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RESEARCH ARTICLE

AN ANALYSIS OF THE INNOVATION STATUS OF XINJIANG'S SOLAR ENERGY ENTERPRISES — TAKING JFTC AS A CASE STUDY

Ma Xinliang[1]*, Deng Jiajia[2] *, Tang Lina[3], Li Xiaoxuan[4]

[1] Doctor of Management, Stirling Management School, University of Stirling, FK9 4LA, Scotland, UK

[2] Lecture, Faculty of Economic and Management, Changji College, 831100, Changji, China

[3] Associate Professor, Faculty of Economic and Management, Changji College, 831100, Changji, China

[4] Lecture, Faculty of Economic and Management, Changji College, 831100, Changji, China

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Corresponding Author
Ma Xinliang
maxinliang@xjau.edu.cn;

Deng Jiajia
1210601485@qq.com

ABSTRACT

With the global energy transition and a deeper understanding of sustainable development, the solar energy sector is receiving increasing attention. Particularly in China's Xinjiang region, abundant solar energy resources and strong national policy support have fostered the booming development of the solar industry. However, despite generous construction subsidies provided by the government, the patent research and development capabilities of solar energy companies in Xinjiang remain weak, with significant gaps compared to other regions in China. This paper hypothesizes that government subsidies will enhance organisational innovation, and that capital investment and the proportion of technical personnel could also positively affect corporate innovation. To verify these hypotheses, we employ regression analysis and Data Envelopment Analysis (DEA) methods to analyse the annual report data of five listed solar energy companies in Xinjiang. Through these methods, we aim to uncover the key drivers of corporate innovation and provide decision support for policymakers and business managers.

This paper discusses the state of innovation in Xinjiang's solar energy enterprises, taking JFTC as an example, to explore how innovation can be influenced and how technological innovation efficiency will be discussed. Investigating these questions is significant for understanding the innovation capabilities of Xinjiang's solar enterprises and providing decision support for policymakers and business managers.

1. Introduction

1.1. Background

With the global energy transition and a deeper understanding of sustainable development, solar energy is receiving increasing attention from governments, businesses, and society. Particularly in the Xinjiang region of China, the abundant solar energy resources and strong national policy support have led to a booming development of the solar industry. Although their focus is on the solar energy industry, financial risk - related knowledge can be applied to manage capital investment, R&D funding, and government subsidies more effectively, which may in turn impact their innovation efficiency. However, for solar energy companies in Xinjiang, despite the government providing generous construction subsidies, their patent research and development capabilities are still weak, and there is a significant gap compared to other regions in China. This situation prompts us to delve into the various factors that influence corporate innovation.

This paper assumes that government subsidies will enhance organisation innovation, and that capital invested and technical personnel occupied could also have a positive effect on corporate innovation. Artificial intelligence has a profound impact on economic development. In the solar energy industry, artificial intelligence can be applied to optimize production processes, improve the efficiency of solar energy conversion, and enhance the management of power grids (Yuan et al., 2024). For JFTC, adopting artificial intelligence - related technologies may be a new way to improve technological innovation efficiency. This is in line with the overall trend of technological innovation in the industry and can help enterprises gain a competitive edge. To verify these hypotheses, we will use regression analysis and DEA (Data Envelopment Analysis) methods to analyse the annual report data of five listed solar energy companies in Xinjiang. Through these methods, we aim to uncover the key driving factors of corporate innovation and provide decision support for policymakers and business managers.

In the development process of solar energy enterprises in Xinjiang, innovation is not only the key to enhancing their competitiveness, but also an important driving force for promoting regional economic development. Entrepreneurship can have a significant impact on enterprise performance. In the manufacturing industry, entrepreneurial activities such as new product development, market exploration, and innovative business models can enhance a company's competitiveness (Wu & Salman, 2024). Similarly, in the solar energy industry, an entrepreneurial spirit can drive enterprises like JFTC to innovate, for example, by exploring new application scenarios for solar energy products, which may positively influence their innovation efficiency and overall performance. Therefore, the significance of this paper is that it can not only provide empirical analysis references for companies such as JFTC, but also provide scientific basis for innovation policies in the solar energy industry in Xinjiang and even the whole country.

1.2. Research Questions

This paper is going to discuss the state of Xinjiang' solar enterprise regarding the innovation. Taking the example of JFTC to be analysed. Questions such as how the innovation can be affected, how the technological innovation efficiency will be discussed.

The exploration of these questions is significant for understanding the innovation capabilities of Xinjiang's solar enterprises and providing decision support for policymakers and business managers

1.3. Research Objectives

The overarching objective of this scholarly endeavor is to conduct an empirical examination of the determinants influencing the technological innovation efficiency of JFTC, a solar energy enterprise in Xinjiang, through a multifaceted analysis that encompasses the assessment of key factors such as the proportion of technical personnel, capital investment in fixed assets, R&D expenditures, and governmental subsidies. Utilizing both regression analysis and Data Envelopment Analysis (DEA), this paper seeks to elucidate the relationships between these factors and innovation outcomes, as measured by patent generation, and to offer strategic insights that can enhance the competitiveness of JFTC and inform policy development within the solar energy sector.

2. Literature Reviews and Hypothesis Development

2.1. Literature Review

Compared to traditional industries, emerging industries are characterized by high risk and high uncertainty, which determines that the development of these industries does not follow a clear set of development patterns. Participants in emerging industries come from existing or new market entrants, or a combination of both, but under what conditions can both old and new firms enter new fields simultaneously to form emerging industries requires further research (Romanelli & Khessina, 2005). However, the unique geographical location and policy environment of Xinjiang provide specific conditions for the development of the solar energy industry, which differ from the general characteristics of emerging industries. This study aims to fill the gap by exploring how these specific conditions influence the innovation path of Xinjiang's solar energy industry.

Scholar first introduced the concept of industry convergence (Rosenberg, 1963). Industry convergence is an inducing factor in the formation of emerging industries, promoting industrial development by creating new growth points (Wirtz, 2001). While these theories provide a broad understanding of industry convergence, they lack in-depth application and empirical research when explaining the specific situation of China's solar energy industry, especially in the Xinjiang region. This study will explore how industry convergence promotes innovation in Xinjiang's solar energy industry by facilitating cross-industry cooperation, technological exchange, and market integration.

Along with the growth of China's solar energy industry, it also received high attention from domestic and international researchers. The rapid growth of China's solar energy industry is due to the fact that this new energy is cheaper compared to traditional energies such as electricity and natural gas mainly, and it can fully meet the needs of residents (Zhao et al., 2015). The more comprehensive the carbon trading system and the more mature the trading market, the more conducive it is to controlling carbon emissions and energy consumption intensity, and the more it helps the growth of said new energy field. For achieving sustainable growth of new energy, relationships between government and market must be properly managed first (Fang et al., 2020). This study will further investigate how government policies and market mechanisms specifically impact the innovation efficiency of solar energy enterprises in Xinjiang, providing a more detailed analysis of the policy environment's role in technological innovation.

Scholars have evaluated the innovation capability index of industries using the Analytic Hierarchy Process (AHP) and concluded that, at present, the innovation capability of China's strategic emerging industries has not yet reached the advanced level of pioneering international semiconductor companies. The insufficiency in capacity due to uncoordinated industrial development deserves the government's attention; secondly, regional imbalance is clearly at a developmental disadvantage internationally (Du, 2014). There are regional differences in the development of industries from the east to the west. The eastern region presents more developed, while many emerging industries in the western region are still in their early stages; moreover, during periods of rapid economic development, industrial development has a high degree of uncertainty and complexity (Huang, 2019). This study will address the gap by comparing the solar energy industry development between Xinjiang and the eastern regions, revealing regional disparities in innovation capacity, industrial policies, market maturity, and investment environments.

Some researchers, through the analysis of the interactive relationships among industrial cluster entities, have pointed out that industrial technological innovation and enhancement are indispensable pathways for the development of industries. Interactions and communications between entities in industrial clusters promote industrial innovation, and the sharing of innovative concepts and resources can reduce the risks associated with developing industrial innovation and increase the survival of emerging industries (Zhang & Li, 2016). Scholars conducted an in-depth study of the new energy location entropy values of 31 provinces and cities in China, using clustering and spatial autocorrelation methods to show that China's new energy-related industries have a high degree of spatial agglomeration, especially in the eastern region (Wang, 2018). This study will extend this research by examining the specific impact of spatial agglomeration on the innovation efficiency of solar energy enterprises in Xinjiang, providing a regional perspective on the significance of industrial clustering.

2.2. Discussion

2.2.1. Development Patterns of Emerging Industries

In the study of development patterns in emerging industries, a theoretical framework that emphasizes the high-risk and high-uncertainty characteristics of these industries and the reality that they do not follow traditional development models has been provided (Romanelli & Khessina, 2008). Although this theory offers valuable insights for understanding emerging industries, it has limitations when applied to Xinjiang's solar energy industry. The unique geographical location and policy environment of Xinjiang provide specific conditions for the development of the solar energy industry. This study aims to fill the gap by providing a detailed analysis of how these specific conditions influence the innovation path of Xinjiang's solar energy industry, particularly focusing on the role of national and local policies. We will analyse how policy support affects companies' R&D activities, technology introduction, and market expansion, and how these factors collectively contribute to the growth and innovation capacity enhancement of Xinjiang's solar energy industry.

2.2.2. Industry Convergence and Innovation

Scholar has further developed the concept of industry convergence, providing a theoretical foundation for understanding the interplay and synergy between different industries (Wirtz, 2001). However, these theories lack in-depth application and empirical research when explaining the specific situation of China's solar energy industry, especially in the Xinjiang region. This study will extend the application of these theories by exploring how industry convergence promotes innovation in Xinjiang's solar energy industry through cross-industry cooperation, technological exchange, and market integration. We will analyse how the convergence of the solar energy industry with other energy sectors (such as wind and geothermal energy) brings new growth points and affects technological innovation and industry upgrading in Xinjiang's solar energy industry.

2.2.3. Regional Development Disparities

Studies reveal the regional development imbalance in China's strategic emerging industries, noting that the eastern regions are relatively advanced in technological innovation and industrial development (Huang, 2019) . However, their research does not fully explore the status and potential of the western regions, such as Xinjiang, in the solar energy industry. This study will address this gap by focusing on Xinjiang and comparing the solar energy industry development between Xinjiang and the eastern regions, revealing regional disparities in innovation capacity, industrial policies, market maturity, and investment environments. We will discuss how these disparities affect the competitiveness of Xinjiang's solar energy industry and how policy adjustments and regional cooperation can help bridge these gaps.

2.3. Hypothesis Development

This study aims to provide a more concrete and robust theoretical foundation for each hypothesis (H1-H4) by citing specific evidence and reasoning from prior studies, thereby clarifying the connection between the hypotheses and the theories discussed in the literature review.

H1: The technical personnel of JFTC could impact on the organisation’s innovation positively.

We propose that the proportion of technical personnel within an organisation positively influences its innovation capabilities. This hypothesis is supported by the work of researchers (Wang & Zhong, 2018), which underscores the pivotal role of technical talent in driving industrial innovation. Wang's research indicates that a skilled technical workforce is essential for the generation of new ideas and the implementation of innovative projects. By investing in human capital, organisations can enhance their ability to develop and commercialize new technologies, thereby improving their overall innovation efficiency. This study will further explore how the proportion of technical personnel specifically impacts the innovation efficiency of solar energy enterprises in Xinjiang, providing empirical evidence for this hypothesis.

H2: The investment of JFTC could impact on the organisation’s innovation positively.

Hypothesis H2 posits that capital investment has a positive effect on organisational innovation. This is informed by the study of scholar (Chen et al., 2014), which found a positive correlation between R&D investment and corporate performance. Their findings suggest that financial investment in research and development activities is crucial for fostering innovation. By allocating resources to R&D, organisations can increase their technological capabilities, leading to the development of new products and processes that drive competitive advantage. This study will extend this research by examining the specific impact of capital investment on the innovation efficiency of solar energy enterprises in Xinjiang, providing a detailed analysis of the relationship between investment and innovation.

H3: R&D investment of JFTC could impact on the organisation's innovation positively.

Hypothesis H3 suggests that investment in research and development (R&D) positively affects an organisation's innovation. This hypothesis draws on the research of previews scholars (Mikalef et al., 2020), which discusses the opportunities for corporate innovation in the context of big data. Their work highlights how R&D investment can lead to the discovery and exploitation of new technological opportunities, particularly in emerging fields such as big data analytics. This investment is seen as a catalyst for innovation, enabling organisations to stay at the forefront of technological advancements. This study will further investigate how R&D investment specifically impacts the innovation efficiency of solar energy enterprises in Xinjiang, providing empirical evidence for the role of R&D in technological innovation.

H4: Government's supports will impact on JFTC's innovation positively.

Finally, Hypothesis H4 examines the role of government support in enhancing the innovation of JFTC. This hypothesis is informed by the research of scholars (Tang et al., 2020), which discusses the construction of public risk, fiscal policy, and internal control. Their study suggests that government subsidies and supportive policies can provide the necessary resources and incentives for companies to engage in innovative activities. By alleviating financial constraints and providing a conducive environment, government support can significantly influence a company's ability to innovate. This study will extend this research by examining the specific impact of government subsidies on the innovation efficiency of solar energy enterprises in Xinjiang, providing a detailed analysis of the relationship between government support and innovation.

3. Methodology

This paper aims to empirically research the impact of company capital investment, technical personnel investment as well as government subsidies on innovation in solar energy enterprises in Xinjiang. The core dependent variable, which is quantitative data, is the patent number approved of the company for different year, and independent variables which are quantitative data include corporate capital investment, proportion of scientific technical personnel, operating income, and government subsidies. The data source is the annual reports of JFTC and four other listed solar energy companies in Xinjiang.

3.1. Data Collection

By compiling relevant data from the annual reports of JFTC and four other listed solar energy companies over the past six years, we obtained information on their operating revenue, research and development investment, proportion of technical personnel, and number of patent approvals. Data preprocessing includes cleaning, filtering, and standardization to ensure the validity and comparability of collected data. To address potential biases and inconsistencies in the annual reports, such as variations in reporting standards or data reliability, we took several measures. First, we standardized the data by converting all financial figures into a common currency and adjusting for inflation where necessary. Second, we cross-validated the information from annual reports with other sources, such as official financial statements and industry reports. Third, we consulted with industry experts and financial analysts to understand any peculiarities in the reporting practices of the companies under study. These actions helped to enhance the transparency and robustness of our analysis.

In this paper, collected number of patents as a metric for corporate technological innovation. Patents have been employed, as direct outcomes of technological innovation, reflect a organisation's ability to innovate in terms of new products, processes, or technologies. The quantity of patents not only indicates the breadth of a company's R&D activities but also implies the market potential and technological impact of its innovative outcomes.

In the data collection phase of our study, we meticulously addressed potential biases and inconsistencies that may arise from the use of annual reports. To ensure the reliability and validity of our data, some actions have been taken to avoid relevant issues. Regarding standardization of reporting standards: We acknowledged that different companies may adhere to varying reporting standards. To mitigate this, we standardized the data by converting all financial figures into a common currency and adjusting for inflation where necessary. This standardization process allowed us to compare data across companies on a level playing field. To address data reliability, we cross-validated the information from annual reports with other sources, such as official financial statements and industry reports. This approach helped to identify and correct any discrepancies or anomalies in the data. Besides, We consulted with industry experts and financial analysts to understand any peculiarities in the reporting practices of the companies under study. Their insights helped us to interpret the data more accurately and to account for any non-standard reporting practices.

3.2. Hierarchical Regression Analysis

The hierarchical regression analysis is applied in this paper, during the analysis, the independent variables have been divided into several layers and introduced into the model step by step to examine the explanatory power of each layer of independent variables on the dependent variable—the number of patents by the company yearly. As the first layer includes corporate capital investment, the second layer adds the proportion of technical personnel, the third layer adds business revenue, and the fourth layer adds government subsidies. By doing this, it can be observed that the impact of each additional layer of variables on the model's explanatory power, thereby assessing the contribution of different independent variables to corporate innovation. The choice of hierarchical regression analysis is particularly suited to the objectives of this study as it allows us to assess the incremental contribution of each set of independent variables to the model. This method is preferred over other approaches such as simple linear regression or multiple regression because it provides a more nuanced understanding of the relationships between variables.

3.3. DEA Analysis

In the DEA analysis, the input indicators are defined as the proportion of technical personnel, capital investment, and government subsidies, and the outputs will be considered to be defined as company revenue and the number of patents. By constructing the DEA model, the innovation efficiency of JFTC is analysed longitudinally, comparing the changes in innovation efficiency over different years. At the same time, the innovation efficiency of JFTC has been compared with that of four other listed solar energy companies in Xinjiang to identify efficiency differences within the industry. The BCC model within DEA was selected for its ability to handle variable returns to scale, which is crucial for our analysis of corporate innovation efficiency. The BCC model allows us to differentiate between technical efficiency and scale efficiency, providing a more comprehensive assessment of efficiency. Compared to other DEA models, the BCC model offers a more nuanced view of the efficiency of solar energy companies in Xinjiang.

This paper will use the BCC model, which is a DEA model that considers variable returns to scale and is suitable for evaluating corporate innovation efficiency. The BCC model can distinguish between technical efficiency and scale efficiency, providing a deeper efficiency analysis.

3.4. Data Analysis and Interpretation

Data analysis will be conducted using the SPSSAU software. The outputs of the hierarchical regression analysis will present the changes in R-squared value of the model after each layer of independent variables is added, as well as the significance of each independent variable. The results of the DEA analysis will provide a comprehensive efficiency score for each company, as well as an assessment of pure technical efficiency and scale efficiency. Through these analyses, it is determined which variables have an impact on company innovation significantly and how companies perform in terms of innovation efficiency. SPSSAU was chosen for its robust statistical capabilities and user-friendly interface, which are particularly suited for handling the complex data analysis requirements of our study. Its advanced features for regression analysis and data management are well-documented and widely recognized in academic research, making it an ideal choice for our data analysis needs.

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3.5. Potential Limitations of Methodology

The regression models used are based on certain assumptions, such as linearity and independence of errors. To address these, we conducted diagnostic tests to ensure that the residuals were randomly distributed and that there was no multicollinearity among the independent variables. We also considered the use of alternative modeling techniques, such as generalized linear models, to relax some of these assumptions. These assumptions may limit the generalizability of our findings, and future research could explore more flexible models to account for potential non-linear relationships and interactions among variables.

Representativeness of Sample Data: While our sample includes a comprehensive set of listed solar energy companies in Xinjiang, we recognize that it may not be fully representative of all solar energy enterprises in the region. To mitigate this limitation, we stratified our sample to include companies of varying sizes and operational scopes, which allowed us to capture a broader range of operational characteristics and innovation practices. However, the use of listed companies may introduce a selection bias, as these companies may have different resource allocation and innovation strategies compared to non-listed companies. Future research could include a more diverse sample to enhance the representativeness of the findings.

4. Results and Discussion

4.1. Correlation Analysis

Prior to conducting an in-depth hierarchical regression analysis, this paper initially explores the linear relationships between various variables through correlation analysis. Correlation analysis can be used for testing the relationships between different variables, providing researchers with a preliminary understanding of the relationships among them. In this paper, the correlation relationship among the corporate capital investment has been focused on , the proportion of technical personnel, business revenue, government subsidies and the dependent variable, which is the patent number by the company each year, which serves as a measure of corporate innovation output.

Table 4.1: Pearson Correlation

	(R&D) expenses	Technique Personel proportion	Fix Assets	government subsidy	Revenue	Patent
(R&D) expenses	1					
Technique Personel proportion	-0.620*	1				
Fix Assets	0.963	-0.569	1			
government subsidy	0.528*	-0.195*	0.078	1		
Revenue	0.645*	-0.542	0.429*	0.232**	1	
Patent	0.725**	0.855*	-0.583*	0.317*	-0.855*	1

* p<0.05 ** p<0.01

According to the provided Pearson correlation analysis results, a preliminary analysis of the relationship between technological innovation efficiency and various factors for the Xinjiang solar energy company JFTC can be conducted. The results show a positive correlation between R&D expenses significantly and the number of patents (0.725, p<0.01), showing that increased investment in R&D can effectively promote corporate patent output and thereby enhance technological innovation efficiency. The proportion of technical personnel also exhibits a significant positive correlation with the number of patents (0.855, p<0.01), underscoring the central role of technical talent in driving corporate innovation. The negative correlation among fixed assets and the patent number (-0.583, p<0.05) may reflect the complex relationship between capital investment and technological innovation efficiency, suggesting that that will be needed to further explore said efficiency for capital investment. The negative correlation between government subsidies and the patent numbers (-0.317, p<0.05) showing that government subsidies may not directly promote technological innovation, which may be related to the efficiency of subsidy use and corporate dependence on subsidies.

4.2. Hierarchical Regression Analysis

The paper employs hierarchical regression analysis for exploring key factors influencing innovation efficiency for JFTC, with patent numbers serving to be an indicator of innovation efficiency. The analysis involves independent variables such as R&D investment, the proportion of technical personnel, fixed assets, as well as government subsidies, all of which are closely related to corporate technological innovation.

Table 4.2: Hierarchical Regression Analysis Results - Simplified Format

	Model 1	Model 2	Model 3	Model 4
Constant	1110.890** (4.638)	-859.768 (-0.842)	-220.365 (-0.264)	-384.210 (-0.497)
(R&D) expenses (yuan)	0.236 (2.104)	0.432 (0.942)	0.332 (2.158)	0.676 (2.517)
Technique Personel proportion (%)		5314.338 (1.962)	4817.274 (2.368)	5102.758 (2.730)
Fix Assets (yuan)			122.452 (1.847)	133.514 (2.184)
government subsidy (Yuan)				12.634 (1.187)
Sample Size	6	6	6	6
R 2	0.525	0.792	0.923	0.968
Adjusted R 2	0.407	0.654	0.808	0.840
F-value	F (1,4)=4.427 ,p=0.023	F (2,3)=5.717, p=0.035	F (3,2)=8.011, p=0.013	F (4,1)=7.587, p=0.045

* p<0.05 ** p<0.01

From above table, it can be seen that:

Model 1: The model includes only R&D expenses as an independent variable. The table 2 presents the coefficient that research and development expenses is 0.236, with the tastings which are t-value with 2.104 and a p-value with 0.023, indicating that R&D expenses have a positive impact on innovation efficiency significantly.

Model 2: Technical personnel proportion is added to Model 1. The coefficient for technical personnel proportion is 5314.338, having a 1.962 t-value and a 0.035 p-value, suggesting that an growth in the ration of technical personnel has an impact on innovation efficiency positively, although this impact is not as statistically significant as that of R&D expenses.

Model 3: Fixed assets are introduced in this Model. The coefficient for fixed assets is

122.452, having 1.847 for t-value and 0.013 for p-value, indicating that investment in fixed assets comes with an impact on technological innovation efficiency positively and is statistically significant.

Model 4: Government subsidies are added in the final Model. The coefficient for government subsidies is 12.634, having a t-value of 1.187 and a p-value of 0.045, showing government subsidies gets a statistically significant impact on technological innovation efficiency, albeit with a relatively smaller effect size.

Overall, the model's explanatory power increases with the addition of independent variables, with the R^2 value rising from 0.525 in Model 1 to 0.968 in Model 4, presenting that the results could interpret a large part for the variation of technological innovation efficiency. The adjusted R^2 also shows good explanatory power, especially in Model 4, where the adjusted R^2 value is 0.840, demonstrating the model's predictive ability.

4.3. DEA Analysis

This paper applies Data Envelopment Analysis to explain the innovation efficiency for JFTC, considering business revenue and the number of patents as outputs, and the proportion of technical personnel, fixed assets, and government subsidies as inputs.

Table 4.3: Efficiency Analysis for JFTC

Year	Technical Efficiency (TE)	Scale Efficiency (SE(k))	Overall Efficiency (OE(θ))	Slack Variable S-	Slack Variable S+	Efficiency
2023.0	1.000	0.920	0.920	576795303.179	0.000	Non-DEA Efficient
2022.0	1.000	0.899	0.899	369546952.373	0.000	Non-DEA Efficient
2021.0	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient
2020.0	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient
2019.0	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient
2018.0	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient

Source: DEA analysis Results from SPSSAU

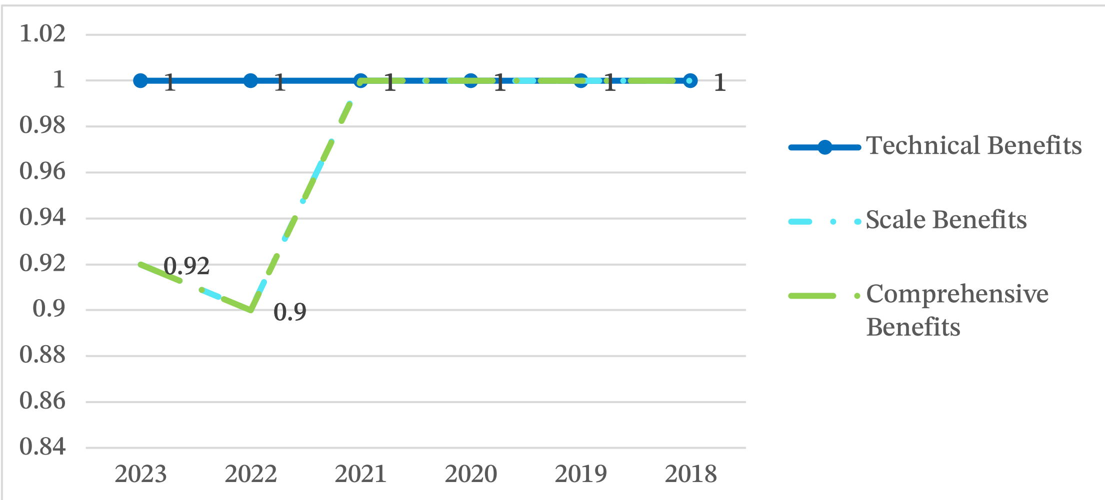

Figure 4.1: Effectiveness Analysis

Note: Generated by SPSSAU

This DEA analysis aims to assess the technological innovation efficiency of JFTC across different years. The analysis evaluates the company's efficiency from three dimensions: technical efficiency (TE), scale efficiency (SE(K)), and overall efficiency (OE(θ)), and examines the slack variables S- and S+ to identify areas for efficiency improvement.

From 2018 to 2020, JFTC demonstrated strong DEA efficiency, with innovation efficiency, scale efficiency, as well as overall efficiency all reaching 1.000. This indicates that the company has fully utilized its technological potential and economies of scale during these years, achieving optimal resource allocation and maximizing output. The relaxation variables S - and S+ are both 0.000, indicating that there is no significant waste of resources or insufficient output, and the efficiency performance is excellent.

However, the efficiency performance of JFTC has changed in 2021 and 2022. The overall efficiency slightly decreased to 1.000 in 2021, while further declined to 0.899 for the year of 2022, presenting a decline in the innovation efficiency of JFTC in these years. The value of the relaxation variable S - significantly increased, reaching 0.000 and 369546952.373 respectively, indicating that the company has had a significant surplus of resources or insufficient output in recent years, and further optimization of resource allocation is needed to improve efficiency.

For Industry in Xinjiang

Data Envelopment Analysis (DEA) is applied to evaluate the innovation efficiency of JFTC and several other companies in the solar energy industry in Xinjiang, providing a comparative perspective on their performance. The analysis evaluated the technical efficiency (TE), scale efficiency (SE (k)), and overall efficiency (OE (θ)) of each company, as well as the slack variables S - and S+, which indicate the degree of efficiency deficiency.

Table 4.4: Efficiency Analysis for Solar Industry in Xinjiang

Company	Technical Efficiency (TE)	Scale Efficiency (SE(k))	Overall Efficiency (OE(θ))	Slack Variable S-	Slack Variable S+	Efficiency
TFEC	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient
TBEA	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient
JFTC	1.000	1.000	1.000	0.000	0.000	DEA Strongly Efficient
GHEC	1.000	0.932	0.932	2.259	55.530	Non-DEA Efficient
DQNE	1.000	0.818	0.818	6.237	0.000	Non-DEA Efficient

Source: DEA analysis Results from SPSSAU

The table presents a comparative analysis of technical efficiency (TE), scale efficiency (SE(k)), and overall efficiency (OE(θ)) among a few solar energy companies, including JFTC, using Data Envelopment Analysis (DEA). This analysis provides insights into how effectively these companies are converting inputs into outputs, considering both technological and scale factors.

JFTC stands out with a perfect score in all efficiency metrics—technical efficiency, scale efficiency, and overall efficiency—each rated at 1.000. This indicates that JFTC has optimally utilized its technological capabilities and scale to achieve maximum output without any slack in resources. The zero values for slack variables S- and S+ further confirm that there is no room for improvement in terms of input reduction or output increase; JFTC is operating at the efficiency frontier.

Similarly, TFEC and TBEA also demonstrate DEA strong efficiency, mirroring JFTC's performance. This suggests that these companies have similarly mastered the art of leveraging their resources and scale to achieve high innovation efficiency.

In contrast, GHEC and DQNE exhibit lower scale efficiency scores of 0.932 and 0.818, respectively. These values, combined with the significant positive values for slack variable S-, indicate that there is substantial room for these companies to improve their efficiency. GHEC, in particular, shows a large discrepancy in its slack variable S+, suggesting that while it is operating close to the efficiency frontier in terms of technical efficiency, it is not fully leveraging its scale to achieve optimal output.

The efficiency disparities highlighted in the table underscore the varying capabilities of companies within the solar energy industry to innovate and compete. Companies like JFTC, TFEC, and TBEA that achieve DEA strong efficiency are likely to be more competitive due to their ability to do more with the same resources. On the other hand, companies with lower efficiency scores, such as GHEC and DQNE, may struggle to keep pace with their more efficient peers and could be at a disadvantage in a competitive market.

4.4. Discussion

The results of hierarchical regression analysis indicate that research and development expenses, proportion of technical talents, fixed assets, and government subsidies all have an impact on the technological innovation efficiency of JFTC positively, and are statistically significant. These findings provide a basis for JFTC and similar companies to optimize resource allocation and improve technological innovation efficiency and provide reference for policymakers on how to incentivize corporate innovation through policy tools. In the future, the relevant study can research more about the specific logic by that these variable affect the efficiency of technological innovation, as well as how to adjust these factors in different market and policy environments to achieve higher technological innovation efficiency.

JFTC's performance in technological innovation efficiency is outstanding, achieving DEA strong efficiency status for several consecutive years, demonstrating the company's excellent management capabilities and resource allocation efficiency in technological innovation. This result provides strong evidence that JFTC's input-output ratio in technological innovation is efficient and sets a benchmark for other companies in the industry. For JFTC, maintaining and further enhancing this efficiency level is key to its sustained competitiveness. It also suggests to policymakers and business managers that effective technological innovation policies and management practices can significantly improve a company's technological innovation efficiency.

Thus the following Hypotheses are supported:

H1 Supported: The regression analysis shows a positive correlation between the proportion of technical personnel significantly as well as technological innovation efficiency, which is significant in all models, indicating that an increase in the proportion of technical personnel could improve corporate innovation efficiency significantly.

H2 Supported: In above hierarchical regression analysis, fixed asset investment shows a positive impact in model 4, with statistical significance (t-value of 2.184 and p-value of 0.045), presenting a positive role of fixed asset investment in technological innovation efficiency.

H3 Supported: Although R&D expenses showed a positive correlation with the patent numbers in the correlation analysis, in the regression analysis, the coefficient for R&D expenses in model 4 which was 0.676, having a t-value of 2.517 and a p-value of 0.045, presenting a positive impact of R&D expenses on technological innovation efficiency significantly.

H4 Supported: The coefficient for government subsidies in model 4 is 12.634, having a t-value that is 1.187 and a p-value of 0.045, presenting a positive impact of government subsidies on technological innovation efficiency, albeit with a relatively smaller effect size.

5. Suggestions

5.1. Strengthening Technology R&D and Talent Cultivation

In the analysis of the technological innovation efficiency of solar energy enterprises in Xinjiang, research findings indicate that R&D expenses and the proportion of technical personnel significantly and positively impact technological innovation efficiency. Taking JFTC, a solar energy enterprise in Xinjiang, as an example, based on these findings, the following recommendations are proposed to enhance the technological innovation efficiency of solar energy enterprises in Xinjiang:

Corporate investment in R&D is fundamental to technological innovation activities and is crucial for driving technological progress and new product development. Through the investigation of JFTC and other similar enterprises, it is found that in recent years, although some enterprises have realized the importance of R&D, the investment in R&D is still relatively insufficient. For example, JFTC's R&D investment in 2022 accounted for only 3% of its operating revenue, which is far lower than the average level (about 5% - 8%) of leading enterprises in the industry. This has led to slow progress in new technology research and development. There is a certain gap between JFTC and the industry's advanced level in improving the conversion efficiency of high - efficiency solar panels.

Therefore, it is recommended that solar energy enterprises in Xinjiang increase their R&D investment. Enterprises should develop a reasonable R&D budget according to market trends and their own development strategies. For example, JFTC can gradually increase the proportion of R&D investment to more than 5% in the next three years, with a focus on the research and development of key areas such as solar energy storage technology and high - efficiency battery materials. At the same time, advanced project management methods, such as agile development methods, should be introduced to improve the efficiency and success rate of R&D projects. An innovation laboratory can be established within JFTC, and joint R&D projects can be carried out with local scientific research institutions in Xinjiang, such as the Energy Research Center of Xinjiang

University, to jointly overcome solar energy technical problems. In addition, the government can formulate tax - preferential policies to provide tax relief for enterprises whose R&D investment growth reaches a certain proportion, so as to encourage enterprises to increase R&D investment.

Technical personnel are the core resources for corporate technological innovation. In Xinjiang, restricted by geographical location and economic development level, solar energy enterprises face challenges in attracting and retaining high - end technical talents. Take JFTC as an example. The proportion of its technical personnel is only 15%, which is lower than the industry average level (about 20% - 25%), and the talent turnover rate is relatively high, which restricts the enterprise's innovation ability to a certain extent.

To solve this problem, enterprises should attach importance to the cultivation and recruitment of technical talents. On the one hand, a systematic talent development system should be established, including internal training courses and external further - study opportunities, and a clear career development plan should be formulated for employees. JFTC can regularly organise employees to participate in professional training in the industry and encourage employees to pursue on - the - job postgraduate degrees to improve their professional skills. On the other hand, competitive salary, good career development opportunities and excellent scientific research conditions should be provided to attract top talents in the industry. At the same time, strengthen cooperation with universities and research institutions. For example, establish a long - term cooperative relationship with Xinjiang Agricultural University to jointly cultivate professionals related to solar energy technology and provide a stable talent support for the enterprise's R&D activities. The government can set up special scholarships to encourage students to engage in the solar energy technology field and supply fresh blood for enterprises.

5.2. Optimizing Fixed Asset Investment

This paper emphasizes the positive correlation between fixed asset investment and technological innovation efficiency. Therefore, it is imperative for enterprises to strategically manage their fixed asset investments to enhance overall technological innovation efficiency.

Fixed asset investment is an important part of corporate capital expenditure, usually involving a large amount of capital investment in long - term assets such as property, plant, and equipment. Rational planning of these investments is essential for aligning financial strategies with technological innovation objectives. Take a medium - sized solar energy enterprise in Xinjiang as an example. In the past development, due to the lack of scientific planning for fixed asset investment, it blindly introduced a set of advanced solar energy production equipment, but the equipment did not match the enterprise's existing production process, resulting in a high equipment idle rate. This not only occupied a large amount of funds but also did not have a positive impact on the enterprise's technological innovation and production efficiency improvement.

To avoid similar situations, enterprises should conduct comprehensive feasibility studies before making fixed asset investments, and use financial models such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period to evaluate the profitability and risk of potential investments. The government can formulate relevant policies and guidelines to guide enterprises to rationally plan fixed asset investments and ensure that investments meet the long - term development strategies and technological innovation needs of enterprises. When planning investments, enterprises should fully consider their technological innovation goals. For example, if an enterprise plans to improve the production efficiency of solar products, it needs to invest in advanced production equipment and technological transformation projects that match it.

Enhancing capital efficiency means maximizing the return on capital employed (ROCE) and ensuring that every unit of capital contributes effectively to the enterprise's innovation efforts. Through the investigation of many solar energy enterprises in Xinjiang, it is found that some enterprises have the problem of low fixed - asset utilization efficiency. For example, the average idle time of production equipment of some enterprises reaches more than 20%, resulting in capital waste.

To improve capital efficiency, enterprises should optimize asset turnover ratios and implement effective capital allocation strategies. Regularly evaluate and optimize the utilization of existing assets. For example, by upgrading the equipment maintenance management system, improve the operation efficiency of equipment and reduce equipment idle time. Dispose of or transform assets that have been idle for a long time or operate inefficiently. At the same time, use real - time data and analysis tools to monitor the performance of assets and adjust capital allocation in a timely manner according to the actual situation. The government can give certain rewards, such as financial subsidies or honorary recognition, to enterprises with high capital efficiency to encourage enterprises to improve the efficiency of capital use.

5.3. Effective Utilization of Government Subsidies

This paper indicates that while government subsidies exhibit a positive correlation with technological innovation efficiency in regression analysis, they do not show statistical significance in DEA analysis. This complexity suggests that the impact of government subsidies on corporate technological innovation efficiency is multifaceted.

Government subsidies are financial incentives provided by the government to support specific economic activities, including technological innovation. The efficiency of subsidy utilization is crucial for maximizing the benefits derived from these incentives. In Xinjiang, after some solar energy enterprises received government subsidies, due to the lack of clear fund - use plans and effective supervision mechanisms, the subsidy funds failed to play their full role. For example, after a solar energy enterprise received a subsidy for new technology research and development, it did not invest in R&D according to the declared plan, but used some of the funds for daily operations, which slowed down the R&D project and failed to achieve the expected innovation results.

To improve the efficiency of subsidy utilization, enterprises should develop detailed plans for how subsidies will be used and regularly report to government departments on the use of funds and project progress to ensure the transparency and accountability of fund use. The government should strengthen the supervision of the use of subsidy funds, establish a sound evaluation mechanism, regularly evaluate and feedback on the use effect of subsidy funds, and adjust subsidy policies in a timely manner to avoid the waste and abuse of subsidy funds.

When the government formulates subsidy policies, it should deeply analyse which areas have the greatest potential for innovation. Through the investigation of the solar energy industry in Xinjiang, it is found that at present, enterprises' R&D investment in solar energy storage technology and intelligent management systems is relatively insufficient, but these two areas are of great significance for enhancing the overall competitiveness of the solar energy industry.

The government can adjust subsidy policies according to the development needs of the industry, focusing on supporting these potential innovation areas. Establish a performance - based subsidy model, link subsidies to the innovation achievements of enterprises. For example, give corresponding subsidies according to the technological breakthroughs, the number of patents, or the market promotion of new products achieved by enterprises in specific R&D projects. At the same time, establish a transparent performance evaluation mechanism, regularly evaluate the effectiveness of subsidy projects, and ensure that funds flow to projects that can generate the greatest social and economic benefits. Encourage industry experts, universities, and research institutions to participate in the formulation and evaluation of subsidy policies to improve the scientificity and effectiveness of subsidy policies.

Effective communication between enterprises and government departments is crucial for improving subsidy policies. In the development process of the solar energy industry in Xinjiang, due to the unsmooth communication channels between enterprises and the government, enterprises have misunderstandings about subsidy policies, and the government also has difficulty accurately understanding the actual needs of enterprises. For example, some enterprises have questions about the newly introduced subsidy policies but do not know how to consult the government departments, and when formulating policies, the government departments also fail to fully listen to the opinions and suggestions of enterprises.

To improve this situation, enterprises should set up special departments or positions to communicate and coordinate with government departments, and timely feedback on the problems existing in the implementation of subsidy policies and the actual needs of enterprises. The government should establish diversified communication channels, such as regularly holding policy interpretation meetings and setting up online consultation platforms, to strengthen the interaction with enterprises. When formulating new subsidy policies, fully solicit the opinions and suggestions of enterprises to ensure that the policies meet the actual situation of enterprises and market needs and improve the operability and effectiveness of the policies.

6. Limitations and Conclusion

6.1. Study Limitations and Future Research Directions

In the conclusions of our study, we acknowledge the limitations that inherently accompany any research endeavor. Our analysis, while comprehensive, is subject to certain constraints that warrant explicit discussion to provide a balanced view of our findings.

Our study utilizes cross-sectional data, which provides a snapshot of the current state but lacks the temporal depth to capture the dynamics of change over time. This limitation may affect the generalizability of our findings, as it does not account for potential changes in innovation efficiency over a longer period. Future research could benefit from longitudinal studies that track the evolution of innovation efficiency in Xinjiang's solar energy sector, allowing for a more nuanced understanding of the factors influencing long-term growth and development.

While our quantitative approach offers robust insights into the relationships between variables, it is limited in its ability to capture the complexities of human experiences and organisational practices. This may lead to an incomplete understanding of the factors that drive innovation efficiency, as it does not consider the role of organisational culture, leadership, or employee motivation. Future studies could integrate qualitative methods, such as interviews and case studies, to gain deeper insights into the challenges and opportunities faced by solar energy companies in their quest for innovation.

Our study touches upon the role of market and policy environments but suggests that a more detailed examination is warranted. A more in-depth analysis of these factors could provide a better understanding of how external conditions influence innovation efficiency and could lead to more targeted policy recommendations. Future research could delve into the specific mechanisms through which policy changes impact innovation and how market conditions shape the strategic decisions of solar energy companies.

6.2. Conclusion

This paper employed regression analysis and Data Envelopment Analysis (DEA) for conducting an in-depth analysis of the innovation efficiency for JFTC empirically, a Xinjiang solar energy enterprise. The results reveal that the proportion of technical personnel has a positive effect on technological innovation efficiency significantly, underscoring the central role of technical talent in driving corporate innovation. Fixed asset investment also demonstrates a positive contribution to corporate technological innovation, indicating that the input of physical capital is equally important for technological innovation. However, while government subsidies show a positive correlation with technological innovation efficiency in the regression analysis, they do not exhibit statistical significance in the DEA analysis, suggesting that the government subsidies' impact on corporate innovation efficiency is more complex and requires more nuanced research to uncover its mechanisms. This finding highlights the need for a more detailed examination of how government subsidies can be more effectively utilized to support innovation.

JFTC has shown strong DEA efficiency in most years, indicating its high efficiency in resource utilization and technology application. However, the downward trend in efficiency in recent years suggests that the company may be facing challenges from changing market environments, internal management adjustments, or other external factors that could impact corporate technological innovation efficiency. This trend indicates the need for continuous monitoring and adaptation of innovation strategies to maintain efficiency in the face of external challenges. The results from this paper provide a basis for JFTC as well as similar enterprises to optimize resource allocation and enhance technological innovation efficiency, and also offer policymakers references on how to motivate corporate innovation through policy tools. Supply chain management and marketing integration can bring competitive advantages to enterprises (Liu, Hazrita Ab

Rahim & Li, 2024). For Xinjiang's solar energy enterprises, integrating supply chain management (such as ensuring the stable supply of raw materials for solar energy products) and marketing (such as promoting innovative solar energy products) can enhance their market competitiveness. This integration may also facilitate the implementation of innovation strategies, as it can help enterprises better understand market demands and allocate resources for innovation more effectively.

6.3. Findings

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CONFLICT STATEMENT

The authors declare no conflict of interest.

COOPERATION STATEMENT

The first author (Ma Xinliang) was responsible for conceptualization, methodology, investigation, writing—the original draft, and data analysis. The second author (Deng Jiajia) provided supervision, guidance, and critical revisions. Both authors (Ma Xinliang and Deng Jiajia) are corresponding authors. The third author (Tang Lina) contributed to the data collection and analysis. The fourth author (Li Xiaoxuan) provided additional insights and edited the manuscript. All authors reviewed and approved the final manuscript.

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