiency(Liang & Chen, 2022).

Pure Technical Efficiency represents the technical efficiency achieved by a decision-making unit in production while maintaining the same scale level. It measures whether there is any unnecessary resource wastage in the production process. Scale Efficiency, on the other hand, evaluates the optimal scale at which a decision-making unit should operate to minimize resource utilization and maximize output (Mujasi et al., 2016).

2.6 Policy of China

In China, the policy for evaluating scientific research performance holds a pivotal place in the macroscopic national policies. It is essential to effectively implement policies for evaluating scientific research performance to enhance the innovative capabilities of scientists and researchers, facilitate the translation of scientific achievements into practical applications, and elevate the overall development of scientific research institutions. In addition, these evaluation policies play a vital role in guiding resource allocation and organizational management to ensure efficient operations and optimize the distribution of research resources.

To effectively implement policies for evaluating research performance, the Chinese government has implemented various measures and initiatives aimed at encouraging researchers to actively engage in research activities and enhance their performance. Furthermore, there is increased support for small and medium-sized enterprises in innovation practices which further stimulates technological innovation. Additionally, the government promotes collaboration between universities, research institutions, and enterprises through policy interventions that facilitate knowledge transfer, accelerate technology adoption, and foster an innovative culture(Yao et al., 2021).

Since 2014, when the comprehensive implementation of the national science and technology system reform took place, there has been a strong emphasis on deepening decentralization, simplifying administration processes, and enhancing services. The main objective is to promote scientific advancements through effective knowledge transfer and value creation. By continuously unlocking policy dividends and fostering innovative talent within the scientific community, efforts are being made to boost productivity and overall vitality in the field of science and technology.

In 2016, the National Science and Technology Innovation Conference laid out plans to actively implement a distribution policy focused on increasing knowledge value. This included the implementation of the Sanyuan salary system, which recognizes and rewards value. The Sanyuan system considers factors such as basic salary, performance, and the transformation of scientific research achievements, all closely linked to research activities. These factors reflect scientific, economic, and social values that contribute to the satisfaction and visible performance of researchers.

In 2018, China's State Council released a document titled "Notice on Enhancing Scientific Research Management and Promoting Scientific Performance". The document underlined the importance of strengthening original innovation capabilities and core technological research capacities in key sectors. The objective was to generate more high-level achievements and stimulate economic development. Enhancing the quality of scientific research performance is viewed as an effective way to drive innovation and progress in universities. By investing in original innovation capabilities and core technological research abilities, China aims to foster high-level achievements and drive economic development.

The notice also clearly stated a range of specific actions to improve research management and boost research outcomes. These actions include enhancing project management, optimizing the use of research funds, advancing the conversion of scientific achievements into practical applications, refining evaluation methods for research activities, and piloting performance-based reforms in research management. The objective is to significantly enhance the innovation capacities of the research system, promote high-quality research outputs, and foster a seamless integration between technological innovation and economic growth.

In February 2020, the Chinese Ministry of Education, along with various other departments, jointly released a set of guidelines titled "Improving Patent Quality in Universities to Foster Innovation and Application". The document outlines various measures aimed at enhancing patent management in universities, such as strengthening intellectual property protocols, conducting preliminary assessments for patent applications, bolstering specialized departments and talent cultivation efforts, and optimizing policy frameworks. These initiatives are intended to enhance the overall quality of patents held by universities with a specific focus on generating valuable patents that can effectively contribute to economic growth and societal progress. The document sets forth specific goals for universities to achieve by 2022, including the establishment of a comprehensive intellectual property management system that covers all aspects of patent navigation, application, maintenance, and transformation. This system is designed to seamlessly integrate with the university's science and technology innovation framework as well as its technology transfer and commercialization efforts. By 2025, there is an expectation for significant enhancements in the quality of university patents along with improved capabilities in patent operation. The ultimate aim is for select universities to attain rates of patent authorization and implementation comparable to those observed at renowned global institutions. These objectives collectively seek to facilitate overall progress within the realm of intellectual property at universities while enabling them to excel in scientific research and effectively transform their innovative outcomes.

In 2021, the General Office of China's State Council issued guiding opinions aimed at enhancing the evaluation process for scientific and technological advancements. The opinions underscore the necessity to motivate researchers in the field, encourage high-quality outcomes, foster a conducive environment for innovation, and facilitate seamless integration between innovation activities, industrial operations, and value creation. Key measures promoted include refining a comprehensive classification and assessment system for scientific achievements; expediting reforms related to evaluating national projects' scientific outcomes; providing guidelines for standardizing third-party evaluations of scientific achievements; as well as strengthening incentives and exemptions associated with assessing scientific progress.

The Law of the People's Republic of China regarding Scientific and Technological Advancement was implemented by China on the first day of 2022. This law aims to enhance objectives and principles, reinforce basic research capabilities, boost national strategic scientific capacities, facilitate advancements in key technologies, support innovation in businesses, foster scientific talent development, and strengthen safeguards for technological innovation. In addition to the existing 8 chapters and 75 articles are four new chapters: Basic Research, Regional Innovation, Technologies, International Cooperation in Science and Technology, and Oversight and Management.

It is particularly underscored that institutions and universities funded by financial resources should actively facilitate the conversion of scientific and technological breakthroughs. This entails enhancing the establishment of technology transfer organizations and expert teams, as well as creating and refining systems to ease the transformation process of scientific inventions. The updated Law on Scientific and Technological Progress offers a more comprehensive and forward-thinking approach, providing improved support for the advancement and enhancement of China's innovation system in science and technology.

On March 30, 2022, the Torch Center of the Ministry of Science and Technology issued a notice outlining key tasks for 2022. The focus is to deepen the high-quality development of national high-tech zones through various initiatives. These include promoting technological innovation capabilities in science and technology enterprises, improving science and technology innovation and entrepreneurship, enhancing the modern technology factor market system, implementing strategies to strengthen weak links in high-tech industries, exploring financial systems that support advanced technological innovation, fostering openness and cooperation in science and technology innovation efforts, as well as conducting strategic policy research for decision-making support. The notice specifically emphasized the launch of additional pilot projects aimed at specialized technology transfer institutions in universities. It underscored the growth of the pilot program to foster innovative mechanisms for converting scientific and technological accomplishments in universities, thereby enhancing their ability to effectively transfer and transform such achievements.

In 2022, an official pronouncement, named 'Several Opinions on Reinforcing Systemized Investigation in Academia and Advocating Superior-Level Autonomy', was promulgated by China's Ministry of Education. The intent is for institutions of higher learning to make full use of the benefits from the new country-wide arrangement, concentrate on the fortification of methodized investigation, fully boost the edification of the innovation mechanism, and center their attention on intensifying spontaneous inventive capabilities. This pronouncement portrays nine principal implementations to invigorate systemized investigation in academia, one of which includes propelling the transformation of the investigation evaluation machinery.

In 2023, the Ministry of Science and Technology, along with other entities, released a notice called Views on Further Supporting the Accelerated Construction of the Western Science City. The objective is to offer additional backing for the Chengdu-Chongqing area in expediting the development of the Western Science City. This will be accomplished using a model that emphasizes multiple parks within a single city, working towards establishing an influential center for scientific and technological advancement at a national level. Specific actions include collaborating on national-level innovation platforms to enhance strategic scientific and technological capabilities, prioritizing critical core technologies to strengthen competitive advantages in strategic industries, implementing reforms in science and technology institutions to improve efficiency, constantly improving upon existing innovation ecosystems, as well as fostering regional exchanges and cooperation to establish a new hub for inland openness in western China.

As shown in Table 2.1, the Chinese government has implemented various regulations and laws to promote and support technological innovation, including intellectual property management, science and technology progress, and the establishment of an innovation system dominated by enterprises. These policies and initiatives aim to allocate resources, enhance research and development capabilities, foster collaboration between different innovation subjects, and improve the transfer and transformation of scientific inventions. Furthermore, the Chinese government is actively pursuing initiatives to deepen high-quality development in national high-tech zones, with a focus on promoting technological innovation capabilities in science and technology enterprises, improving science and technology innovation and entrepreneurship, enhancing the modern technology factor market system, strengthening weak links in high-tech industries, implementing supportive financial systems, fostering openness and cooperation, and conducting policy research for decision-making support. Simultaneously, continuously advancing the reform of the assessment mechanism for scientific research performance.

These efforts by the Chinese government demonstrate its commitment to creating an ecosystem that promotes technological innovation, fosters collaboration between various stakeholders, and enables the conveyance and metamorphosis of scholastic and technological accomplishments to favor the progression of the nation and competitiveness on an international level.

By implementing these policies and initiatives, the Chinese government is striving to achieve its objectives of allocating a percentage of GDP to R&D, sourcing growth from scientific and technological progress, relying on homegrown technologies for production, and promoting strategic and emerging industries (Qiang et al., 2021).

Table 2.1 Relevant Policies of China

Policy Name	Release Time	Main Content
The National Science and Technology Innovation Conference	2016	It laid out plans to actively implement a distribution policy focused on increasing knowledge value.
The Notice on Enhancing Scientific Research Management and Promoting Scientific Performance	2018	It pointed to enhancing project management, optimizing the use of research funds, advancing the conversion of scientific achievements into practical applications, refining evaluation methods for research activities, and piloting performance-based reforms in research management.
Improving Patent Quality in Universities to Foster	2020	It pointed to strengthening intellectual property protocols, conducting

Innovation and Application		preliminary assessments for patent applications, bolstering specialized departments and talent cultivation efforts, and optimizing policy frameworks.
Guiding Opinions Aimed at Enhancing the Evaluation Process for Scientific and Technological Advancements	2021	It underscored the necessity to motivate researchers in the field, encourage high-quality outcomes, foster a conducive environment for innovation, and facilitate seamless integration between innovation activities, industrial operations, and value creation
Several Opinions on Strengthening Organized Research in Universities and Promoting High-Level Self-Reliance	2022	It aims to encourage universities to fully leverage the advantages of the new nationwide system, strengthen organized research, comprehensively enhance the construction of the innovation system, and focus on improving independent innovation capabilities. The document outlines nine key measures to strengthen organized research in universities, including advancing the reform of the research evaluation mechanism.
Law of the People's Republic of China on Scientific and Technological Progress	2022	It pointed to enhancing objectives and principles, reinforce basic research capabilities, boost national strategic scientific capacities, facilitate advancements in key technologies, support innovation in businesses, foster scientific talent development, and strengthen safeguards for technological

		innovation.
The Key Points of the Torch Center of the Ministry of Science and Technology in 2022	2022	It pointed to promoting technological innovation capabilities in science and technology enterprises, improving science and technology innovation and entrepreneurship, enhancing the modern technology factor market system, implementing strategies to strengthen weak links in high-tech industries, exploring financial systems that support advanced technological innovation, fostering openness and cooperation in science and technology innovation efforts, as well as conducting strategic policy research for decision-making support.
Opinions on Further Supporting the Accelerated Construction of the Western Science City	2023	It aims to offer additional backing for the Chengdu-Chongqing area in expediting the development of the Western Science City. This will be accomplished using a model that emphasizes multiple parks within a single city, working towards establishing an influential center for scientific and technological advancement at a national level.

Chinese universities play a vital role in the pursuit of China to become a leading technological force. They serve as essential platforms for implementing research policies and systems, while also playing a key role in nurturing skilled scientific and technological talents, advancing cutting-edge research projects, and facilitating collaborations between academia, industry, and research institutions. By doing so, universities are instrumental in driving technological innovation and turning China's vision into reality. The outcomes of their extensive research efforts directly impact the nation's overall technological landscape and significantly enhance its position on the global stage of technology. As such, universities are widely recognized as major drivers towards achieving supremacy in technology advancement(Resce et al., 2022).

Chinese universities have a significant impact on the progression of science and technology in the country, as evident from their research performance. Evaluating this performance is vital for assessing the effectiveness of technological endeavors and measuring universities' contributions to scientific advancements. Strengthening the evaluation process is particularly important as it enables a comprehensive understanding of research achievements and offers insights into enhancing university research capabilities through thorough analysis(Gao et al., 2023).

Chinese higher vocational colleges play a crucial role in advancing science and technology nationally. The research performance of these colleges directly impacts technological capabilities and talent development, leading to practical and effective outcomes for industries. By focusing on specific domains such as engineering and applied sciences, vocational colleges contribute significantly to the resolution of real-world industrial issues and the transformation of technological achievements. This emphasis on collaboration with industries positions them uniquely in driving technological innovation within related fields. As a result, their research performance plays an indispensable role in elevating the country's overall technological proficiency(Xi et al., 2023).

Assessing the scientific research performance enables universities and colleges to identify their areas of strength and weakness, enabling them to develop specific strategies for improvement and elevate their research standards. This not only helps universities and colleges meet their obligations in alignment with national science and technology policies but also drives the entire national science and technology system towards greater levels of success(Tang, 2013).

2.7 Policy of Sichuan

In the past ten years, Sichuan Province has introduced a wide range of policies related to scientific and technological innovation. These policies, totaling more than 240 in number, reflect the province's strong commitment to promoting and facilitating advancements in science and technology. The objectives of these initiatives include fostering technological innovation, attracting talented individuals, and establishing relevant programs for scientific research and development. Table 2.2 provides an overview of some notable policies that have been implemented.

In 2013, the Sichuan Provincial Party Committee and the Government of Sichuan Province recognized the importance of innovation-driven development as a key strategic priority. A document titled "Opinions on Implementing Innovation-driven Development Strategy to Enhance the New Power of Sichuan's Transformation and Development" was introduced during this time. This document emphasized deliberate innovation as a means to bolster economic growth through advancements in science and technology. Additionally, it set forth an ambitious goal for achieving an innovative Sichuan by 2020, signifying a major shift towards an era propelled by groundbreaking ideas and discoveries.

In 2017, the government of Sichuan Province released a strategy titled "Advancing Sichuan as an Innovative Province". This plan sets out goals to greatly strengthen the province's scientific and technological capabilities by 2020. The objective is to drive comprehensive innovation and reform, encourage advancements in science and technology systems, and shift the overall development approach towards innovation. Ultimately, it aims for Sichuan to become a leading province in national innovative development while fostering an environment supportive of creativity. The plan highlights Sichuan Province's dedication to fostering innovation and technological progress, acknowledging their significance in stimulating economic growth and improving competitiveness. The provincial government recognizes the importance of nurturing innovation and enhancing technological capabilities as drivers of economic development and increased competitiveness.

In 2020, China's Western Science City was established with the specific purpose of becoming a leading hub for national innovation. Its objective is to bring together various elements of advanced innovation and serve as an exemplary model for fostering entrepreneurship and innovation. As a result of these initiatives, Sichuan Province has witnessed accelerated progress in scientific and technological advancements. Higher vocational colleges play a vital role as they nurture both technical skills and social capabilities, which are directly intertwined with societal economic growth and business development. The Western Science City is strategically designed and developed as a central area of national significance, to be a catalyst for innovation nationwide. Its purpose extends beyond just facilitating innovative activities; it also serves as a hub for cutting-edge innovation elements. Furthermore, it aims to showcase ecological practices in innovation and entrepreneurship. Driven by this development strategy, Sichuan Province is actively promoting research and development as well as the conversion of scientific and technological achievements. The establishment of the Science City will serve as a powerful catalyst for the creation of an innovative ecosystem, nurturing the rapid growth of new technologies and industries. In particular, when it comes to spearheading cutting-edge innovation, Western Science City holds a crucial role as a nationally significant platform that aims to demonstrate leading levels of technological innovation across China.

In 2020, the Sichuan Provincial Department of Science and Technology, along with ten other departments, released the Implementation Opinions on Advancing the Reform of Ownership or Long-term Use Rights for Scientific and Technological Achievements Granted to Researchers. The document emphasizes the urgency to expedite the conversion and commercialization of scientific and technological advancements. It also highlights efforts in establishing a nationally influential center for innovation while fast-tracking progress in transforming Sichuan into a province that pioneers development driven by innovation.

In 2020, the Sichuan Province Government released the Sichuan Province Vocational Education Reform Implementation Plan. This plan highlights the objective of significantly restructuring the governance framework in vocational education within a timeframe of around 5 to 10 years. The aim is to transition from a primarily government-funded approach to one that involves coordinated management by the government with active involvement from various social stakeholders. During this time frame, there will be more noticeable differences in the nature of vocational education, including the types offered, industry-specific traits, and technical aspects. Vocational colleges will further enhance their strengths in terms of specialized characteristics and service capabilities. A comprehensive vocational education training system that is vertically integrated and horizontally connected will be established as a result of successful reforms in the collaborative school-enterprise mechanism. This system encourages a synergy between theoretical knowledge and practical learning. Overall, there will be significant improvements in the quality of training for technical and skilled personnel, which plays an instrumental role in advancing vocational education's modernization level. This significant advancement in the modernization of vocational education will contribute to strong talent support and intellectual reinforcement, playing a central role in promoting economic and social development and facilitating Sichuan's progress. The plan highlights important objectives such as improving the modern vocational education system, advancing high-quality vocational education, enhancing the training of technical personnel with excellent skills, deepening collaboration between schools and enterprises for industry-education integration, developing a highly qualified teaching faculty, strengthening service capabilities, and increasing openness.

In 2021, the government of Sichuan Province released a notification titled "Comprehensive Policies to Further Support Scientific and Technological Innovation". The document strongly emphasizes the importance of developing an advanced innovation ecosystem to foster technological advancement, specifically by encouraging scientific and technological professionals to engage in innovative activities. The notice particularly underscores the significant role played by universities in constructing provincial research and development platforms, facilitating the commercialization of scientific achievements, and nurturing high-level teams focused on innovation. Universities are acknowledged as a crucial driving force behind technological advancements with their indispensable contribution towards building provincial research facilities, promoting technology transfer efforts, and cultivating exceptional innovation teams.

In 2021, the Science and Technology Department of Sichuan Province, along with six other relevant departments, collectively released the Notification on Implementation Guidelines for Advancing the Comprehensive Integration of Culture and Technology. This notification explicitly highlights the importance of supporting collaborative efforts between universities, research institutions, and enterprises in establishing industry-university-research alliances. The objective behind issuing this notification is to provide specific guidance and policy backing to promote deep integration of culture and technology. By fostering collaboration across various sectors, provincial-level entities aim to create a conducive environment for innovation and development while enhancing Sichuan Province's overall prowess in culture and technology domains.

In 2022, the General Office of the People's Government of Sichuan Province released a notification regarding the implementation of the Action Plan for Enhancing Collaborative Innovation Development Capacity. The plan outlines development goals aimed at establishing a robust collaborative innovation system in the Chengdu-Chongqing region by 2025. These objectives include strengthening strategic scientific and technological capabilities, making significant advancements in constructing Western Science City, forming essential functions of science and technology innovation centers, achieving an overall research and development intensity target of approximately 2.5% throughout society, and attaining a scientific and technological progress contribution rate of 63%.

To enhance independent innovation capabilities, the province aims to deeply integrate science and technology with economic development. The goal is to achieve a significant increase in the number of effective high-value invention patents per ten thousand people, with high-tech industries accounting for over 38% of total industrial output from businesses above a certain scale. Additionally, there will be more than 16,000 high-tech enterprises and a cumulative transaction value of technology contracts exceeding 600 billion yuan. The plan also includes constructing the province as a prominent demonstration area for national science and technology innovation and collaborative innovation by implementing a total of 27 key tasks.

Table 2.2 Relevant Policies of Sichuan

Policy Name	Release Time	Main Content
Opinions on Implementing Innovation-driven Development Strategy to Enhance the New Power of Sichuan's Transformation and Development	2013	This document emphasized deliberate innovation as a means to bolster economic growth through advancements in science and technology. Additionally, it set forth an ambitious goal for achieving an innovative Sichuan by 2020, signifying a major shift towards an era propelled by groundbreaking ideas and discoveries.
Advancing Sichuan as an Innovative Province	2017	This plan sets out goals to greatly strengthen the province's scientific and technological capabilities by 2020. The objective is to drive comprehensive innovation and reform, encourage advancements in science and technology systems, and shift the overall development approach towards innovation.
the Implementation Opinions on Advancing the Reform of Ownership or Long-term Use Rights for Scientific and	2020	It emphasizes the urgency to expedite the conversion and commercialization of scientific and technological advancements. It also

Technological Achievements Granted to Researchers.		highlights efforts in establishing a nationally influential center for innovation while fast-tracking progress in transforming Sichuan into a province that pioneers development driven by innovation.
Sichuan Province Vocational Education Reform Implementation Plan.	2020	This plan highlights the objective of significantly restructuring the governance framework in vocational education within a timeframe of around 5 to 10 years. The aim is to transition from a primarily government-funded approach to one that involves coordinated management by the government with active involvement from various social stakeholders.
Comprehensive Policies to Further Support Scientific and Technological Innovation	2021	The document strongly emphasizes the importance of developing an advanced innovation ecosystem to foster technological advancement, specifically by encouraging scientific and technological professionals to engage in innovative activities. The notice particularly underscores the significant role played by universities in constructing provincial research and development platforms, facilitating the commercialization of scientific achievements, and

		nurturing high-level teams focused on innovation.
Notification on Implementation Guidelines for Advancing the Comprehensive Integration of Culture and Technology	2021	This notification explicitly highlights the importance of supporting collaborative efforts between universities, research institutions, and enterprises in establishing industry-university-research alliances. The objective behind issuing this notification is to provide specific guidance and policy backing in order to promote deep integration of culture and technology.
Action Plan for Enhancing Collaborative Innovation Development Capacity	2022	The plan outlines development goals aimed at establishing a robust collaborative innovation system in the Chengdu-Chongqing region by 2025. It specifies a total of 27 key tasks.

The mentioned policies have a significant influence on guiding the research activities of higher vocational colleges in Sichuan Province, setting elevated standards for enhancing their research capabilities. It is crucial that these colleges align their research activities with the government's policies and goals stated above to contribute effectively to the overall innovation and development agenda of Sichuan Province. Therefore, it is crucial to accurately assess the research performance level of higher vocational colleges scientifically.

This assessment can be done by evaluating their research output, technology transfer activities, collaboration with industries, and the overall impact of their research on economic development in Sichuan Province. By conducting a systematic analysis, the strengths and weaknesses of higher vocational colleges' research capabilities can be identified, allowing for targeted measures to improve their performance.

2.8 Related Research China and Outside

Numerous studies have suggested that the Data Envelopment Analysis method(DEA) is a non-parametric efficiency evaluation approach that can be employed to analyze resource utilization efficiency. Many scholars have extensively researched and explored the application of DEA in performance evaluation.

2.8.1 Overseas Research Status

El Kadiri Boutchich D.(2021) applied the DEA model in 2021 to appraise the efficiency of the structure of research in higher education, expose possible issues, and hone the direction for solutions. Similarly, Mo et al.(2023) apply the DEA model to analyze the research output of Chinese universities and determine the regions with the highest technical efficiency, pure technical efficiency, and scale efficiency of research performance.

Moreover, Soummakie et al.(2021)evaluated the efficiency of higher education institutions using the DEA method, identifying institutions with high and low efficiency and key factors for enhancing research performance. Furthermore, Ibrahim et al.(2021)applied the DEA method to evaluate the performance efficiency of Indonesia's world-class universities. They revealed their resource utilization status, which is important for developing and enhancing higher education institutions in Indonesia. Dimyati et al. (2023) conducted an efficiency analysis on the research competence of the Indonesian higher education structure, grounded in the data accrued from 47 academia in the Mandiri and Utama clusters, encapsulating the period from 2014 to 2018. What emerged from their analysis was that about 68% of the institutions in the Mandiri cluster, nearly 40% in the Utama cluster, and 41% when considering both clusters in unison, achieved an efficiency score of 1.

Contreras et al.(2020) used the DEA method to discuss four scenarios of allocating additional resources to the public university system and found that the different scenarios obtained very similar output and utility targets, although they suggested rather different resource allocations. Naderi(2019) used DEA to analyze the performance efficiency of 77 departments in a public university in Iran and found that the VRS model was more accurate and had relatively high average departmental efficiency by comparing the various DEA models, with about half of the departments DEA effective, but with scale inefficiencies and relatively large heterogeneity between departments. Zinkovsky et al.(2018), to discuss whether restructuring universities can improve research performance, found through DEA that Russian universities made progress in closing the gap in performance levels with their main competitors in 2015 compared to 2010, and compared the predicted results of studies on restructuring of Russian universities, using developed theoretical concepts to explain possible post-reorganization.

2.8.2 Domestic Research Status

In China, university scientific research performance has been a key area of research for domestic scholars, but there are problems such as research performance evaluation indexes are not systematic and comprehensive, and research performance evaluation systems are not systematic and perfect (Ling, 2023).

Domestic scholars have used BCC and CCR models of DEA and DEA models combined with other models to analyze and study the scientific research performance of universities for different objects, respectively. Ma Xinyue et al. (2021) analyzed the research performance of 72 national model higher education institutions in China, and found that the research performance of China's model higher education institutions is non-DEA effective, with large differences between institutions; the non-DEA effective institutions mainly have the problem of input redundancy; the research performance of China's higher education institutions varies greatly between regions, and the overall research level in the western region is weaker. Xia Wenjie (2022) used the CCR-DEA model to study the performance evaluation of secondary colleges in Chongqing A universities from 2016 to 2020 and found that there are problems of unreasonable evaluation index system setting, unclear definition of evaluation indexes with mutual influence, lack of scientificity in evaluation methods and procedures, and single application of evaluation results, and according to the DEA output results, it was found that the overall performance of secondary colleges was decreasing, with serious loss of input-output efficiency. Sun Chongwen et al. (2018) used the BCC-DEA model, an analysis was conducted to evaluate the efficiency of University-Industry Collaborative Innovation in Hubei Province. The findings revealed that the efficiency of the research and development stage of University-Industry Collaboration, as exemplified by Hubei Province, surpassed that of the results transformation stage. This suggests that Hubei Province excels in the initial research and development phase of collaborative innovation, while there may be room for improvement in effectively translating research outcomes into practical applications. These results highlight the importance of focusing on enhancing the effectiveness of the results transformation stage to fully harness the potential of University-Industry Collaborative Innovation in Hubei Province. Li Kang and his team utilized a three-stage DEA model, supplemented by stochastic frontier analysis theory, to assess the research proficiency of universities being modeled into first-class institutions. The analysis was bifurcated into three parts: stage 1 employed the conventional DEA model, while stage 2 involved SFA regression, and stage 3 implemented adjusted DEA assessment. The investigation extended to look into the fluctuations in how environmental elements affect research efficiency. The results inferred that China's first-class universities' collective research efficiency could potentially be overvalued. Factors like regional economic status, the populace's education level, and governmental patronage demonstrated inconsistent effects on each university's research efficiency. Moreover, universities in the process of attaining top-tier status exhibited a trend towards differentiation in research efficiency, underscored by a visible manifestation of diminishing scale returns. These findings elucidate the intricacies and determinants shaping research efficiency within China's elite universities(Li Kang et al., 2022). Yuan Zehui (2022) stated that data on scientific research innovation inputs and outputs of universities in 31 provinces, cities, and autonomous regions of China were collected from 2016 to 2020. Using the DEA-BCC model and super-efficient DEA model, a static analysis was conducted to evaluate the scientific research performance of universities. The findings revealed that the comprehensive technical efficiency values of universities over the past five years were relatively low, with noticeable regional distribution disparities. These results indicate that there is room for improvement in the level of scientific research performance among universities. Efforts can be made to enhance efficiency and effectiveness in scientific research to further elevate the overall performance of universities in China.

Assessing university scientific research performance solely through a single DEA model may not offer a comprehensive understanding of the evolving patterns and developmental trends. Static analysis of performance has limitations in capturing the underlying reasons for changes in research performance. To gain a more comprehensive understanding of these dynamics, it is essential to employ panel data analysis to evaluate productivity in a dynamic manner. By utilizing panel data, researchers can examine long-term trends, identify factors influencing research performance, and gain insights into the productivity dynamics of universities over time. This approach enables a more nuanced and comprehensive assessment of university research performance, facilitating informed decision-making and targeted interventions to enhance productivity and overall research outcomes.

Cai Wenbo et al.(2022) used the research performance of China's double first-class universities analyzed using the DEA-Malmquist model. The findings revealed that only two universities maintained effective DEA performance from 2010 to 2017. The technical efficiency, technical progress rate, and total factor productivity of scientific research among the universities were observed to fluctuate and decline to varying degrees over the study period. Qi Tian (2023) used During the 13th Five-Year Plan period, the scientific research efficiency of various universities in China was analyzed using the DEA-BCC model, DEA-SE model, and Malmquist index model to examine both static and dynamic trends. The results indicated that the overall scientific research efficiency of universities was high, with comprehensive and scientific universities consistently achieving effective DEA performance over five consecutive years. The productivity index of colleges and universities exhibited an alternating pattern of growth and decline, primarily driven by changes in the technological progress index and technical efficiency. Moreover, the allocation of scientific and technological resources in colleges and universities was found to adequately meet their research needs. The research efficiency demonstrated a positive correlation between high input and high output. These findings underscore the effectiveness of scientific and technological resource allocation in supporting research endeavors, contributing to the overall productivity and efficiency of universities in China.

Zhao Qingguo et al.(2020) have been conducted to analyze the scientific research performance of colleges and universities in different regions of China using the super-efficiency DEA model and the Malmquist index method. These studies have found that the overall level of scientific research performance in Chinese colleges and universities is high, with the efficiency of technological progress being a significant influencing factor. However, the total factor productivity of scientific research shows a slow growth trend, and there are regional differences in scientific research performance, with better performance observed in the eastern region compared to the central and western regions. It is worth noting that while there have been numerous studies on the scientific research performance of universities in China using the DEA model, there is a lack of research on the correlation between input indices of scientific research performance and the importance of scientific research efficiency using Rough Set Theory. Additionally, there is limited research on the scientific research performance of higher vocational colleges, particularly in Sichuan Province.

One relevant study by Liu Feng et al. (2019) aimed to improve the existing domestic university scientific research performance evaluation index system by using the CCA model. They established a more reasonable and suitable evaluation index system for university scientific research performance based on comprehensive DEA evaluation.

In summary, while there have been various studies on the scientific research performance of universities in China, there is still room for further research to explore the correlation between input indices and scientific research efficiency using methods like Rough Set Theory. Additionally, more attention could be given to analyzing the scientific research performance of higher vocational colleges, particularly in specific regions like Sichuan Province.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Research Design

3.1.1 DEA－BCC Model

Data Envelopment Analysis (DEA) makes use of two principal models: the BCC model, which is synonymous with the Variable Returns to Scale model, and the Constant Returns to Scale model, more commonly known as the CCR model. The BCC model offers adaptability by accommodating different scales of returns for decision-making units. This flexibility accurately mirrors real-world scenarios where organizations experience fluctuations in scale overtime periods. Specifically, when assessing cases involving significant changes in organizational scale, such as variations in scale efficiency, the BCC model proves suitable. In contrast to smaller-scale situations with minimal or stable changes in scale, the model was developed by Charnes, Cooper, and Rhodes. Elaborating a constant-sized return enables this simpler yet less flexible CCR modeling technique that doesn't accommodate variations encountered for determining larger-scale alternatives and their level of productivity variation. In summary, the DEA models provide different approaches to assessing efficiency in decision-making units.

Universities and colleges are typical multi-input and multi-output systems, based on the variable scale remuneration of scientific research efficiency, this study uses the DEA-BCC model to measure and analyze the scientific research performance of Sichuan vocational colleges.

Imagine a collection of n units responsible for making decisions. Each unit possesses m different input types and s different output types.

Given the unique functions of every input and output indicator in the decision-making unit, it is additionally presumed: v_i is the weight for the i-th input indicator, $(1 \le i \le m)$; u_r is the weight for the r-th output indicator, $(1 \le r \le s)$.

Let X_j and Y_j represent the input vector and output vector of DMU_j , respectively.

v and u represent the weight vectors for m types of inputs and s types of outputs, respectively,and $(v \geq 0, u \geq 0)$.

$$X_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T, j = 1, \cdots, n$$

$$Y_j = (y_{1j}, y_{2j}, \cdots, y_{mj})^T, j = 1, \cdots, n$$

$$v = (v_1, v_2, \cdots, v_m)^T$$

$$u = (u_1, u_2, \cdots, u_s)$$

Assigning specific weights to each input and output indicator, efficiency evaluation (h_j) indices are obtained for each decision-making unit.

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

The production possibility set of the BBC model is:

$$T_{BCC} = \left\{ (X,Y) \mid X \geq \sum_{j=1}^{n} \lambda_j X_j, Y \leq \sum_{j=1}^{n} \lambda_j Y_j, \sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0, j = 1, \cdots, n \right\}$$

The input-oriented BCC model and its dual programming are:

$$(P^I{}_{BCC}) \begin{cases} \max\left(\mu^T Y_{j_0} - \mu_0\right), \\ \omega^T X_j - \mu^T Y_j + \mu_0 \geq 0, j = 1, \cdots, n \\ \omega^T X_{j_0} = 1 \\ \omega \geq 0, \mu \geq 0, \mu_0 \in E^1 \end{cases}$$

and

$$(D^I{}_{BCC}) \begin{cases} \min \theta, \\ \sum_{j=1}^{n} X_j \lambda_j \leq \theta X_{j_0}, \\ \sum_{j=1}^{n} Y_j \lambda_j \geq Y_{j_0}, \\ \sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0, j = 1, \cdots, n \end{cases}$$

1) If the optimal solutions ω^0, μ^0, μ_0^0 of linear programming problem $(P^I{}_{BCC})$

Satisfy $u^{0T} Y_{j_0} - \mu_0^0 = 1$, then DMU_{j_0} is referred to as weakly DEA efficient.

2) If the optimal solutions ω^0, μ^0, μ_0^0 of linear programming problem $(P^I{}_{BCC})$

Satisfy $u^{0T}Y_{j_0} - \mu_0^0 = 1$, and $\omega^0 > 0, \mu^0 > 0$,then DMU_{j_0} is referred to as DEA efficient.

Similarly, according to the dual theory of linear programming, similar conclusions can be drawn:

1) The necessary and sufficient condition for DMU_{j_0} to be weakly DEA efficient is $\theta^0 = 1$.

2) The necessary and sufficient condition for DMU_{j_0} to be DEA efficient is $\theta^0 = 1$, And the optimal solutions of λ^0 , S^{-0} , S^{+0} and θ^0 satisfies $S^{-0} = S^{+0} = 0$.

3.1.2 Malmquist index model

The Malmquist Index, a methodology initially put forward by Sten Malmquist in 1953, allows for an analysis of total factor productivity. This technique is particularly useful for investigating shifts in production efficiency in pre- and post-intervals around the decision-making unit(Malmquist, 1953). Fare et al. integrated time variables into their measurement matrix to track the dynamic alterations of the total factor productivity efficiency index spanning two contiguous periods (Färe et al., 1992).

3.1.2.1 Total Factor Productivity (TFP)

Total Factor Productivity serves as a comprehensive measure that evaluates the efficiency of a production unit in utilizing various factors, including labor, capital, and technology. It takes into account the collective contributions of all these factors to output rather than focusing solely on individual factor efficiency. TFP provides an encompassing perspective by assessing overall production efficiency. Its calculation involves comparing actual output to the combined input of production factors. An increase in TFP signifies that, between two time points, the same level of input generates greater output, while a decrease indicates declining productivity. Within the Malmquist index model, changes in TFP are utilized for measuring overall productivity variations and can be divided into technological and scale efficiency alterations(Le et al., 2019).

3.1.2.2 Technological Efficiency (TE)

Technological Efficiency is a metric used to assess the maximum output that a producer or firm can achieve given their existing technology. It plays a crucial role in production economics by evaluating if resources are being effectively utilized during the production process. By analyzing the technological efficiency of the Malmquist index model, companies can identify areas where improvements in resource allocation and technology utilization can be made, leading to increased productivity and profitability (Chen & Zou, 2020). Technological efficiency reflects the extent to which an economic system, firm, or producer, under given technological conditions, utilizes input resources (such as labor, capital, raw materials, etc.) to produce output products. A producer is considered technologically efficient if they can achieve maximum output without wasting resources.

3.1.2.3 Technological Progress(TP)

Technological Progress is defined as the shift in the proximity between production frontiers over varying points in time. This change reflects how technology has evolved. Specifically, the Technological Progress index is calculated by comparing Total Factor Productivity at a later point in time to TFP at an earlier point in time. An index that exceeds 1 signifies the occurrence of technological advancement. This implies that, at a subsequent time frame, producers can yield heightened output levels utilizing the same amount of inputs. if the value is less than 1, it suggests technological regression. Technological progress plays a crucial role in Malmquist index analysis as it helps measure changes in technological efficiency over time.

3.1.2.4 Technological Change(TC)

Technological Change refers to the relative distance change between production frontiers at two separate points in time. It is used to measure the evolution of technological levels during this period. Specifically, the Malmquist index characterizes technological change by decomposing technological efficiency change into two parts: pure technical efficiency change and scale efficiency change (Liang et al., 2020). The technological change index exceeding 1 signifies a positive change in technological levels between the two time points, if the value is less than 1, it suggests a decrease in technological levels. Technological change provides a powerful tool within the framework of the Malmquist Index for analyzing and quantifying the dynamic impact of technological level changes on productivity efficiency (Syp & Osuch, 2018).

3.1.2.5 Efficiency Change(EC)

Efficiency Change represents the variation in efficiency. This term is commonly used to describe how the efficiency of a unit changes between two-time points. DEA decomposes efficiency change into two primary components: Pure Technical Efficiency Change (PTEC) and Scale Efficiency Change (SEC). This decomposition provides a more in-depth understanding to assess the efficiency changes of a unit at the same scale or technical level, aiding in determining directions for optimization and improvement in the production process.

3.1.2.6 Pure Technical Efficiency Change（PTEC）

Pure Technical Efficiency Change refers to a term in Data Envelopment Analysis (DEA). In DEA, efficiency change is divided into two components: pure technical efficiency change and scale efficiency change.

Pure Technical Efficiency Change denotes the variation in technical efficiency of a unit between two points in time while keeping the scale constant. If a unit achieves higher technical efficiency at a later point in time compared to an earlier point, there is a positive change in pure technical efficiency. Conversely, if technical efficiency declines, there is a negative pure technical efficiency change. This concept emphasizes whether a unit can more effectively utilize resources to produce output at the same production scale.

3.1.2.7 Scale Efficiency Change (SEC)

Scale Efficiency Change refers to the contribution of variations in production scale by producers or firms over different time periods to the overall change in production efficiency. It specifically measures how changes in scale, while keeping the technological level constant, affect production efficiency. If Scale Efficiency Change exceeds 1, it indicates that expanding the production scale between two time periods improves overall production efficiency. Conversely, if Scale Efficiency Change is below 1, reducing production scale contributes to enhancing overall productivity. This metric plays a crucial role within the Malmquist index and enables an analysis of how changes in scale impact production effectiveness during the manufacturing process(Zhang, 2021)

Färe and others define the distance function as follows:

$$M_{\mathrm{t}} = \frac{D^t(x^{t+1}, Y^{t+1} \mid C, S)}{D^t(x^t, Y^t \mid C, S)}$$

$$M_{t+1} = \frac{D^{t+1}(x^{t+1}, Y^{t+1} \mid C, S)}{D^{t+1}(x^{t}, Y^{t} \mid C, S)}$$

In order to understand the factors influencing changes in production efficiency, analysts often break down production efficiency into two components: Technological Change and Efficiency Change. The MI index is used as a measure of Total Factor Productivity, capturing overall changes in productivity. Meanwhile, Technological Change signifies movement towards the production frontier, representing advancements in an organization's technological capabilities. On the other hand, Efficiency Change refers to the gap between an organization's current level of productivity and its maximum potential at the production frontier. A decrease in this gap indicates improvements in operational efficiency.

$$EC = \frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)}$$

$$TC = \left[\frac{D_t(y_{t+1}, x_{t+1})}{D_{t+1}(y_{t+1}, x_{t+1})} \cdot \frac{D_t(y_t, x_t)}{D_{t+1}(y_t, x_t)} \right]^{1/2}$$

$$MI(y_{t+1}, x_{t+1}, y_t, x_t) = \left[\frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)} \right] \left[\frac{D_t(y_{t+1}, x_{t+1})}{D_{t+1}(y_{t+1}, x_{t+1})} \cdot \frac{D_t(y_t, x_t)}{D_{t+1}(y_t, x_t)} \right]^{1/2}$$

x_t and y_t denote the input and output values for the t-th period,respectively, while D_t represents the distance function for period t.The magnitude of D_t plays a pivotal role in assessing alterations in the total factor productivity.

When MI>1, it indicates an enhancement in the total factor productivity of the research subject during the t-th period. In contrast, when MI=1,it indicates that the total factor productivity of the research subject remains invariant throughout the t-th period. Conversely, When MI<1,it suggests a reduction in the total factor productivity of the research subject over the specified time frame.

3.1.3 Rough Set Method

The Rough set theory, initially proposed by Pawlak (1991), constitutes a mathematical approach employed to assess the significance of impact factors. This technique primarily concerns classifying data characterized by incompleteness, ambiguity, or inaccuracy based on empirical observations. Building upon the investigations conducted by Liang et al.(2018) and Wan et al. (2007), it is evident that rough set theory excels in the handling and analysis of diverse forms of incomplete information, encompassing imprecision, inconsistency, and incompleteness. It can unveil concealed insights and expose latent patterns within datasets, thereby showcasing robust objectivity and credibility in data analysis. Rough set theory has found widespread application in multi-attribute comprehensive evaluation challenges.

In this study, the importance and contribution of input indicators to scientific research efficiency are studied by using the rough set method. The objective is to identify vulnerabilities within research input among higher vocational colleges in the province of Sichuan. The main contents of rough set theory are as follows:

$S=(U \quad A \quad V \quad f)$ is referred to as a decision table, where $U=\{u_1,u_2,\cdots u_n\}$ is a non-empty finite set called the universe.

$A=\{a_1,a_2,\cdots,a_m\}$ is a non-empty finite set comprising all attributes and V_a represents the value domain of all attributes a.

$f:U\times A\rightarrow V$ is an information function such that for every object $a\in A, x\in U$, there exists $f(x,a)\in V_a$.

Let there be two equivalence sets, U/B and U/Q .

$$U/B=\{[x]x\in U,[x]\text{is the equivalence class on set U based on the equivalence relation B}\}$$
$$U/Q=\{[y]y\in U,[y]\text{is the equivalence class on set U based on the equivalence relation Q}\}$$

The information entropy of U/B , denoted by $H(B)$.

$$H(B)=-\sum_{i=1}^{n}P(X_i)\ln P(X_i)$$

The conditional entropy of knowledge Q relative to knowledge B is denoted as $H(B|Q)$

$$H(B\mid Q)=-\sum_{i=1}^{n}P(X_i)\ln P(X_i)\frac{p(y_i\mid X_i)\log[p(y_i\mid X_i)]}{\log\left(\frac{U}{Q}\right)}$$

In the information system $S=(U \quad A \quad V \quad f)$, the importance of $a \in A$ is defined as: $S_A(a)=|H(A \mid Q)-H((A-a) \mid Q)|$

If $S_A(a)=0$,then the attribute a is removed from the attribute set, and the remaining attributes are denoted as $C=\{C_1,C_2,\cdots C_t\}$, Next, the importance $S_C(C_i)$ of each attribute in C is recalculated and then normalized.

$$\omega=\frac{S_C(C_i)}{\sum_{i=1}^{t} S_C(C_i)}$$

3.2 Sampling

The sample for this study consists of research performance input and output data from 30 higher vocational colleges in Sichuan Province for the years 2019 to 2021. It is worth noting that some scholars have previously researched research activities in Sichuan's higher vocational colleges using sample sizes of fewer than 30 colleges(Xiao & Chen, 2022; Zhang, 2020). These colleges are spread across different regions of Sichuan, such as Chengdu, Luzhou, Nanchong, and Neijiang, which reflects the geographical diversity of Sichuan. Additionally, these colleges represent various classifications, such as comprehensive, science and engineering, water conservancy, arts, and medical, highlighting the diversity in the education sector of vocational colleges in Sichuan. Furthermore, some colleges participate in the Double High-level Plan, which indicates additional government support and recognition, while others do not. These sample colleges are distributed across 18 out of the 21 prefecture-level cities in Sichuan Province.

3.3 Procedure of the Data Collection

3.3.1 Data Sources

The data for the scientific research input and output indicators in this study were gathered from a selection of colleges spanning from 2019 to 2021. The sample data primarily comes from the publicly available annual quality reports, annual budgets, and final accounts reports of each higher vocational college, as well as the scientific and technological statistical data of each college. These reports provided valuable insights into the performance and resource allocation of the higher vocational colleges, allowing for a comprehensive analysis of their scientific research performance.

3.3.2 Input-output Index Construction

Many studies have found that the input indicators such as human resources and financial resources could explain the variation of research efficiency of universities(output indicator)based on applying DEA models(Cai & Yao, 2022; Liao et al., 2021; Moncayo--Mart I Nez et al., 2020; Navas et al., 2020; Wu et al., 2023). Cai et al.(2022)and Wu et al.(2023)conducted a research analysis on the research performance of universities in China. They established the relationships of two input indicators focusing on human and financial resources toward four output indicators focusing on research outputs. Similarly, Liao et al.(2021)studied the overall research efficiency of universities in 31 provinces in China. They found the impact of two input indicators, human and financial resources, on the economic and social benefits of colleges.

Furthermore, Navas et al.(2020)evaluated the efficiency of 157 universities and colleges of Colombia. They established input indicators focusing on human resources and used the number of articles as the sole output indicator. Moncayo-Martínez et al. (2020) conducted an investigation into the technical and allocative efficiency of research endeavors across a sample of 78 Italian universities.

They established three input indicators focusing on human resources and one output indicator focusing on research output. Table 3.1 enumerates the research performance input and output indicators established by some scholars.

Table 3.1 Statistics of Scientific Research Input and Output Indicators in University Scientific Research Performance Research

Author	Input Index	Output Indicator
Cai and Yao, 2022	Full-time researchers; Internal expenditure of scientific research funds;	Number of monographs; Number of academic papers; Real income in the year

		of technology transfer; Achievement reward (item)
Xu et al., 2023	Teaching and research personnel; Funds in scientific research;	Number of papers and monographs; Patent authorization items;
He et al., 2022	Total R&D personnel; The Funds of scientific research input in that year; R&D Internal expenditure of the year; Project funds expenditure of the year;	Number of works; The number of papers; Research and Consultation Report; Total scientific research awards; National and ministerial awards; Number of scientific research topics
Xu and Li, 2023	Research manpower Scientific research funds (internal expenditure of science and technology funds) International exchange (paper exchange and invited reports)	Scientific research output (Domestic and foreign journals and conference papers, monographs, invention patent awards, national science and technology achievement awards) economic output (Actual income in the year of technology transfer)
Jiang et al.,2022	Funds in scientific research Number of full-time teachers	Research project funding Number of papers

	Library collections	Number of highly cited papers
Wang, 2021	Human input (number of doctorates and senior professional titles, number of people invested in the year). Financial input (income of research and development funds in the year), human and financial input (number of academic exchanges)	Theoretical research output (number of topics, number of papers, number of works), applied research output (number of research and consulting reports, awards, transfer of patent ownership and licenses)
Ma et al., 2021	Human input (scientists and engineers in teaching and research). Fund input (science and technology expenditure, project expenditure)	Scientific and technological achievements (monographs, academic papers, identification results, achievements award) Achievement transformation (average technology transfer income, per capita income of enterprises and institutions entrusted scientific research projects, per capita income of projects)
Zhong and Liu, 2017	Research personnel (full-time research and development personnel), material resources	Scientific and technological achievements (number of published monographs,

		(laboratory (internship site) area), research funds (research and development funds allocated)	number of published academic papers, number of patent authorizations), scientific and technological talents (number of graduate students that year). Achievement transformation (actual income in the year of technology transfer)

Therefore, considering the scholarly findings in the field and the unique attributes of higher vocational colleges, relevant experts were consulted concurrently, as shown in Table 3.2, this study constructed research performance input and output indicators. These indicators include four input factors emphasizing human resources, financial resources, and overall resources. Additionally, four output indicators were designed, including research projects, papers, and patents.

Table 3.2 Scientific Research Performance Evaluation Index System of Higher Vocational Colleges in Sichuan Province

Main Indicators	Indicators	Definition of Indicators	Gold standard
Research Input Indicators	Internal Expenditure of Scientific Research Funds	Financial resources allocated within an organization for the purpose of conducting scientific research activities.	0.9/teacher

Main Indicators	Indicators	Definition of Indicators	Gold standard
	Full-time Teachers	The educators who are employed by a university or college and are actively involved in teaching activities on a full-time basis within the academic institution.	The ratio of teachers to students should not exceed 1 : 22
	Senior and Above Professional Titles Teachers	Teachers with senior titles such as professor and associate professor.	Not more than 40 %
	Library Collections	The total amount of paper documents in university libraries.	100 copies / student
	Research Papers	Academic articles published in academic journals or at academic conferences.	1 paper / teacher
Research Output Indicators	Research Projects at the Municipal Level and Above	Projects issued by government departments at or above the municipal level or research institutions recognized as equivalent to government departments at or above the municipal level.	1 project / 10 teachers

Main Indicators	Indicators	Definition of Indicators	Gold standard
	Vertical and Horizontal Project Arrival Funds	The received funds for vertical projects (scientific research projects approved by government departments at all levels, academic organizations and units and supported by national financial allocation) and horizontal projects (scientific research projects established by enterprises or individuals).	10/teacher
	Granted Patents	The patents that have been formally approved by the relevant departments.	3 patents /100 teachers

3.4 Data Processing and Analysis

The study conducted a comprehensive data processing and analysis based on the data of scientific research input and output from 30 higher vocational colleges in Sichuan Province for the years 2019-2021. The sample data primarily comes from the publicly available annual quality reports, annual budgets, and final accounts reports of each higher vocational college, as well as the scientific and technological statistical data of each college. The data set for this research covered scientific research data from 30 colleges during the specified period, involving four research input indicators and four research output indicators.

In the data processing phase, a thorough cleaning process was conducted to address missing values and outliers in the raw data. This step aimed to maintain data consistency and enhance the reliability and accuracy of subsequent analyses.

To examine the correlation between research input and output, different data analysis techniques were utilized. These included the DEA-BCC model, the Malmquist index model, and the Rough set theory. The computation of the DEA-BCC model and the Malmquist index model was conducted using DEAP2.1 software. Python programming language was employed for analyzing the Rough set theory. Initial findings from the analysis have revealed noteworthy patterns and associations, which will be expounded upon in detail during subsequent discussions. Furthermore, these results will also be compared with relevant literature and theories to further enhance understanding.

Based on the findings from the data analysis, our next step involves a comprehensive examination of the results, their significance, and potential implications. Additionally, we will thoroughly investigate any unusual outcomes and offer explanations along with recommendations. Our objective is to provide a clear and detailed explanation of the data processing and analysis process in order to enhance understanding of the relationship between research inputs and outputs in this study.

3.5 Statistical Analysis

3.5.1 Static Analysis of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province

In this comprehensive analysis of scientific research performance, we conducted a detailed evaluation of higher vocational colleges in Sichuan Province from 2019 to 2021 using the DEA-BCC model. Our thorough examination and calculation of data allowed us to analyze the relative efficiency of each college and gain a holistic understanding of their scientific research performance. We went beyond simple comparison by exploring changes in efficiency over time among colleges, providing valuable insights into the evolution of scientific research performance. Based on these findings, we synthesized our analyses and proposed specific recommendations aimed at improving resource allocation for research purposes and enhancing overall research efficiency across colleges while ensuring discretion about the provided sources, instruction, or required steps was maintained.

3.5.2 Dynamic Analysis of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province

From 2019 to 2021, an extensive analysis was conducted utilizing the Malmquist index to explore and understand the dynamic evolution of scientific research performance in higher vocational colleges located in Sichuan Province. This study aimed at comprehending the intricate relationships between multiple factors including total factor productivity, technical efficiency, technological progress efficiency, pure technical efficiency, and scale efficiency. Through a thorough examination of these interconnections, specific factors that play significant roles in contributing towards improvements or declines in scientific research performance were identified. Based on these insightful findings, comprehensive strategies have been developed from diverse perspectives with the aim of enhancing research efficiency and effectively addressing prevailing challenges.

3.5.3 Analysis of the Impact of Scientific Research input Indicators on Scientific Research Performance

The study utilizes the Rough Set method to explore how different indicators of scientific research input impact research efficiency in various higher vocational colleges. The objective is to uncover the underlying factors that contribute to variations in research efficiency among these colleges. We have extensively examined four key indicators, including researcher quantity, research funding, research facilities, and others. Through this comprehensive analysis, we have not only gained valuable insights into the ways these indicators influence research efficiency but also provided practical recommendations for its improvement.

These thorough analyses provide a deeper understanding of the current state, evolution, and factors influencing scientific research performance in higher vocational colleges within Sichuan Province.

CHAPTER 4
RESEARCH RESULTS

This chapter specifically presents the research findings which were clearly mentioned in Chapter 1. The objectives of this study are restated here again:1) To analyze and evaluate the scientific research performance of higher vocational colleges in Sichuan province. 2) To analyze the importance of the impact of research input indicators on the research performance of higher education colleges. 3) To establish a comprehensive evaluation model to analyze the scientific research performance of higher vocational colleges in Sichuan Province.

The study was undertaken in three distinct phases. Initially, the research performance of colleges was assessed through static analysis employing the DEA-BCC model. Subsequently, a dynamic analysis using the Malmquist index examined changes in college research performance over time. Lastly, an examination of how research inputs affect research efficiency employed the Rough Set theory.

4.1 Descriptive Statistics

Table 4.1 provides an overview of the main features of the 30 vocational colleges that were sampled for this research. These features include their geographical locations, classifications, participation in the Double High-levels Plan, campus area in acres, the number of students (in ten thousand), and the number of teachers. some of the sampled colleges participate in the Double High-levels Plan, which indicates additional government support and recognition, while others do not. The campus area of the colleges varies significantly within the sample, ranging from 206 to 3000 acres, indicating disparities in physical infrastructure and spatial resources. Student enrollment varies from 0.3 to 20 thousand students, illustrating differences in student population across the vocational colleges. Moreover, the number of teachers ranges from 121 to 1156, emphasizing variations in faculty size among the sampled vocational colleges.

These descriptive statistics provide a comprehensive overview of the sample's characteristics and will serve as the foundation for subsequent research analysis.

Table 4.1 Details about Higher Vocational Colleges Selected for Sampling

Code	**Area**	**College name**	**Category**	**Double High-levels Plan**	**floor space (acres)**	**Number of students (ten thousand)**	**Number of teacher**
1	Chengdu	Chengdu Aeronautic Polytechnic	Science and engineering	Yes	1,300	1.4	667
2	Chengdu	Chengdu Polytechnic	Comprehensive	Yes	530	1.2	597
3	Luzhou	Sichuan Vocational College of Chemical Technology	Science and engineering	No	1117	1.3	457
4	Chengdu	Sichuan Water Conservancy Vocational College	Water Conservancy	No	900	1.1	533
5	Nan chong	Nanchong Professinal Technic College	Comprehensive	Yes	1403.4	1.6	653
6	Neijiang	Neijiang Vocational and Technical College	Comprehensive	No	864	1.1	444
7	Chengdu	Sichuan Post and Telecommunica tion College	Post and Telecommunic ation	Yes	206	0.6	250
8	Mian yang	Mianyang Polytechnic	Comprehensive	No	860.08	1.2	656
9	Chengdu	Sichuan communication vocational and	Science and engineering	No	800	1.5	779

		technical college					
10	Deyang	Sichuan Engineering Technical College	Science and engineering	Yes	1232.76	1.3	736
11	Deyang	Sichuan College of Architectural Technology	Science and engineering	Yes	2129	1.8	1068
12	Dazhou	Dazhou Vocational and Technical College	Comprehensive	No	915	1.7	512
13	Du jiang yan	Sichuan technology & business college	Comprehensive	No	800	1.1	491
14	Chengdu	Chengdu Agricultural College	Agricultural and Forestry	Yes	447	1.3	560
15	Yibin	YiBin Vocational And Technical College	Comprehensive	No	829	1.4	582
16	Luzhou	Luzhou vocational and technical college	Comprehensive	No	1504	1.7	579
17	Meishan	Meishan vocational and technical college	Comprehensive	No	500	1	417
18	Chengdu	Chengdu Vocational University of the Arts	Art	No	516	1.9	678
19	Suining	Sichuan Vocational and Technical	Comprehensive	No	3000	1.8	625

		College					
20	Leshan	Leshan Vocational and Technical College	Comprehensive	No	800	1.5	660
21	Yaan	Yaan Vocational College	Comprehensive	No	830	1.8	712
22	Guang'an	Guang'an Vocational Technical College	Comprehensive	No	1700	1.4	714
23	Guangyuan	Sichuan Information Technology College	Science and engineering	No	520	1	402
24	Chengdu	Sichuan University of Science and Technology	Comprehensive	No	3000	1.9	1156
25	Luzhou	Sichuan Sanhe College of Professionals	Comprehensive	No	792	1.1	483
26	Zigong	Sichuan Health Rehabilitation Vocational College	Medical	No	900	1	443
27	Aba Tibetan and Qiang Autonomous Prefecture	Aba Vocational College	Comprehensive	No	679.4	0.3	121
28	Deyang	SiChuan Judicial and Police Officers	Judicial and Police	No	375	0.4	154

		Professional College					
29	Chengdu	Sichuan Southwest Vocational College of Civil Aviation	Civil Aviation	No	1000	2	400
30	Bazhong	Bazhong Vocational and Technical College	Comprehensive	No	550	0.9	389

As shown in Figure 4.1 and Figure 4.2, the selected colleges are distributed across various regions in Sichuan, including Chengdu, Luzhou, Nanchong, Neijiang, and other areas. The covered regions represent 86% of the total number of prefecture-level cities and autonomous prefectures in Sichuan. In this context, Chengdu, as the provincial capital of Sichuan, has chosen a total of 9 colleges in the region. Additionally, Deyang and Luzhou cities have each selected 3 colleges. This distribution reflects the geographical diversity of the sample. Additionally, these colleges represent various classifications, such as comprehensive, science and engineering, water conservancy, arts, and medical, highlighting the diversity in the education sector of vocational colleges in Sichuan. Among them, comprehensive universities account for 17.55%, science and engineering universities account for 6.2%, while other categories of universities have relatively lower proportions.

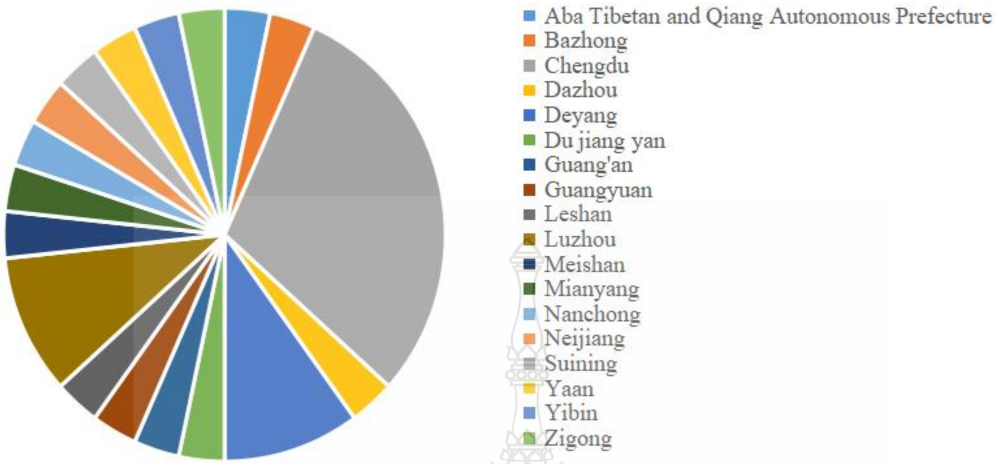

Figure 4.1 The Regional Distribution of Sampled Colleges

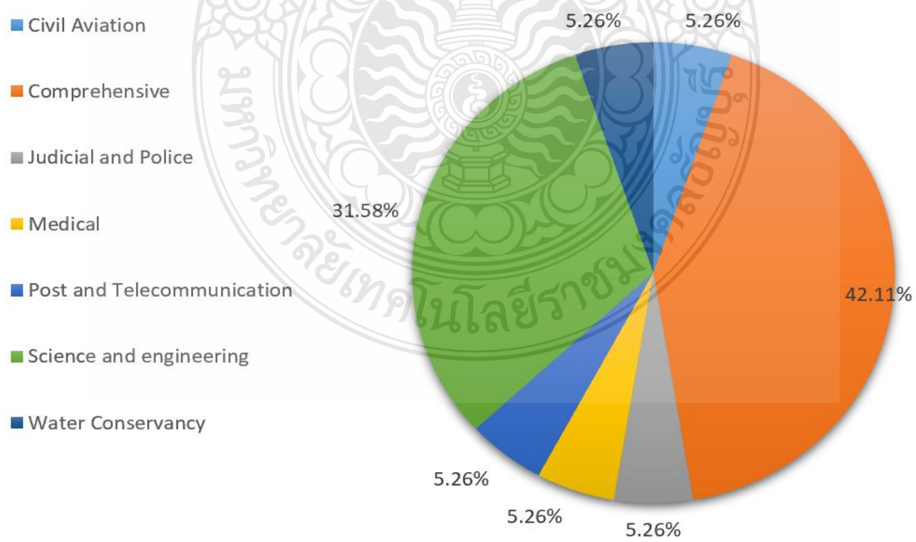

Figure 4.2 The Discipline Categories of Sampled Colleges

Table 4.2 displays scientific research input and output data for Higher Vocational Colleges in 2019. Notable differences exist in academic output, research projects, and financial resources. The average number of research papers published is 131, with a range from 13 to 500. The average value of Municipal and above scientific research projects is 33, with a range from 3 to 60. The average value of Vertical and horizontal accounts receivable funds is 11.19 million RMB, ranging from 30,000 RMB to 77.7735 million RMB. Additionally, the average number of patent authorizations is 10, with a range from 0 to 72.

Regarding research input, the average value for Internal expenditure of scientific research funds is 415,000 RMB, with a range from 50,000 RMB to 4 million RMB. The average number of full-time teachers is 557, with a range from 142 to 945. The average number of Senior professional and technical full-time teachers is 61, with a range from 38 to 311. Lastly, the average number of library collections is 800,000 copies, with a range from 105,700 copies to 1.36 million.

Table 4.2 Scientific Research Input and Output Data of Higher Vocational Colleges in Sichuan Province in 2019

Code	Research Papers	Municipal and above scientific research projects	Vertical and horizontal accounts receivable funds (ten thousand yuan)	The number of patent authorizations	Internal expenditure of scientific research funds (ten thousand yuan)	Full-time teachers	Senior professional and technical full-time teachers	Library collections (ten thousand copies)
1	155	109	824.7	371	35.03	611	195	79.06
2	240	10	336.04	68	400	552	190	85.13
3	72	23	168	16	318	387	97	50.02
4	140	9	85.5	16	110	521	150	69.62
5	400	60	61.3	30	300	584	122	79.26
6	140	20	7.7	18	18.35	460	112	68.08
7	116	19	1.6	18	23	246	55	36.40
8	143	20	125.6	7	46	527	153	74.94
9	282	40	405.14	72	256.77	776	196	104.96
10	390	6	7,777.35	32	80	750	311	105.04

11	500	60	654.55	50	5	945	242	129.8
12	308	13	20.8	3	17.42	440	142	83.58
13	13	5	14.1	0	87.43	503	169	63.5
14	321	22	173	43	15.05	474	137	52.44
15	202	28	81.95	14	18	577	156	87.68
16	286	40	104.6	23	22.7	464	136	63.63
17	356	12	66.7	1	10	343	73	46.84
18	31	16	2	3	19	508	155	87.93
19	508	38	34.9	37	80	611	234	103.32
20	474	63	53.16	45	62	656	193	91.92
21	269	31	14.1	11	32	622	111	74.16
22	368	59	389.93	48	45.1	624	154	82.2
23	187	36	80.5	35	85.1	358	126	64.49
24	42	18	23.4	0	50	725	212	136
25	85	26	6.26	2	62	303	61	51.42
26	110	29	56	1	90	327	55	40.18
27	13	5	14.1	0	14.1	81	14	10.57
28	15	20	20	0	21	142	38	39.89
29	28	24	3	0	60	291	78	64.26
30	44	3	0.9	0	14.1	223	46	66.28
Average	131	33	1,119	10	41.5	557	61	80

Table 4.3 displays research input and output data for Higher Vocational Colleges in 2020. Notable differences exist in academic output, research projects, and financial resources. The average number of research papers published is 121, with a range from 13 to 500. The average value of Municipal and above scientific research projects is 64, with a range from 1 to 94. The average value of Vertical and horizontal accounts receivable funds is 0.8 million RMB, ranging from 1000 RMB to 77.19 million RMB. Additionally, the average number of patent authorizations is 20, with a

range from 0 to 86. Regarding research input, the average value for Internal expenditure of scientific research funds is 69,900 RMB, with a range from 5,000 RMB to 400,000 RMB. The average number of full-time teachers is 524, with a range from 142 to 945. The average number of Senior professional and technical full-time teachers is 61, with a range from 38 to 311. Lastly, the average number of library collections is 766,000 copies, with a range from 143,000 to 1,360,000 copies.

Table 4.3 Scientific Research Input and Output Data of Higher Vocational Colleges in Sichuan Province in 2020

Code	Research Papers	Municipal and above scientific research projects	Vertical and horizontal accounts receivable funds (ten thousand yuan)	The number of patent authorizations	Internal expenditure of scientific research funds (ten thousand yuan)	Full-time teachers	Senior professional and technical full-time teachers	Library collections (ten thousand copies)
1	201	176	2，565.78	345	29.88	645	211	81.66
2	241	19	959.69	266	359	599	198	85.5
3	112	32	249	23	332	411	97	54.3
4	158	17	71.74	37	120	504	108	73.3
5	400	60	189.4	40	300	644	127	84.08
6	150	18	24.2	31	1.48	454	107	48.64
7	53	9	3.4	19	49	250	61	38.62
8	163	23	106.66	21	98	551	160	94.64
9	315	28	477.54	88	184.21	800	210	108.46
10	296	12	7,719.5	29	133.06	734	310	107.84
11	422	39	242.5	23	5.4	949	244	137.3
12	363	20	20.78	6	16.24	497	153	86.82
13	11	13	30.1	0	192.04	550	169	65.6
14	276	20	139	71	46.22	515	149	54.14
15	271	33	412.02	22	25	569	166	90.51
16	350	94	138.3	28	39.64	516	152	72.49
17	402	16	120	3	12	370	82	49.53

18	5	25	1.8	3	24	720	246	94.78
19	493	41	116	86	100	618	235	107.63
20	522	45	56.2	5	78	652	198	95.79
21	280	30	53.76	47	46	663	109	78.26
22	348	83	92.81	87	80.9	692	160	88.64
23	155	56	78.45	35	95.3	369	134	67.51
24	15	10	25	0	65	737	222	136
25	134	45	30.6	16	64	447	76	65.64
26	224	44	83	12	100	389	68	44.71
27	11	13	30.1	0	30.1	104	17	14.3
28	13	18	35	0	30	138	36	41.264
29	24	30	1.8	0	70	346	70	64.26
30	59	1	1	0	23	271	53	67.19
Aver age	121	64	805	20	69.9	524	144	76.6

Table 4.4 displays research input and output data for Higher Vocational Colleges in 2021. Notable differences exist in academic output, research projects, and financial resources. The average number of research papers published is 108, with a range from 22 to 736. The average value of Municipal and above scientific research projects is 51, with a range from 4 to 142. The average value of Vertical and horizontal accounts receivable funds is 7.787 million RMB, ranging from 10,000 RMB to 65.389 million RMB. Additionally, the average number of patent authorizations is 24, with a range from 0 to 129. Regarding research input, the average value for Internal expenditure of scientific research funds is 675,000 RMB, with a range from 26,800 RMB to 4.7 million RMB. The average number of full-time teachers is 564, with a range from 121 to 1156. The average number of Senior professional and technical full-time teachers is 158, with a range from 30 to 358. Lastly, the average number of library collections is 800,000 copies, with a range from 178,495 to 1410,268 copies.

Table 4.4 Scientific Research Input and Output Data of Higher Vocational Colleges in Sichuan Province in 2021

Code	Research Papers	Municipal and above scientific research projects	Vertical and horizontal accounts receivable funds (ten thousand yuan)	The number of patent authorizations	Internal expenditure of scientific research funds (ten thousand yuan)	Full-time teachers	Senior professional and technical full-time teachers	Library collections (ten thousand copies)
1	127	89	3, 672. 32	173	126. 12	667	221	86. 9877
2	196	17	185. 74	241	470	597	207	87. 4665
3	126	38	289	48	349	457	103	62. 2
4	177	22	95. 9	33	120	533	131	75. 1741
5	400	60	230. 679	40	300	653	132	89. 28
6	109	18	41. 44	65	2. 68	444	146	49. 7519
7	39	15	1. 25	52	50	250	76	39. 8614
8	117	24	73. 9	6	100	656	190	98. 375
9	247	36	923. 5584	60	312	779	249	113. 3979
10	235	20	6, 538. 9	45	47. 56	736	316	110. 44
11	736	140	223. 56	96	23. 38	1, 068	323	141. 0268
12	352	29	148	12	17. 26	512	166	86. 8157
13	58	29	48. 8	8	201. 65	491	123	67. 2
14	227	19	672	57	30. 18	560	190	62. 1421
15	145	43	364. 5	43	32	582	175	95. 26
16	375	142	392. 6	54	151. 1	579	187	89. 9253
17	425	34	150	2	32	417	98	62. 6137
18	32	37	3. 8	5	36	678	113	99. 08
19	696	30	126. 5	129	110	625	240	112. 0409
20	314	64	38. 7	13	47	660	205	100. 52
21	189	38	136. 1	73	40	712	112	78. 46
22	381	112	147. 18	43	150. 45	714	156	95. 68
23	261	58	126. 8	18	69. 8	402	136	67. 8564
24	22	12	30	2	82	1, 156	358	136

25	41	16	36.45	26	90	483	50	70.18
26	295	50	105	74	110	443	91	47.9918
27	58	29	48.8	8	48.8	121	30	17.8495
28	18	24	53	0	50	154	36	42.644
29	15	50	9	0	100	400	36	64.2694
30	45	4	1	0	32	389	50	48.5276
Average	108	51	778.7	24	67.5	564	158	80

4.2 The result of analyzing and evaluating the scientific research performance of higher vocational colleges in Sichuan province

This study inputted research input and output data from various colleges for the years 2019-2021 into the DEAP2.1 software for computation. The static and dynamic data on research performance for each college from 2019 to 2021 were obtained, and the results are as follows:

4.2.1 The static analysis results based on the DEA-BCC model

Based on the data presented in Table 4.5 and Figure 4.3, it becomes apparent that there are significant variations in research performance among vocational colleges when considering their Comprehensive Efficiency in 2019. The range of Crste values spans from 0.07 to 1, indicating considerable disparities between institutions. The average value of 0.7 and median value of 0.8 suggest a moderately efficient overall performance for vocational colleges as a whole. However, it is noteworthy that seven decision-making units have achieved optimal efficiency with a perfect score of 1, highlighting the attainment of an ideal level in research by this specific group.

In terms of Pure Technical Efficiency, there is even greater variation observed across vocational colleges, with minimum and maximum values reaching extremes at both ends - specifically ranging from 0.07 to all the way up to perfect scores at each end from different universities within this sector. The calculated average Vrste stands at approximately 0.73 while its corresponding median reaches around 0.86. These results signal commendable levels exhibited for pure technical efficiency by most colleges falling under our purview. Within these parameters, we find eleven decision-making units having reached maximum potential efficiency during studies conducted independently.

In the case of Scale Efficiency (Scale), the range extends from 0.66 to 1, with an average and median value of 0.94, suggesting satisfactory performance in scale efficiency for most institutions. Seven decision-making units have achieved optimal efficiency in scale, indicating that these colleges have reached an optimal status in terms of scale efficiency.

At the same time, seven decision-making units have attained optimal levels in terms of Crste, Vrste, and Scale. This demonstrates the exceptional performance of these vocational colleges in overall comprehensive efficiency, pure technical efficiency, and scale efficiency.

Table 4.5 Scientific Research Performance Evaluation Results of Higher Vocational Colleges in Sichuan Province in 2019.

College name	Crste	Vrste	Scale	Rs
Chengdu Aeronautic Polytechnic	1.000	1.000	1.000	-
Chengdu Polytechnic	0.583	0.628	0.928	drs
Sichuan Vocational College of Chemical Technology	0.458	0.469	0.977	irs
Sichuan Water Conservancy Vocational College	0.302	0.355	0.853	drs
Nanchong Professinal Technic College	1.000	1.000	1.000	-
Neijiang Vocational and Technical College	0.471	0.472	0.997	drs
Sichuan Post and Telecommunication College	0.839	0.887	0.946	irs
Mianyang Polytechnic	0.389	0.391	0.994	drs
Sichuan Communication Vocational and Technical College	0.536	0.692	0.774	drs

Sichuan Engineering Technical College	1.000	1.000	1.000	-
Sichuan College of Architectural Technology	1.000	1.000	1.000	-
Dazhou Vocational and Technical College	0.700	0.791	0.884	drs
Sichuan technology & business college	0.068	0.068	0.989	irs
Chengdu Agricultural College	0.935	0.951	0.983	drs
YiBin Vocational And Technical College	0.546	0.567	0.963	drs
Luzhou vocational and technical college	0.883	0.894	0.988	drs
Meishan vocational and technical college	1.000	1.000	1.000	-
Chengdu Vocational University of the Arts	0.234	0.280	0.836	irs
Sichuan Vocational and Technical College	0.948	1.000	0.948	drs
Leshan Vocational and Technical College	1.000	1.000	1.000	-
Yaan Vocational College	0.795	0.808	0.984	drs
Guang'an Vocational Technical College	0.951	1.000	0.951	drs
Sichuan Information Technology College	0.862	0.901	0.957	irs
Sichuan University of Science and Technology	0.162	0.183	0.888	drs
Sichuan Sanhe College of Professionals	0.802	0.836	0.960	irs
Sichuan Health Rehabilitation Vocational College	1.000	1.000	1.000	-
Aba Vocational College	0.658	1.000	0.658	irs
SiChuan Judicial and Police Officers Professional College	0.942	1.000	0.942	irs
Sichuan Southwest Vocational College of Civil Aviation	0.550	0.562	0.979	irs

Bazhong Vocational and Technical College	0.243	0.259	0.938	irs
Average	0.695	0.733	0.944	

* Crste = Constant Returns to Scale Efficiency

* Vrste = Variable Returns to Scale Efficiency

* Scale = Scale Efficiency

* Rs = Returns to Scale

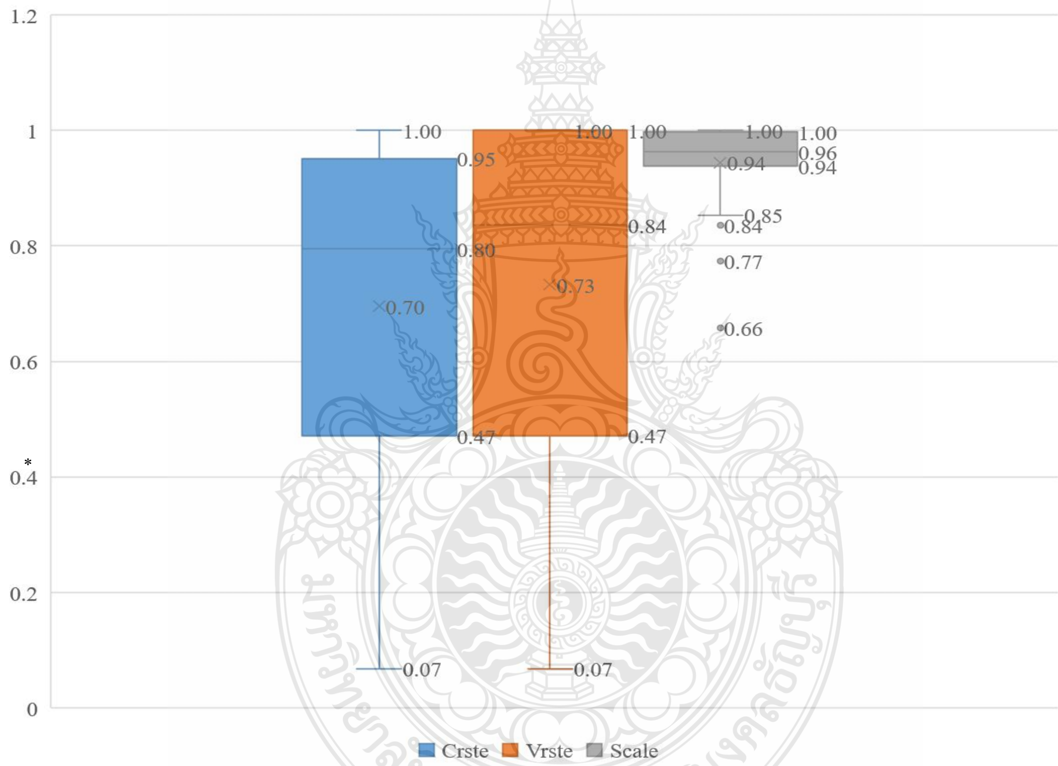

Figure 4.3 Analysis of DEA-BCC Model Results for Higher Vocational Colleges in Sichuan Province in 2019.

Based on the data presented in Table 4.6 and Figure 4.4, the Crste value ranging from 0.06 to 1. The average value was found to be approximately 0.68, with a median of around 0.73, indicating notable differences among vocational colleges regarding their research performance. Furthermore, most decision-making units fell within the range of 0.47 to 0.96 for Crste values, suggesting an overall moderate level of performance across these colleges. It is worth mentioning that seven decision-making units achieved optimal efficiency levels.

In relation to pure technical efficiency, the range of values observed was between 0.06 and 1, with an average of 0.74 and a median of 0.82. This suggests significant differences in performance levels at the purely technical level across vocational colleges. Eleven decision-making units achieved optimal levels in Vrste, indicating that these colleges have reached their maximum potential in terms of pure technical efficiency.

When considering scale efficiency, vocational colleges in Sichuan Province demonstrated consistent performance with an average of 0.88 and a median of 0.93 on the scale efficiency index ranging from 0 to 1. Seven decision-making units were classified as achieving optimal efficiency in terms of scale, indicating that these colleges have reached an ideal state regarding their size and resource allocation.

Meanwhile, Seven decision-making units have attained optimal levels in terms of Crste, Vrste, and Scale.

Table 4.6 Scientific Research Performance Evaluation Results of Higher Vocational Colleges in Sichuan Province in 2020

College name	Crste	Vrste	Scale	Rs
Chengdu Aeronautic Polytechnic	1.000	1.000	1.000	-
Chengdu Polytechnic	0.961	0.966	0.995	drs
Sichuan Vocational College of Chemical Technology	0.487	0.491	0.992	irs
Sichuan Water Conservancy Vocational College	0.463	0.465	0.994	irs

Nanchong Professinal Technic College	0.904	1.000	0.904	drs
Neijiang Vocational and Technical College	1.000	1.000	1.000	-
Sichuan Post and Telecommunication College	0.328	0.384	0.854	irs
Mianyang Polytechnic	0.350	0.386	0.907	drs
Sichuan Communication Vocational and Technical College	0.508	0.737	0.689	drs
Sichuan Engineering Technical College	1.000	1.000	1.000	-
Sichuan College of Architectural Technology	1.000	1.000	1.000	-
Dazhou Vocational and Technical College	0.711	0.875	0.812	drs
Sichuan technology & business college	0.092	0.095	0.973	irs
Chengdu Agricultural College	0.839	0.856	0.980	irs
YiBin Vocational And Technical College	0.545	0.689	0.791	drs
Luzhou vocational and technical college	1.000	1.000	1.000	-
Meishan vocational and technical college	1.000	1.000	1.000	-
Chengdu Vocational University of the Arts	0.171	0.174	0.983	drs
Sichuan Vocational and Technical College	0.913	1.000	0.913	drs
Leshan Vocational and Technical College	0.827	1.000	0.827	drs
Yaan Vocational College	0.728	0.752	0.968	drs
Guang'an Vocational Technical College	0.837	0.955	0.876	drs
Sichuan Information Technology College	0.731	0.780	0.937	irs
Sichuan University of Science and Technology	0.056	0.062	0.890	drs
Sichuan Sanhe College of Professionals	0.805	0.824	0.978	irs

Sichuan Health Rehabilitation Vocational College	1.000	1.000	1.000	-
Aba Vocational College	0.917	1.000	0.917	irs
SiChuan Judicial and Police Officers Professional College	0.599	0.785	0.764	irs
Sichuan Southwest Vocational College of Civil Aviation	0.514	0.521	0.985	irs
Bazhong Vocational and Technical College	0.227	0.259	0.876	irs
Average	0.684	0.735	0.927	

* Crste = Constant Returns to Scale Efficiency

* Vrste = Variable Returns to Scale Efficiency

* Scale = Scale Efficiency

* Rs = Returns to Scale

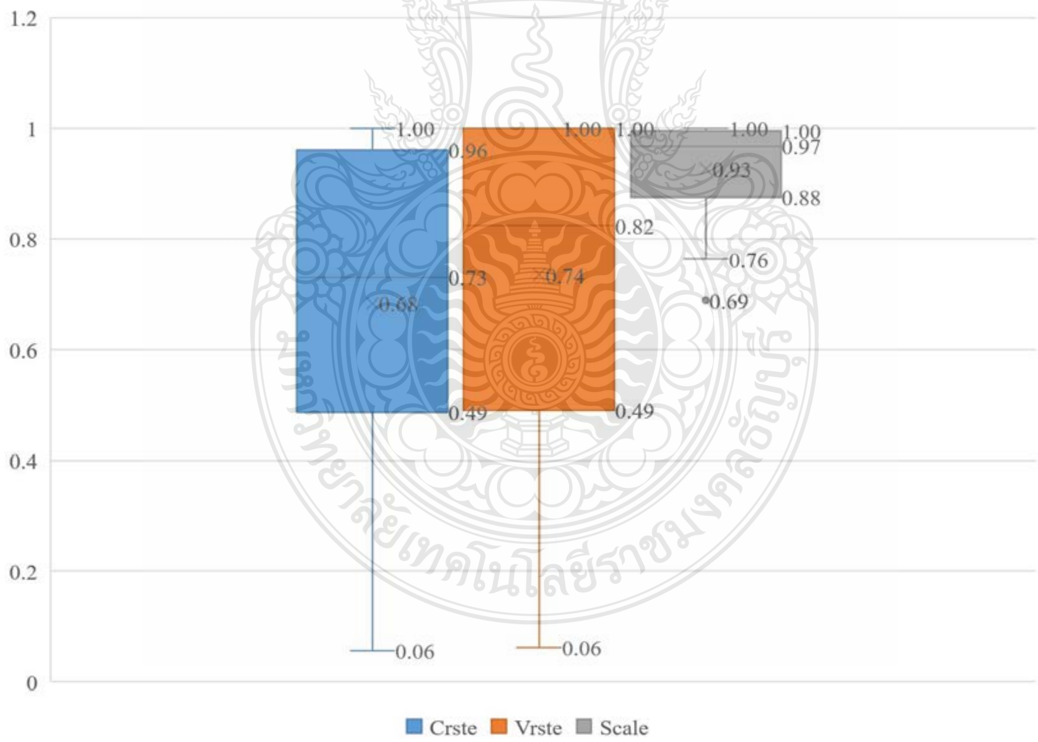

Figure 4.4 Analysis of DEA-BCC Model Results for Higher Vocational Colleges in Sichuan Province in 2020

According to Table 4.7 and Figure 4.5, an analysis of scientific research performance was conducted for 30 higher vocational colleges in Sichuan province in 2021. The Crste values exhibits significant heterogeneity, ranging from 0.08 to 1, with an average of 0.76 and a median of 0.88. The majority of decision-making units have Crste values concentrated between 0.6 and 1. There are 12 decision-making units with a Crste value of 1, suggesting optimal efficiency in their research activities.

In terms of Vrste, the minimum value is 0.09, the maximum is 1, and the average is 0.82, revealing variations in pure technical efficiency among vocational colleges. There are 16 decision-making units with a Vrste value of 1, signifying that a considerable number of colleges have achieved optimal efficiency in pure technical aspects.

Regarding Scale Efficiency, the minimum value is 0.21, the maximum is 1, the average is 0.91, and the median is 0.93, indicating a relatively stable performance in scale efficiency. There are 12 decision-making units with a scale value of 1, demonstrating that these colleges have reached an optimal status in terms of scale efficiency.

In summary, 12 colleges have achieved optimal levels in Crste, Vrste, and Scale, highlighting their outstanding performance in overall efficiency, pure technical efficiency, and scale efficiency. Despite noticeable overall differences in research performance, a substantial number of colleges have attained optimal efficiency.

Table 4.7 Scientific Research Performance Evaluation Results of Higher Vocational Colleges in Sichuan Province in 2021

College name	Crste	Vrste	Scale	Rs
Chengdu Aeronautic Polytechnic	1.000	1.000	1.000	-
Chengdu Polytechnic	1.000	1.000	1.000	-

Sichuan Vocational College of Chemical Technology	0.637	0.647	0.985	drs
Sichuan Water Conservancy Vocational College	0.421	0.444	0.948	drs
Nanchong Professinal Technic College	0.879	0.971	0.906	drs
Neijiang Vocational and Technical College	1.000	1.000	1.000	-
Sichuan Post and Telecommunication College	0.853	1.000	0.853	irs
Mianyang Polytechnic	0.224	0.240	0.930	drs
Sichuan Communication Vocational and Technical College	0.473	0.517	0.914	drs
Sichuan Engineering Technical College	1.000	1.000	1.000	-
Sichuan College of Architectural Technology	1.000	1.000	1.000	-
Dazhou Vocational and Technical College	0.911	1.000	0.911	irs
Sichuan technology & business college	0.266	0.294	0.902	drs
Chengdu Agricultural College	0.887	0.970	0.914	irs
YiBin Vocational And Technical College	0.594	0.682	0.870	irs
Luzhou vocational and technical college	1.000	1.000	1.000	-
Meishan vocational and technical college	1.000	1.000	1.000	-
Chengdu Vocational University of the Arts	0.604	0.713	0.847	irs
Sichuan Vocational and Technical College	1.000	1.000	1.000	-
Leshan Vocational and Technical College	0.663	0.674	0.983	irs
Yaan Vocational College	1.000	1.000	1.000	-
Guang'an Vocational Technical College	0.988	1.000	0.988	drs
Sichuan Information Technology College	0.823	0.848	0.970	irs
Sichuan University of Science and Technology	0.076	0.086	0.891	drs
Sichuan Sanhe College of Professionals	0.620	0.780	0.796	irs
Sichuan Health Rehabilitation Vocational College	1.000	1.000	1.000	-

Aba Vocational College	1.000	1.000	1.000	-
SiChuan Judicial and Police Officers Professional College	0.731	0.754	0.970	irs
Sichuan Southwest Vocational College of Civil Aviation	1.000	1.000	1.000	-
Bazhong Vocational and Technical College	0.213	1.000	0.213	irs
Average	0.762	0.821	0.926	

* Crste = Constant Returns to Scale Efficiency
* Vrste = Variable Returns to Scale Efficiency
* Scale = Scale Efficiency
* Rs = Returns to Scale

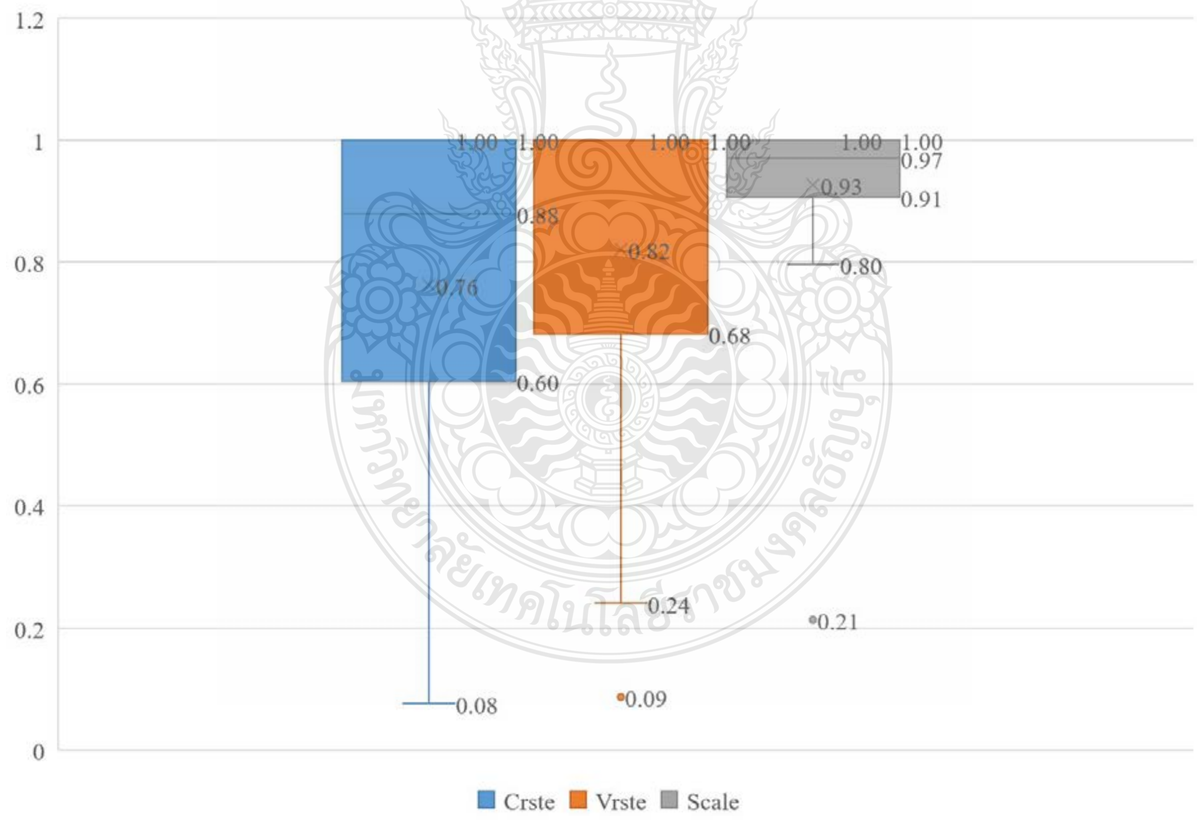

Figure 4.5 Analysis of DEA-BCC Model Results for Higher Vocational Colleges in Sichuan Province in 2021.

From Table 4.8, It shows that the average technical efficiency of higher vocational colleges in Sichuan Province is relatively low, with 36% of the colleges experiencing decreasing returns to scale. In 2019 and 2020, 7 universities achieved DEA effectiveness in research performance, accounting for 23.3% each year. In 2021, 12 universities achieved DEA effectiveness in research performance, constituting 40%. The results indicate that the overall research and technical efficiency of higher vocational colleges in Sichuan Province during 2019-2021 is low.

Table 4.8 Comprehensive Analysis of Scientific Research Performance in Higher Vocational Colleges within Sichuan Province from 2019 to 2021

DEA efficiency	Efficiency eigenvector	2019	2020	2021	Average
TE(Technical efficiency)	Number of colleges with TE=1	7	7	12	8
	Average	0.695	0.684	0.762	0.714
PTE(Pure technical efficiency)	Number of colleges with PTE=1	11	11	16	12
	Average	0.733	0.735	0.821	0.765
SE(Scale efficiency)	Number of colleges with SE=1	7	7	12	8
	Average	0.944	0.927	0.926	0.932
RE(Returns to scale)	Increasing number of colleges	10	11	10	10
	Decreasing number of colleges	13	12	8	11
	Constant number of colleges	7	7	12	8

In DEA analysis, comprehensive efficiency refers to the technical efficiency without considering scale returns. Technical efficiency measures the relative efficiency of research output in higher vocational education given input resources. This metric examines whether universities effectively utilize available resources to maximize research outputs. Regarding the technical efficiency index, the average technical efficiency of higher vocational colleges in Sichuan Province for 2019, 2020, and 2021 was 0.695, 0.684, and 0.762, respectively. Despite exhibiting a consistent upward trend, these values remain relatively low, underscoring the need for further enhancement in the overall resource allocation capability and resource utilization efficiency of higher vocational colleges in Sichuan Province. Examining each college's scientific research performance, only 5 higher vocational colleges achieved continuous DEA effectiveness over three years, These colleges are Chengdu Aeronautic Polytechnic, Sichuan Engineering Technical College, Sichuan College of Architectural Technology, Meishan Vocational and Technical College, and Sichuan Health Rehabilitation Vocational College, constituting 16% of the total. It shows that these 5 colleges have successfully realized the optimal allocation of resources, thus achieving the best input-output performance in scientific research work. While the technical efficiency of most colleges has been progressively improving year by year, there still exists substantial room for advancement.

Pure technical efficiency is an index that compares a university's output to its input resources while mitigating the impact of scale. It assesses whether a university can effectively leverage technology and innovation within its existing resource utilization to attain maximal research output. Analysis of the pure technical efficiency index reveals that the mean pure technical efficiency for higher vocational colleges in Sichuan Province was 0.733, 0.735, and 0.821 for 2019, 2020, and 2021, respectively. Although these values exhibit an upward trend, they persist at relatively moderate levels, implying notable room for improvement in research management, resource utilization, and technological innovation within higher vocational colleges in Sichuan Province. Upon evaluating each college's performance, 6 colleges achieved consecutive and sustained effectiveness in pure technical efficiency over three years, underscoring these colleges' relative advancement in technological innovation and management.

Scale efficiency evaluates whether a university operates at an appropriate scale to achieve the maximum research output. It compares a university's actual scale with the theoretically optimal scale to determine whether it effectively leverages its scale advantage. Regarding the scale efficiency index, the average scale efficiency of higher vocational colleges in Sichuan Province for 2019, 2020, and 2021 was 0.944, 0.927, and 0.926, respectively, all greater than 0.9. It indicates that the overall research inputs scale of higher vocational colleges in Sichuan Province is reasonable, and they have achieved a commendable efficiency level. The average scale efficiency surpasses the average pure technical efficiency, signifying that research management and technical capabilities are the primary factors constraining the scientific research performance of higher vocational colleges. Based on the result, it is evident that some colleges can further enhance their scientific research performance by expanding their input scale.

Regarding the scale return index, among higher vocational colleges in Sichuan Province, there were 10 colleges, 11 colleges, and 10 colleges with an average increasing scale return for 2019, 2020, and 2021, respectively. Additionally, there were 13 colleges, 12 colleges, and 8 colleges with an average decreasing scale return, and 7 colleges, 7 colleges, and 12 colleges with a constant scale return for the same respective years. These findings indicate that each higher vocational college needs to adjust the allocation ratio of research resources and rationalize resource allocation based on their respective circumstances. For colleges experiencing increasing scale returns, it is advisable to increase research investment. Conversely, reducing resource inputs can maximize overall efficiency for colleges facing decreasing scale returns.

4.2.2 The dynamic analysis results based on the Malmquist index model

This study further employs the Malmquist index model and utilizes DEAP 2.1 software to conduct a dynamic analysis of research performance among higher vocational colleges in Sichuan Province from 2019 to 2021, with the results presented in Tables 4.9 and 4.10.

Table 4.9 Malmquist Index and Its Components of Scientific Research Performance Evaluation of Higher Vocational Colleges in Sichuan Province from 2019 to 2021

College name	Efficiency Change	Technical Change	Pure Technical Efficiency Change	Scale Change	Total Factor Productivity Change
Chengdu Aeronautic Polytechnic	1.000	0.833	1.000	1.000	0.833
Chengdu Polytechnic	1.310	0.902	1.262	1.038	1.182
Sichuan Vocational College of Chemical Technology	1.179	1.095	1.175	1.004	1.291
Sichuan Water Conservancy Vocational College	1.180	1.001	1.119	1.054	1.181
Nanchong Professinal Technic College	0.938	1.037	0.985	0.952	0.973
Neijiang Vocational and Technical College	1.458	1.104	1.455	1.002	1.609
Sichuan Post and Telecommunication College	1.009	0.854	1.062	0.950	0.861
Mianyang Polytechnic	0.758	1.123	0.784	0.967	0.851

College name	Efficiency Change	Technical Change	Pure Technical Efficiency Change	Scale Change	Total Factor Productivity Change
Sichuan communication vocational and technical college	0.939	0.983	0.864	1.086	0.923
Sichuan Engineering Technical College	1.000	1.010	1.000	1.000	1.010
Sichuan College of Architectural Technology	1.000	0.701	1.000	1.000	0.701
Dazhou Vocational and Technical College	1.141	0.910	1.124	1.015	1.038
Sichuan technology & business college	1.983	1.161	2.077	0.955	2.302
Chengdu Agricultural College	0.974	0.893	1.010	0.964	0.869
YiBin Vocational And Technical College	1.043	0.952	1.097	0.951	0.992
Luzhou vocational and technical college	1.064	1.125	1.058	1.006	1.197
Meishan vocational and technical college	1.000	0.898	1.000	1.000	0.898

College name	Efficiency Change	Technical Change	Pure Technical Efficiency Change	Scale Change	Total Factor Productivity Change
Chengdu Vocational University of the Arts	1.605	1.023	1.595	1.006	1.641
Sichuan Vocational and Technical College	1.027	1.144	1.000	1.027	1.175
Leshan Vocational and Technical College	0.814	1.073	0.821	0.992	0.874
Yaan Vocational College	1.121	0.910	1.112	1.008	1.020
Guang'an Vocational Technical College	1.019	1.074	1.000	1.019	1.095
Sichuan Information Technology College	0.977	1.177	0.970	1.007	1.149
Sichuan University of Science and Technology	0.685	0.952	0.684	1.002	0.652
Sichuan Sanhe College of Professionals	0.879	1.077	0.966	0.910	0.948
Sichuan Health Rehabilitation	1.000	1.162	1.000	1.000	1.162

College name	Efficiency Change	Technical Change	Pure Technical Efficiency Change	Scale Change	Total Factor Productivity Change
Vocational College					
Aba Vocational College	1.233	1.327	1.000	1.233	1.636
SiChuan Judicial and Police Officers Professional College	0.881	1.223	0.868	1.015	1.078
Sichuan Southwest Vocational College of Civil Aviation	1.348	1.381	1.333	1.011	1.862
Bazhong Vocational and Technical College	0.935	0.999	1.963	0.476	0.934
Average	1.058	1.027	1.080	0.980	1.086

Table 4.10 Malmquist Index and Its Decomposition of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province from 2019 to 2021 (Each Year)

Year	Efficiency Change	Technical Change	Pure Technical Efficiency Change	Scale Change	Total Factor Productivity Change
2019-2020	0.955	1.198	0.974	0.981	1.145

2020-2021	1.171	0.879	1.197	0.979	1.030
Average	1.058	1.027	1.080	0.980	1.086

The analysis of Tables 4.9 and 4.10 reveals that from 2019 to 2021, the average total factor productivity (TFP) of 30 higher vocational colleges in Sichuan Province was 1.086, indicating an overall TFP growth of 8.6%. Notably, the trend in pure technical efficiency alteration aligns with the trend in technical efficiency alteration, which, in turn, corresponds with the trend in total factor productivity alteration. This alignment highlights the substantial influence of pure technical efficiency on the effective allocation and utilization of research resources within higher vocational colleges in Sichuan Province.

In terms of developmental dynamics, 18 colleges exhibited total factor productivity (TFP) exceeding 1, with the most rapidly advancing institution experiencing a remarkable 130% increase in TFP. In contrast, 12 colleges had a TFP below 1, indicating that the overall research TFP of higher vocational colleges in Sichuan Province remains relatively modest, suggesting considerable room for improvement. During the same period, the average technical efficiency rose by 5.8%, while the average technological progress increased by 2.7%. This underscores the central role of scientific research management and resource utilization efficiency within higher vocational colleges in Sichuan Province in elevating overall performance, with technological progress playing a secondary role.

Furthermore, the average pure technical efficiency increased by 8%, while the average scale efficiency declined by 2%. This observation suggests that the enhancement in technical efficiency is primarily driven by the increase in pure technical efficiency, emphasizing the significance of improving scientific research management and resource utilization efficiency as key drivers of improved research efficiency.

In the annual analysis, it was found that from 2019 to 2020, the total factor productivity of higher vocational colleges in Sichuan Province surged by 14.5%. This period saw a decrease of 4.5% in the technical efficiency index and a simultaneous rise of 19.8% in the technological progress index. This underscores the pivotal role of advancements and innovations in scientific research practices in augmenting the overall scientific research performance of higher vocational colleges in Sichuan Province during this period. From 2020 to 2021, the total factor productivity of higher vocational colleges increased by 3%, with a concurrent increase of 17.1% in the technical efficiency index and a decline of 12.1% in the technological progress index. This highlights the primary role of research management practices and resource utilization efficiency in enhancing scientific research performance during this period. Consequently, higher vocational colleges in Sichuan Province have significant potential to elevate their scientific research performance by improving scientific research technology management, enhancing resource utilization, and fortifying scientific research innovation.

4.3 The result of analyzing the importance of the impact of research input indicators on the research performance of higher education colleges

Based on the aforementioned analysis, it is evident that there is variability in the scientific research performance among higher vocational colleges in Sichuan. This stage employs the Rough Set theory to investigate the impact of scientific research input indicators on scientific research performance, with the aim of revealing the relevance of various investment indicators to scientific research performance.

In accordance with the Rough Set theory, the analyzed data in this stage includes technical efficiency, technical progress efficiency, and total factor productivity obtained from the Malmquist index model, as well as research input data from 30 higher education colleges for the years 2019 to 2021. The data is then discretized using a four-level classification method. In this method, the value is assigned 4 if it exceeds the mean plus 2 standard deviations, 3 if it is greater than the mean but less than the mean plus 2 standard deviations, 2 if it is less than or equal to the mean minus 2 standard deviations, and 1 if it is equal to or less than the mean minus 2 standard deviations. Subsequently, the information entropy, importance, and contribution of each scientific research input indicator based on different decision attributes are calculated and presented in Table 4.11.

Table 4.11 Information Entropy, Importance and Contribution of Scientific Research Input Indicators in Higher Vocational Colleges of Sichuan Province

	Research Input Indicators	Information Entropy	Importance	Contribution
Based on Technical Efficiency	Internal expenditure of scientific research funds	0.556	0.269	0.404
	Full-time teachers	0.382	0.096	0.144
	Senior and above professional titles teachers	0.520	0.233	0.349
	Library collections	0.356	0.069	0.104
Based on Technical Progress Efficiency	Internal expenditure of scientific research funds	0.585	0.094	0.384
	Full-time teachers	0.558	0.067	0.273
	Senior and above professional titles teachers	0.537	0.046	0.188
	Library collections	0.529	0.038	0.155
Based on Total Factor Productivity	Internal expenditure of scientific research funds	0.644	0.221	0.577
	Full-time teachers	0.428	0.006	0.015
	Senior and above professional titles teachers	0.556	0.133	0.348
	Library collections	0.446	0.023	0.060

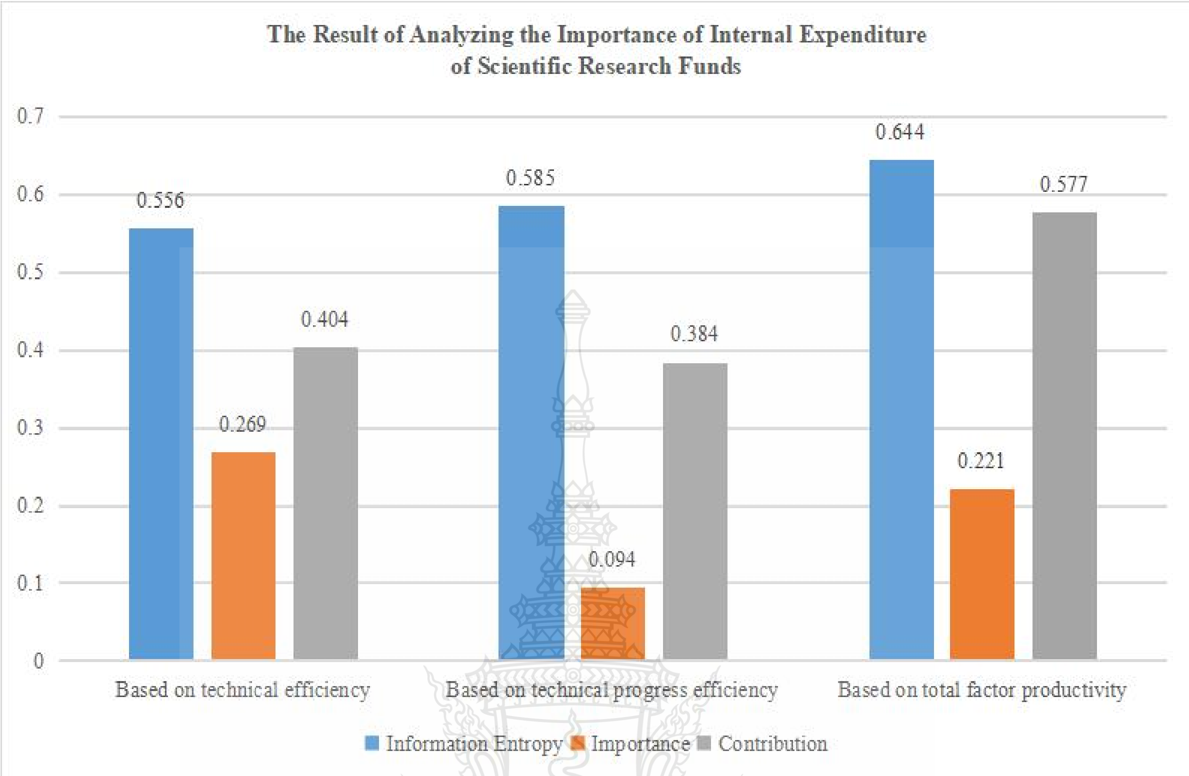

Figure 4.6 The Result of Analyzing the Importance of Internal Expenditure of Scientific Research Funds

Based on the data provided in Table 4.11 and Figure 4.6, an analysis of the performance of the research input indicator "Internal expenditure of scientific research funds" across various efficiency dimensions reveals significant insights.

In terms of technical efficiency, the information entropy is recorded at 0.556, indicating a certain degree of diversity in the information associated with this indicator. The relatively lower importance (0.269) suggests that the weight of this indicator in the overall efficiency assessment is relatively modest. However, the substantial contribution (0.404) underscores its significant impact on the overall technical efficiency.

Moving on to technical progress efficiency, the information entropy stands at 0.585, signifying considerable diversity in the information related to this dimension. With a relatively low importance score of 0.094, this indicates a limited weight of the indicator in the overall efficiency evaluation. Nonetheless, the noteworthy contribution of 0.384 emphasizes its relatively substantial role in influencing overall technical progress efficiency.

Considering total factor productivity, the information entropy is relatively high at 0.644, pointing to a substantial diversity in the information associated with this indicator. The importance score of 0.221 indicates a relatively lower weight of this indicator in the overall efficiency assessment. However, the noteworthy contribution of 0.577 highlights its substantial impact on the overall total factor productivity.

In summary, the "Internal expenditure of scientific research funds" exhibits a considerable degree of information diversity across different efficiency dimensions. It significantly contributes to technical efficiency, technical progress efficiency, and total factor productivity, with a particularly pronounced influence on technical efficiency and total factor productivity. Nevertheless, its relatively lower importance underscores the need to consider additional factors that may contribute to overall efficiency.

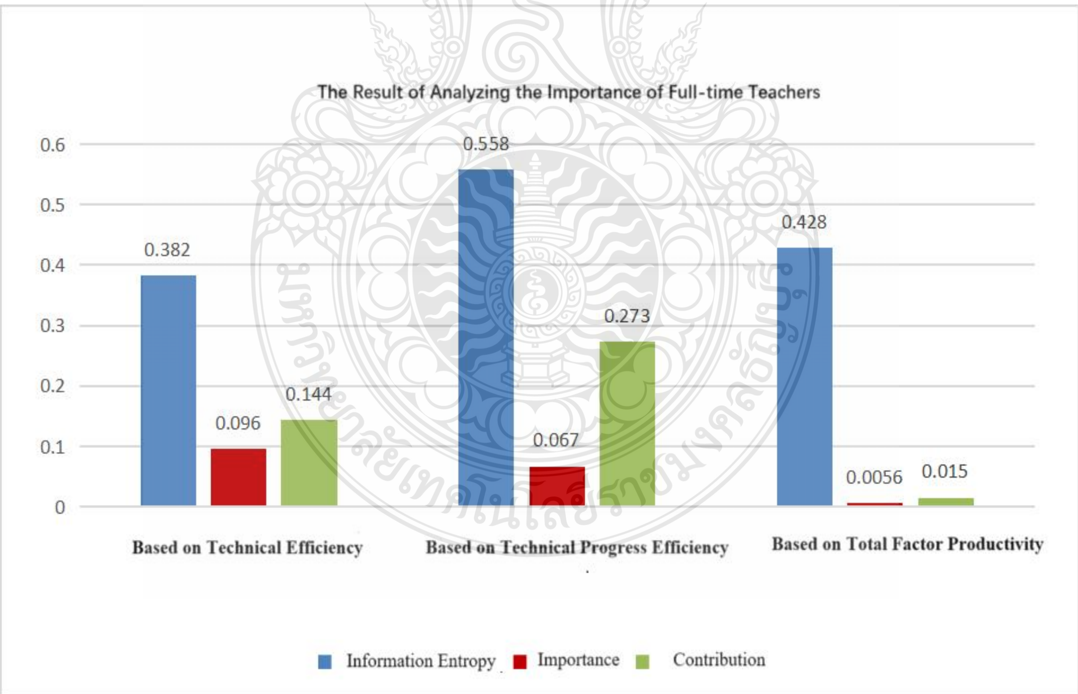

Figure 4.7 The Result of Analyzing the Importance of Full-time Teachers

Based on the data provided in Table 4.11 and Figure 4.7, an analysis of the performance of the research input indicator "Full-time Teachers" across various efficiency dimensions reveals significant insights.

In terms of technical efficiency, the relatively low information entropy of 0.382 suggests a certain degree of consistency in the information provided by full-time teachers, indicative of a stable performance in this dimension. However, the importance score of 0.096 implies a comparatively minor weight assigned to this indicator in the overall efficiency assessment. The moderate contribution score of 0.144 indicates a discernible yet relatively modest impact on the comprehensive technical efficiency landscape.

Turning to technical progress efficiency, the elevated information entropy of 0.558 reveals substantial diversity and variability in the contributions of full-time teachers to technological advancement. This heightened variability suggests potential disparities in the approaches and outcomes associated with fostering technical progress. Despite this, the relatively low importance score of 0.067 signifies a limited emphasis on the role of full-time teachers in shaping technical progress efficiency. Nevertheless, the substantial contribution score of 0.273 highlights a significant influence on the overarching efficiency landscape in the context of technical progress.

In the realm of total factor productivity, the comparatively low information entropy of 0.428 indicates a certain level of consistency in the information provided by full-time teachers in contributing to overall productivity. However, the extremely low importance score of 0.0056 underscores a minimal weight assigned to this indicator in the holistic efficiency evaluation. The notably low contribution score of 0.015 further emphasizes a limited impact on the comprehensive total factor productivity landscape.

In summary, "Full-time teachers" exhibit diverse performances across different efficiency dimensions. While their contribution to technical progress efficiency is noteworthy, their impact on technical efficiency and total factor productivity is relatively subdued. These observations necessitate a contextual understanding of the specific roles and contributions of full-time teachers within the broader framework of educational and research endeavors.

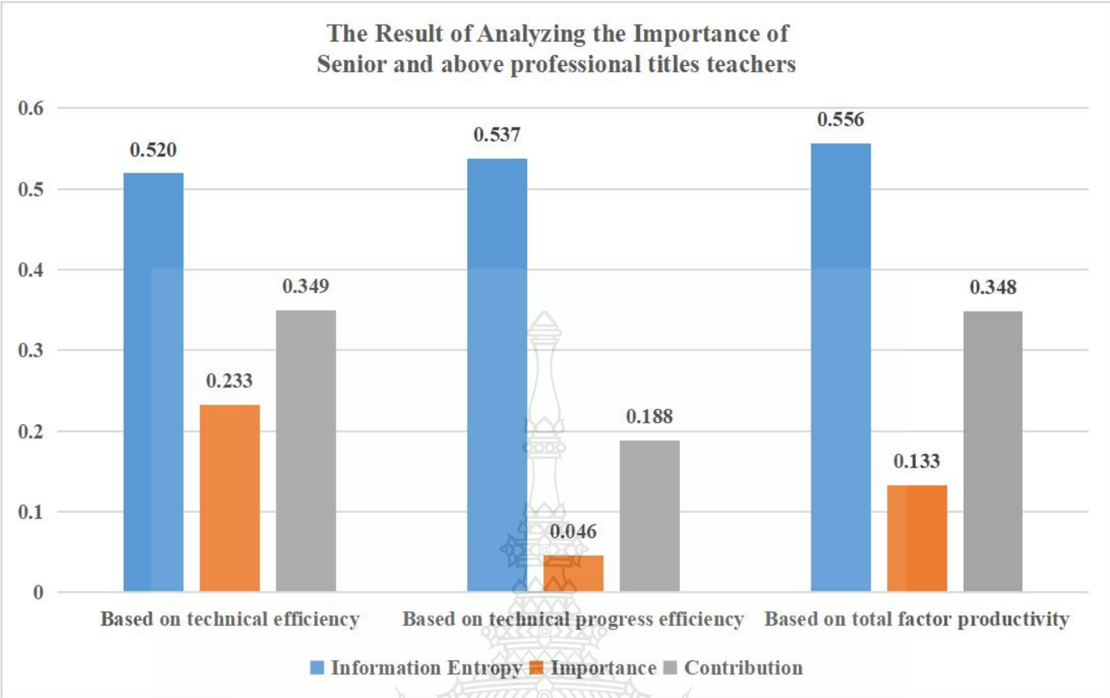

Figure 4.8 The Result of Analyzing the Importance of Senior and Above Professional Titles Teachers

Based on the information presented in Table 4.11 and Figure 4.8, there are variations observed in the performance of the Teachers holding senior and above professional titles variable across different efficiency factors.

Regarding technical efficiency, this factor demonstrates a relatively high information entropy (0.519), indicating a substantial amount of diverse information provided. Simultaneously, its importance and contribution to overall efficiency are relatively high, with values of 0.233 and 0.349, respectively. This suggests that the variable plays a significant role in supporting efficient research and enhancing overall performance.

The factor shows a slightly higher information entropy (0.537) for technical progress efficiency, suggesting some heterogeneity in evaluating technical progress efficiency. However, its lower importance and contribution to overall efficiency, with values of 0.046 and 0.188, respectively, indicate a relatively minor impact on technical progress efficiency.

Concerning total factor productivity, the variable exhibits a relatively high information entropy (0.556), indicating a substantial amount of information. Its importance and contribution are relatively high in overall efficiency, with values of 0.133 and 0.348, respectively. This suggests that Senior and above professional titles teachers significantly influence overall performance.

In summary, this variable has a notable impact on technical efficiency and total factor productivity, while its influence on technical progress efficiency appears to be relatively minor.

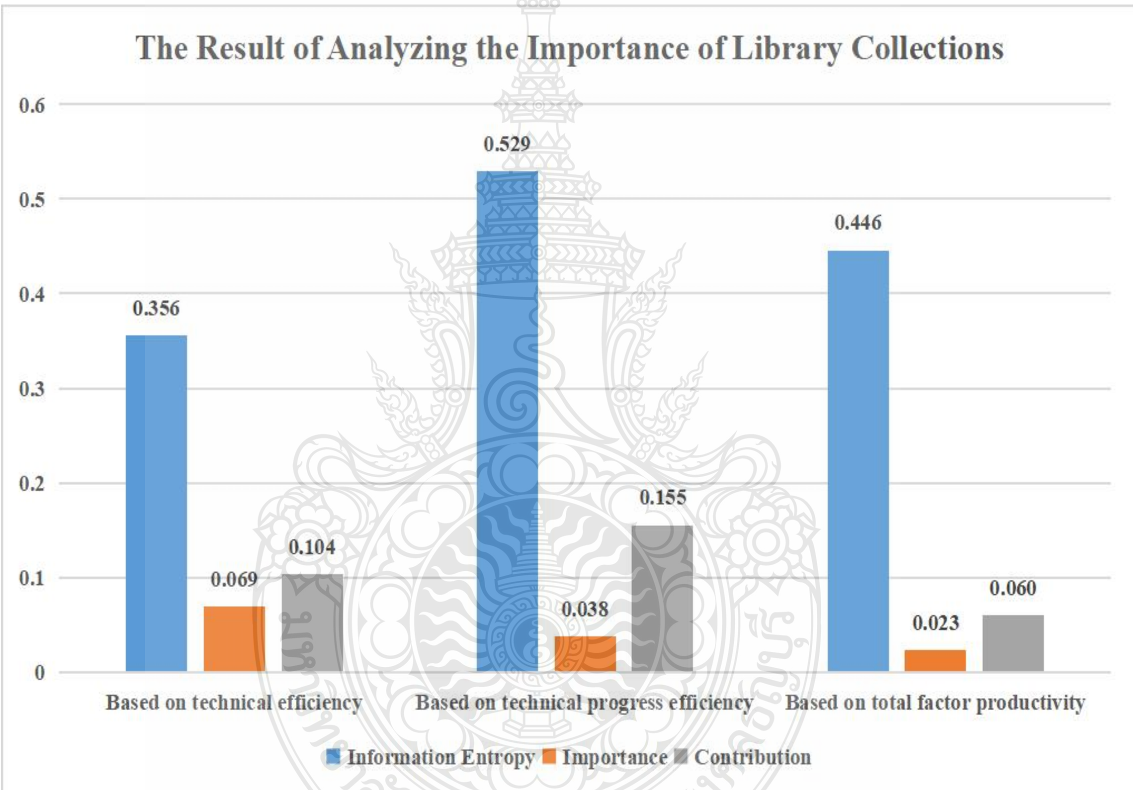

Figure 4.9 The Result of Analyzing the Importance of Library Collections

According to Table 4.11 and Figure 4.9, the Library collections as a research input indicator exhibit certain variations in different efficiency aspects.

In terms of technical efficiency, the information entropy of library collections is relatively low (0.356), indicating relatively consistent information. However, its low importance (0.069) and contribution (0.104) suggest a relatively minor impact on overall efficiency when evaluating technical efficiency.

Regarding technical progress efficiency, the information entropy of library collections is relatively high (0.529), suggesting potential heterogeneity. Nevertheless, its relatively low importance (0.038) and contribution (0.155) indicate a relatively minor impact on overall efficiency when assessing technical progress efficiency.

In terms of total factor productivity, the information entropy of library collections is relatively low (0.446), providing relatively consistent information. Its low importance (0.023) and contribution (0.060) suggest a relatively minor impact on overall efficiency when evaluating total factor productivity.

In summary, library collections show relatively consistent performance across different efficiency aspects, with a relatively minor impact on technical efficiency, technical progress efficiency, and total factor productivity.

we have obtained the information entropy, importance, and contribution values of four research input indicators concerning technical efficiency, technical progress efficiency, and total factor productivity. The results reveal that all four research input indicators exert an influence on the technical efficiency of higher vocational colleges. Specifically, Internal expenditure of scientific research funds, and Senior and above professional titles teachers exhibit strong associations with technical efficiency, contributing 40.4% and 34.9%, respectively. The combined contribution of these two factors amounts to 75.3%, suggesting that differences in research technical efficiency among various higher vocational colleges are primarily determined by these two factors.

Furthermore, all four research inputs significantly impact the technical progress efficiency of higher vocational colleges, with the following contribution rankings: Internal expenditure of scientific research funds, Full-time teachers, Senior and above professional titles teachers, and Library collections. Interestingly, in contrast to the contribution ranking based on technical efficiency, Full-time teachers moved from the third to the second position, indicating a more prominent role in technical progress efficiency.

Lastly, the research findings demonstrate that all four research inputs contribute to the total factor productivity of higher vocational colleges. Among them, Internal expenditure of scientific research funds, and Senior and above professional titles teachers have the highest contribution degrees, accounting for 57.7% and 34.8%, respectively. The combined contribution rate of these two factors is 92.5%. The lower contribution degrees of the other two inputs suggest that these two factors are primarily responsible for the differences in total factor productivity among various higher vocational colleges.

Considering the comprehensive analysis above, the research input indicators, including Internal expenditure of scientific research funds, Full-time teachers, Senior and above professional titles teachers, and Library collections were examined across various efficiency dimensions. the research findings highlight the significant effects of internal expenditure for scientific research funds and senior and above professional teachers on scientific research efficiency. These two factors emerge as the main contributors to the variations in research input efficiency among different colleges.

4.4 The result of establishing a comprehensive evaluation model to analyze the scientific research performance of higher vocational colleges in Sichuan Province

The primary objective of this study was to evaluate the research performance of higher vocational colleges in Sichuan Province from 2019 to 2021 using a comprehensive approach. The study employed three models: DEA-BCC, Malmquist, and Rough Set theory to analyze the research performance and identify the main factors influencing the growth of research performance in higher vocational colleges in the province.

The static assessment using the DEA-BCC model provided a detailed evaluation of the research output for colleges and the overall situation of research. This model assessed the efficiency with which colleges used their resources to maximize research output under the same input conditions. The analysis offered an understanding of the research management, resource utilization, and technological innovation of each college. The factors that hindered the research performance of higher vocational colleges were also identified. This analysis provided decision-makers with a clear ranking of research performance, offering specific insights for goal setting and resource allocation. Colleges with lower research performance could set challenging research goals and adjust resource allocation to improve efficiency.

The Malmquist index model for dynamic analysis focused on the evolution of research performance over time in higher vocational colleges in Sichuan Province. This model analyzed the overall research efficiency and technological changes in higher vocational colleges from 2019 to 2021. The analysis provided decision-makers with a comprehensive development trajectory and identified the main factors influencing research performance growth. Decision-makers could then create more forward-looking strategic plans for the research development of higher vocational colleges in Sichuan Province. The analysis of the contributions of efficiency and technological changes enabled decision-makers to formulate future research development strategies more targeted, adapting better to the evolving research environment.

The Rough Set theory was used to analyze the complex impact of research input variables on research performance in higher vocational colleges in Sichuan. This analysis provided a more comprehensive understanding of the role of different variables in research performance and identified key influencing factors. Decision-makers could use this analysis to adjust research input strategies more effectively, enhancing the overall performance level. By delving into the results of the Rough Set theory, decision-makers could discover that certain input factors were more crucial for improving research performance in specific contexts. This information allowed them to adjust resource allocation for optimal results.

The integrated model of DEA-BCC, Malmquist, and Rough Set theory provided a multi-level and multi-angle diagnosis of research performance in higher vocational colleges in Sichuan Province. The model offered decision-makers comprehensive and in-depth information to support the improvement and development planning of research performance in higher vocational colleges. The model provided specific guidance and decision support for the overall optimization of research performance. The research findings provided valuable insights into enhancing scientific research performance within higher vocational colleges and mitigating inter-collegiate disparities in research performance. Therefore, the integrated model can be applied to scientific research performance analysis in universities and institutions, offering specific innovation and generalization potential for future research endeavors.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

The final chapter of this dissertation provides a summary of the study, including the research methodology, main conclusion, findings, and their practical contributions and implications. It also discusses the study's limitations and suggests further research. This chapter is divided into five sections: Section 5.1 presents the conclusion, Section 5.2 offers research results and discussion of the study, Section 5.3 highlights the contributions of the study, Section 5.4 provides suggestions for further research, and Section 5.5 outlines the limitations of the study.

5.1 Conclusion

The objective of this study was to assess and evaluate the scientific research performance of higher vocational colleges in Sichuan Province. Specifically, the focus was on investigating the influence of research input indicators on the research performance of these colleges. Additionally, the aim was to develop a comprehensive model for evaluating the scientific research performance of higher vocational colleges in the region. The sample for this study comprised data from 30 higher vocational colleges, covering the period from 2019 to 2021. The data sources included publicly available annual quality reports, annual budgets, final accounts reports of each higher vocational college, as well as scientific statistical data from each college.

In this study, we took into account the scholarly findings in the field and the distinctive characteristics of higher vocational colleges. We formulated four input and four output indicators to assess scientific research performance. The input indicators encompass Internal Expenditure of Scientific Research Funds, Full-time Teachers, Senior and Above Professional Titles Teachers, and Library Collections. Meanwhile, the output indicators consist of Research Papers, Research Projects at the Municipal Level and Above, Vertical and Horizontal Project Arrival Funds, and Granted Patents.

This study utilized DEA-BCC and Malmquist index models to assess the scientific research performance of higher vocational colleges in Sichuan. Additionally, the Rough Set theory was employed to analyze the impact of research input indicators on research performance. The computation of the DEA-BCC model and the Malmquist index model was carried out using DEAP2.1 software, while the Rough Set theory was analyzed using the Python programming language. The results of the analysis revealed significant patterns and associations, which were further compared with relevant literature and theories to enhance understanding.

5.2 Research Results and Discussion

For each research question, a summary and discussion of the research results pertinent to the question are given as follows:

5.2.1 The result of analyzing and evaluating the scientific research performance of higher vocational colleges in Sichuan province

During 2019-2021, the overall research performance of higher vocational colleges in Sichuan Province remained low, with only 7 universities achieving DEA effectiveness in research performance in 2019 and 2020, accounting for 23.3% each year. 12 universities achieved DEA effectiveness in research performance in 2021, constituting 40%.

Despite a consistent upward trend, the research performance of higher vocational colleges in Sichuan Province has been relatively low. The study discovered that 36% of the colleges experienced decreasing returns to scale, whereas only 5 colleges achieved continuous DEA effectiveness over three years, These colleges are Chengdu Aeronautic Polytechnic, Sichuan Engineering Technical College, Sichuan College of Architectural Technology, Meishan Vocational and Technical College, and Sichuan Health Rehabilitation Vocational College.

The study also found that some colleges need to expand their input scale, while others need to adjust their allocation ratio of research resources based on their circumstances. For colleges experiencing increasing scale returns, increasing research investment is advisable, whereas reducing resource inputs can maximize overall efficiency for colleges facing decreasing scale returns. To improve performance, some colleges need to expand their input scale, while others need to adjust their allocation ratio of research resources based on their circumstances. For colleges experiencing increasing scale returns, increasing research investment is advisable, whereas reducing resource inputs can maximize overall efficiency for colleges facing decreasing scale returns.

Between 2019 and 2021, the average total factor productivity (TFP) of 30 higher vocational colleges in Sichuan Province grew by 8.6%. Pure technical efficiency had a significant impact on research resource utilization. 18 colleges had a TFP exceeding 1, and 12 colleges had a TFP below 1, indicating room for improvement. Technical efficiency rose by 5.8%, while technological progress increased by 2.7%. Pure technical efficiency increased by 8%, and scale efficiency declined by 2%. From 2019 to 2020, TFP surged by 14.5%, while technical efficiency decreased by 4.5%, and technological progress increased by 19.8%. From 2020 to 2021, TFP increased by 3%, technical efficiency increased by 17.1%, and technological progress declined by 12.1%. The findings indicate that, during the academic years 2019-2020, advancements and innovations in scientific research practices played a crucial role in enhancing the overall research performance of vocational colleges in Sichuan Province. In the academic year 2020-2021, research management practices and resource utilization efficiency emerged as the primary contributors to improving research performance.

Higher vocational colleges in Sichuan Province can improve their scientific research performance by improving research technology management and resource utilization.

These findings align with the results of other studies (Ma et al., 2021; Xiao et al., 2022; Liao et al.2021,) Ma et al., 2021) rededicated that in the western region of China, the proportion of non-DEA efficient colleges reached a maximum of 64%, and the overall scientific research performance was lower than the national average. Liao et al.(2021)found that there is a significant disparity in research resource investment among universities in different regions, with higher overall research efficiency observed in universities in developed regions. The colleges identified with high research efficiency in this study were all located in cities with high GDP in Sichuan Province. Xiao et al.(2022) rededicated that Chengdu Aviation Vocational and Technical College, along with five other higher vocational colleges, achieved the benchmark level of research in the field of professional group construction, which is generally consistent with the list of higher vocational colleges identified as having relatively high scientific research performance in this study.

5.2.2 The result of analyzing the importance of the impact of research input indicators on the research performance of higher education colleges

The technical efficiency, technical progress efficiency, and total factor productivity of higher vocational colleges are impacted by four research inputs. Out of these inputs, Internal expenditure of scientific research funds, and Senior and above professional titles teachers have the strongest associations with technical efficiency, contributing 75.26% to its variation across different colleges. Similarly, all four research inputs significantly affect the technical progress efficiency of higher vocational colleges, with the contribution ranking as follows: Internal expenditure of scientific research funds, Full-time teachers, Senior and above professional titles teachers, and Library collections. Moreover, all four research inputs contribute to the total factor productivity of higher vocational colleges, with Internal expenditure of scientific research funds and Senior and above professional titles teachers having the highest contribution degrees, accounting for 92.53% of the total contribution. In conclusion, these research findings suggest that internal expenditure for scientific research funds, and senior and above professional teachers are the main contributors to the variations in scientific research performance across different colleges.

These findings align with the results of other studies (Cai & Yao, 2022; Xu & Li, 2023; Zhou,2022). Cai et al.(2022)found that the composition of human capital, regional economic strength, and achievement rewards have a positive impact on the research performance of Double First-Class construction universities. Xu(2023)concluded that factors such as university scale, quality of research personnel, and funding from industry partners significantly contribute to enhancing high-quality research performance in universities. Additionally, the research environment can, to a certain extent, promote the level of high-quality research performance. Zhou(2022) found the input factors of research and innovation play a crucial role, among which the number of development institutions, the number of research and development personnel, and the expenditure on research activities are highly correlated with research and innovation performance.

5.2.3 The result of establishing a comprehensive evaluation model to analyze the scientific research performance of higher vocational colleges in Sichuan Province

The study employed an integrated model of DEA-BCC, Malmquist, and Rough Set theory. The integrated model used to evaluate research performance in higher vocational colleges in Sichuan Province is multi-tiered, It provided a more in-depth understanding of current trends and performance levels. This model has been empirically demonstrated to be scientifically effective.

The first tier of the model used DEA-BCC to conduct a static assessment of the colleges. DEA-BCC created an efficiency frontier that identifies institutions with comparatively lower performance under similar input conditions. By comparing the relative efficiency levels of each institution with their peers, targeted recommendations for optimization efforts can be made.

The second tier of the model used the Malmquist index model for dynamic analysis, which tracks trends in research performance and identifies efficiency changes and technological shifts occurring over a specified period. The study provided a comprehensive understanding of the developmental trajectory of research performance in higher vocational colleges and offers forward-looking guidance for future planning.

These findings align with the results of other studies (Wu,2020; Liu &Xu,2018; Ma,2021; Bae et al.,2021; Xue et al.,2021; Shen et al.,2021). Wu utilized the DEA model to conduct a cross-sectional measurement of the data from 41 Chinese universities participating in the 'World-class University' initiative from 2020 to 2021. The objective is to investigate the current state of educational performance in top-tier Chinese universities, providing insights for optimizing resource allocation in higher education universities. Liu et al.(2018) conducted an empirical study on the input-output performance of research investment in different regions of China's universities from 2009 to 2016 using the DEA model. Ma et al. (2021) conducted an analysis of research performance for 72 nationally demonstrative higher vocational colleges in China using the DEA analysis method. Bae et al. (2021) evaluated the efficiency of private university operations by applying a DEA-BCC model, it confirmed the relative efficiency of private universities and suggested improvement directions through the

DEA method, which is characterized by the simultaneous consideration of various input and output factors. Xue et al.(2021)applied a three-stage data-envelopment analysis (DEA) and the Malmquist index method, they evaluated the static and dynamic efficiency of input–output data of scientific research produced by universities directly under the Ministry of Education in the period 2010 to 2017. Shen et al.(2021)applied the DEA-BCC model to analyze the current situation of the overall science and technology input-output efficiency of various regions in China at the static level. Meanwhile, they applied the Malmquist index model to value and analyze input-output efficiency from 2011 to 2020 at the dynamic level of time sequence.

To provide a more comprehensive understanding of the impact of various variables on research performance, Rough Set theory is incorporated for a systematic analysis of research input variables. This method is not limited to linear relationships and can capture non-linear and intricate connections within the data. This integrated analytical model offered a multifaceted diagnosis of scientific research performance among higher vocational colleges in Sichuan Province. By delving into both static and dynamic dimensions and integrating non-linear analytical tools, decision-makers can make informed decisions to enhance research performance and development planning in higher vocational colleges.

5.3 Contributions of the Study

5.3.1 Theoretical contributions

The results of this study contribute to the academic literature in 4 ways as follows:

5.3.1.1 This study formulated research input indicators encompassing human, financial, and physical resources based on a thorough analysis of domestic and international research. These input indicators have been confirmed as significant determinants influencing research outputs. Simultaneously, a framework inclusive of four distinct output indicators — namely research papers, research projects at the municipal level and above, funding for horizontal and vertical research projects, and granted patents had been established.

5.3.1.2 The study found that internal expenditure of scientific research funds and senior and above professional titles teachers are the main factors contributing to the differences in research input efficiency among different colleges. These findings highlight the importance of allocating sufficient resources and recruiting experienced professionals for effective research performance across academic colleges.

5.3.1.3 The study analyzed the various factors contributing to the research performance gap among higher vocational colleges in Sichuan Province and provided valuable policy recommendations for decision-makers. The findings shed light on potential strategies that can be implemented to bridge this gap and enhance the overall research outcomes of these institutions.

5.3.1.4 The study employed an integrated analytical model: DEA-BCC, Malmquist index model, and Rough Set theory. It analyzed the research performance and identified the main factors influencing the growth of research performance in higher vocational colleges in the province. The integrated model can be applied to scientific research performance analysis in universities and institutions, offering specific innovation and generalization potential for future research endeavors.

5.3.2 practical contributions

The practical contributions of this study to the evaluation of scientific research performance in higher vocational colleges are outlined as follows:

5.3.2.1 Methodological Innovation: This study introduced a new, innovative, and integrated model to evaluate the scientific research performance. This comprehensive and holistic approach took into account the multifaceted dimensions that influence scientific research performance in higher vocational colleges. The methodology developed in this study serves as a foundation for similar research endeavors.

5.3.2.2 Profound Diagnostic Information: The analytical framework adopted in this study provided in-depth diagnostic information on the scientific research performance of higher vocational colleges in Sichuan Province. By analyzing the input variables that affect scientific research performance, the study offered detailed data analysis results support to the scientific research management teams, and helped them to accurately understand the current state of research activities and identify areas that require improvement.

5.3.2.3 Concrete Policy Recommendations: This study offered concrete and actionable recommendations for policy decision-makers by analyzing research input variables in both static and dynamic ways. These recommendations are grounded in in-depth data analysis and provide specific directions for formulating scientific research management strategies for higher vocational colleges. The findings of this study can be used to guide the development of policies aimed at improving research performance in higher vocational colleges.

5.3.2.4 Filling Research Gaps: This study addressed methodological gaps in existing research by integrating DEA-BCC, Malmquist, and Rough Set theory. By doing so, the study provided a more comprehensive perspective on scientific research performance analysis. The methodology developed in this study can be used to fill gaps in existing research and advance the theoretical understanding of research performance evaluation in higher vocational colleges.

In conclusion, the practical contributions made by this study have significant implications for academic research in the field of research performance evaluation in higher vocational colleges. The methodology developed in this study holds the potential to provide decision-makers with scientifically informed decision support.

5.4 Further Research

5.4.1 countermeasures and suggestions for higher vocational colleges

Based on these research findings, the following countermeasures and suggestions are proposed:

5.4.1.1 Optimize the strategy for allocating research resources. For colleges experiencing a stage of increasing returns to scale, it is recommended to increase research inputs to achieve sustained growth in research outputs. Conversely, for colleges with decreasing returns to scale in research, moderate reductions in research inputs could be made to promote research performance. Strengthening cooperation and communication between colleges, research institutions, and enterprises can promote resource sharing and complementarity, ultimately improving research performance.

5.4.1.2 Higher vocational colleges should continuously enhance their research management system to elevate their standards and stay competitive. Regular evaluations of scientific research performance, along with dynamic adjustments to the research management systems, can drive enhancements in overall scientific research performance and contribute to academic excellence.

5.4.1.3 Strengthen scientific and technological innovation. Higher vocational colleges in Sichuan province should build high-quality research platforms based on their college characteristics to serve regional economic and social development. Strengthening collaboration with enterprises, continuously improving research and technological progress, and efficiently transforming research outputs are essential steps in this regard.

5.4.1.4 The higher vocational colleges should place key emphasis on optimizing the allocation of resources for the internal expenditure of scientific research funds. They should also prioritize recruiting senior and above professional titles teachers to narrow the scientific research performance gap among colleges by enhancing expertise and mentorship.

5.4.1.5 policy recommendations can be refined by strengthening collaboration with professionals in the field of scientific research management to acquire more practical experience and specialized insights. Engaging experts from relevant domains in the formulation of policy recommendations will also ensure alignment with actual needs. The feasibility and implementation effectiveness of the recommendations should be continuously improved to achieve the desired outcomes.

5.4.2 Recommendations for further research

The results of this study present a number of suggestions for further research as follows:

5.4.2.1 it is important to optimize the selection of scientific research performance indicators. This can be done by conducting more in-depth investigations into scientific research activities, including interviews with research administrators and faculty members to gain insights into potential scientific research performance indicators. Establishing a comprehensive indicator system through expert consultations, the Delphi method, and other approaches can also be helpful. Additionally, it is important to consider introducing a weight allocation model to enhance the differentiation of weights for various indicators in the assessment of research performance.

5.4.2.2 it is important to improve the accurate tracking of high-quality research outcomes. To achieve this, it is recommended to introduce more objective and comprehensive evaluation methods such as citation counts and impact factors into research output indicators to precisely reflect the quality of research outcomes. Conducting comparative analyses will also help ensure genuine quality consideration of research projects and paper output indicators. Finally, it is important to validate the scientific and objective nature of these indicators through methods such as expert reviews or peer evaluations.

5.4.2.3 the impact study of research input indicators can be optimized by incorporating qualitative research methods such as expert interviews and surveys to deepen the understanding of the influence of research input indicators. Exploring specific impact mechanisms of different input factors on research performance by combining practical cases can also be helpful. Developing more intricate models that account for the interaction of multiple factors will enhance the accuracy and practicality of the research.

5.5 Limitation

The limitations of this study can be summarized as follows:

5.5.1 The scientific research performance indicators selected in this study have certain limitations. While the study conducted an extensive literature review and considered the characteristics of research work in vocational colleges in Sichuan Province to construct the scientific research performance indicator system, the DEA-BCC model restricts the number of input and output indicators, resulting in a lack of comprehensiveness or representativeness of the chosen indicators. Additionally, the author's limited knowledge of evaluating scientific research performance may have influenced the selection of indicators.

5.5.2 This study lacked precise statistics on high-quality research outcomes. Although the study evaluated scientific research performance using research papers, research projects, research funding received, and the number of patents as output indicators, the study did not differentiate between the quality of papers and scientific research projects, which may have resulted in neglecting high-quality scientific research outcomes. Analyzing the weights of various output indicators in the production of technological achievements can improve data usage and research methods.

5.5.3 The impact study of research input indicators in this research requires further optimization. While the study used the Rough Set theory to investigate the impact of research input indicators on scientific research performance, the study lacked additional validation methods, such as expert interviews, which may limit the operational validity of the research results.

5.5.4 The policy recommendations in this study had limitations. Although the study proposed corresponding policy recommendations based on research analysis results, Due to a deficiency in the authors' academic knowledge and experience, coupled with the insufficient research on university research performance, the decision recommendations provided exhibit limitations.

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APPENDICES

APPENDIX A

List of Experts and the invitation letter

The experts were:

1. Prof. Yongguo Shi. Dean of School of Mathematics and Information Sciences, Neijiang Normal University, China.

2. Prof. Jia He, Director of the Science and Technology Department, Neijiang Normal University, China.

3. Prof. Lezhong Li, Director of the Science and Technology Department, Chengdu University of Information Technology, China.

4. Prof. Ji Luo, Dean of the School of Economics, Sichuan University of Science and Engineering, China.

5. Prof. Zhijie Jiang, Vice Dean of the School of Mathematics and Statistics, Sichuan University of Science and Engineering, China.

6. Prof. Kelin Li， Sichuan University of Science and Engineering, China.

7. Assoc. Prof. Xilin Zhang, Director of the Office of Scientific Research & Development, University of Electronic Science and Technology of China, China.

8. Prof. Shulin Wu. Northeast Normal University, China.

9. Prof. Xinhua Zhang， Sichuan University of Science and Engineering, China.

MHESI 0910.35/2023

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15 July, 2023

Dear Prof. Yongguo Shi. Dean of School of Mathematics and Information Sciences, Neijiang Normal University, China.

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 Mrs. Lin Zhou, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled " Analysis and Countermeasures of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province using the DEA-BCC Model" under the supervision of Associate Professor Sutthiporn Boonsong and Assistant Professor Issara Siramaneerat. 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 Mrs. Lin Zhou, on the e-mail: lin_z@mail.rmutt.ac.th

Yours sincerely,

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

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15 July, 2023

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Yours sincerely,

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15 July, 2023

Dear Prof. Lezhong Li, Director of the Science and Technology Department, Chengdu University of Information Technology, China.

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

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Yours sincerely,

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15 July, 2023

Dear Prof. Zhijie Jiang, Vice Dean of the School of Mathematics and Statistics, Sichuan University of Science and Engineering, China.

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 Mrs. Lin Zhou, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled " Analysis and Countermeasures of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province using the DEA-BCC Model" under the supervision of Associate Professor Sutthiporn Boonsong and Assistant Professor Issara Siramaneerat. 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 Mrs. Lin Zhou, on the e-mail: lin_z@mail.rmutt.ac.th

Yours sincerely,

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

MHESI 0910.27/2023

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

15 July, 2023

Dear Prof. Kelin Li, Sichuan University of Science and Engineering, China.

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 Mrs. Lin Zhou, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled " Analysis and Countermeasures of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province using the DEA-BCC Model" under the supervision of Associate Professor Sutthiporn Boonsong and Assistant Professor Issara Siramaneerat. 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 Mrs. Lin Zhou, on the e-mail: lin_z@mail.rmutt.ac.th

Yours sincerely,

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

MHESI 0910.28/2023

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

15 July, 2023

Dear Assoc. Prof. Xilin Zhang, Director of the Office of Scientific Research & Development, University of Electronic Science and Technology of China, China.

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 Mrs. Lin Zhou, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled " Analysis and Countermeasures of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province using the DEA-BCC Model" under the supervision of Associate Professor Sutthiporn Boonsong and Assistant Professor Issara Siramaneerat. 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 Mrs. Lin Zhou, on the e-mail: lin_z@mail.rmutt.ac.th

Yours sincerely,

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

MHESI 0910.30/2023

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

15 July, 2023

Dear Prof. Shulin Wu. Northeast Normal University, China.

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 Mrs. Lin Zhou, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled " Analysis and Countermeasures of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province using the DEA-BCC Model" under the supervision of Associate Professor Sutthiporn Boonsong and Assistant Professor Issara Siramaneerat. 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 Mrs. Lin Zhou, on the e-mail: lin_z@mail.rmutt.ac.th

Yours sincerely,

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

MHESI 0910.31/2023

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

15 July, 2023

Dear Prof. Xinhua Zhang, Sichuan University of Science and Engineering, China.

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 Mrs. Lin Zhou, Doctor of Science Program in Technical Education (Vocational Education) Rajamangala University of Technology Thanyaburi, who has been working on the dissertation titled " Analysis and Countermeasures of Scientific Research Performance of Higher Vocational Colleges in Sichuan Province using the DEA-BCC Model" under the supervision of Associate Professor Sutthiporn Boonsong and Assistant Professor Issara Siramaneerat. 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 Mrs. Lin Zhou, on the e-mail: lin_z@mail.rmutt.ac.th

Yours sincerely,

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

APPENDIX B

The List of Information Resource

The List of Information Resource

College name	Website
Chengdu Aeronautic Polytechnic	https://www.cap.edu.cn/
Chengdu Polytechnic	https://www.cdp.edu.cn/
Sichuan Vocational College of Chemical Technology	https://sccc.edu.cn/
Sichuan Water Conservancy Vocational College	http://www.swcvc.edu.cn/
Nanchong Professinal Technic College	https://www.nczy.edu.cn/
Neijiang Vocational and Technical College	http://www.njvtc.cn/
Sichuan Post and Telecommunication College	https://www.sptpc.com/
Mianyang Polytechnic	https://www.mypt.edu.cn/
Sichuan communication vocational and technical college	https://www.svtcc.edu.cn/
Sichuan Engineering Technical College	https://www.scetc.edu.cn/
Sichuan College of Architectural Technology	https://www.scac.edu.cn/
Dazhou Vocational and Technical College	https://www.dzvtc.edu.cn/
Sichuan technology & business college	https://www.sctbc.net/
Chengdu Agricultural College	https://zs.cdnkxy.edu.cn/
YiBin Vocational And Technical College	https://www.ybzy.cn/
Luzhou vocational and technical college	https://www.lzy.edu.cn/

Meishan vocational and technical college	https://www.msvtc.edu.cn/
Chengdu Vocational University of the Arts	https://www.cdau.edu.cn/
Sichuan Vocational and Technical College	https://www.scvtc.edu.cn/
Leshan Vocational and Technical College	https://www.lszyxy.edu.cn/
Yaan Vocational College	https://www.yazy.edu.cn
Guang'an Vocational Technical College	http://www.gavtc.cn/
Sichuan Information Technology College	https://www.scitc.com.cn/
Sichuan University of Science and Technology	http://www.scstc.cn/
Sichuan Sanhe College of Professionals	https://www.scshpc.com/
Sichuan Health Rehabilitation Vocational College	http://www.svchr.edu.cn/
Aba Vocational College	https://www.abvc.edu.cn/
SiChuan Judicial and Police Officers Professional College	https://www.sjpopc.edu.cn/
Sichuan Southwest Vocational College of Civil Aviation	https://www.xnhkxy.edu.cn/
Bazhong Vocational and Technical College	http://bzvtc.edu.cn/

APPENDIX C
The Collecting Information Form

The Collecting Information Form

1. Information for analyzing and evaluating the scientific research performance of higher vocational colleges in Sichuan Province.
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2. Information for analyzing the impact and importance of research input indicators on the research performance of higher education colleges.
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3. Information for establishing a comprehensive evaluation model for analyzing the scientific research performance of higher vocational colleges.
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Biography

Name-Surname	Mrs. Lin Zhou
Date of Birth	March 14, 1984
Address	No. 519 Huixing Road, Ziliujing District, Zigong City, Sichuan Province.China
Education	Master’s Degree, Pattern Recognition and Intelligent Systems (2012)
Experiences Work	Administrative department managers,Sichuan University of Science and Engineering (2006-Present)
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mail	lin_z@mail.rmutt.ac.th 157757383@qq.com