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Market structure and performance: An empirical study of the Chinese solar cell industry

Yun Li, Dan Nie*, Xingang Zhao, Yanbin Li

Department of Economics and Management, North China Electric Power University, Beijing 102206, China

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ABSTRACT

Based on an analysis of 9 solar cell enterprises from 2008 to 2014, this paper examined the Chinese solar cell industry's market structure and performance. The empirical results reveal that China's photovoltaic (PV) cell market supports the X-efficiency structure hypothesis and that enterprises with higher levels of production technology and management earn higher profits. However, market concentration, market share, and scale efficiency are not significantly related to corporate performance. In addition, reasonable and effective control of the debt-to-assets ratio of such enterprises is conducive to revenue improvement. Based on these conclusions, this paper offers suggestions on how to improve the performance of the PV cell industry from the perspectives of enterprise and government. The research results have substantial significance for the promotion of enterprise reform and the optimization of industrial resource allocation.

1. Introduction

The world is rich in solar energy resources. When converted into electrical energy, these resources can promote environmental protection and energy efficiency. Given that various countries are emphasizing the importance of renewable energy development and the rapid development of new energy technologies, photovoltaic (PV) power generation has entered a new, large-scale phase after an initial phase of slow development. From 2000 to the present, due to the decreasing cost of PV power generation, the global PV industry has become a rapidly developing market, and newly added PV power generation capacity has increased annually. In 2014, global newly added PV power generation capacity was 47 gigawatts (GW), with cumulative capacity reaching 188.8 GW. Global cumulative installed capacity between 2005 and 2014 is shown in Fig. 1 [1]. Due to the early implementation of a feed-in tariff system, countries of the European Union emerged as leaders in the global PV industry [2,3]. However, affected by the European debt crisis in 2011, countries such as Germany and Italy quickly decreased the feed-in tariff, which resulted in a decrease in Europe's share of newly added PV power generation capacity from 85.12% of global capacity in 2008 to 23.70% in 2013 [4]. The development pattern of the global PV industry has thus been changing with the rapid development of emerging markets, such as China, Japan, and the United States, whose market shares continue to increase [1]. In 2014, China's market share of global newly added power generation capacity increased to 27.70%, up from 0.60% in 2008, ranking first worldwide for the first time. Japan's newly added PV capacity was 10.5 GW, ranking second, while that of the United States was 8.6 GW, ranking third [5].

The vigorous development of overseas emerging markets has pushed China's PV industry structure towards globalization instead of heavy dependence on the European market. Encouraged by national policies and funding, China's PV industry has developed rapidly. Through the introduction, digestion, absorption, and re-innovation of overseas technology, China has become the world's largest producer of solar cells [6]. Of the world's 10 largest solar cell manufacturers, China accounts for six [8]. In 2012, due to factors such as overcapacity and harsh competition, the price of solar cells substantially decreased. By 2015, at least 180 solar cell manufacturers worldwide had entered bankruptcy or merged [9]. In 2014, the global PV industry started to recover. In that year, China's solar cell industry had a total energy production of 4,736.90 million kilowatts, which represented an increase of 28.14%. As the industry is expanding, market concentration is decreasing. Changes in the market structure and the enhancement of competition will inevitably have a profound impact on China's PV cell industry. In the same year (2014), the performance of solar cell enterprises in the same external environment varied substantially. Is the implication that the performance of China's solar cell companies is also affected by efficiency? Studying the source of the performance of China's solar cell enterprises has substantial practical significance and is thus a necessity. Research in this area will help promote sustainable development in China [10].

* Corresponding author.
E-mail address: dan_nieh@outlook.com (D. Nie).

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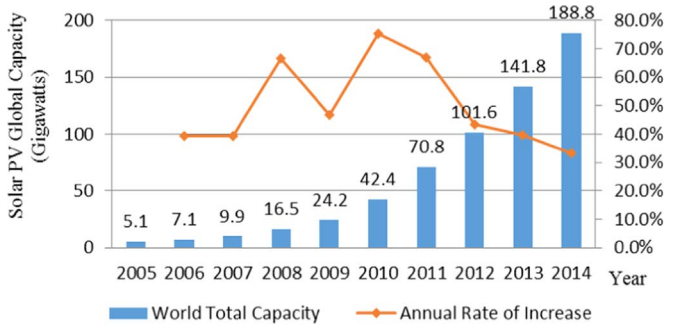

Fig. 1. Global cumulative installed capacity between 2005 and 2014.

This paper primarily uses data envelopment analysis (DEA) to examine the efficiency of the PV cell industry and establishes a test model, a mixed regression model, and a fixed effects model for market concentration, efficiency, and performance [11,12]. The paper uses Eviews statistical software to estimate the model coefficients, analyse their relevance, and thus establish the main source of the performance of China's PV cell industry. Introducing the efficiency variable into research on the relationship between market structure and performance, this study reveals the source of the performance of China's PV cell industry. Based on our results, we suggest useful means of enhancing the market performance and industrial competitiveness of the PV cell industry. In addition, our results can provide a theoretical basis forthe development of the policies in photovoltaic cell industry.

2. Methods

2.1. Literature review

The core of industrial-organizational research is the study of the horizontal relationship between market structure and performance. This research includes the market power hypothesis and the efficiency structure hypothesis.

1. Market power hypothesis

The Harvard School, represented by J. Bain, first proposed the theory of industrial organization. This theory considers that external conditions determine market structure and affect corporate behaviour. In turn, corporate behaviour determines market performance [13]. It is easy for enterprises in a highly concentrated industry to set hurdles and increase prices using their monopolistic market power to reap monopoly profits. Market performance is determined by market power. This hypothesis can be stated in two forms: the conspiracy hypothesis and the relative market power hypothesis [14,15]. The conspiracy hypothesis, or so-called structure-conduct-performance (SCP) paradigm, argues that large enterprises with a higher market share can gain power to manipulate the market through collusion and thus develop higher prices to earn monopoly profits. The relative market power hypothesis holds that large enterprises with a higher market share can utilize their price-setting power to obtain high profits after achieving better product differentiation.

2. Efficient structure hypothesis

In the 1960s, the Chicago School, represented by Demsetz and Peltzman, argued that the Harvard School's theory was overly concerned with market structure and ignored the role of efficiency. Subsequently, they proposed the efficiency structure hypothesis [16–18]. According to this hypothesis, the process of market competition involves the free play of market power and self-regulation. Market equilibrium cannot be achieved by government regulation. Business efficiency is the primary factor underlying market structure and performance. Highly efficient enterprises employ a higher level of management and technology to increase profits and market share, which results in a higher degree of market concentration and enhanced market power. The efficiency structure hypothesis can be divided into the X-efficiency structure hypothesis and the scale efficiency hypothesis [19,20]. The X-efficiency structure hypothesis (Demsetz [16] and Peltzman [18]) argues that enterprises with higher X-efficiency have lower costs and higher profits. Thus, they can gain a higher market share and enhance market concentration. The scale efficiency hypothesis (Lambson [19]) holds that each enterprise's management level and technical level are similar and that the difference between enterprises lies instead in economies of scale. Enterprises with larger economies of scale have higher corporate profitability and thus a higher market share and degree of market concentration.

According to both hypotheses, a positive correlation exists between the performance level and the market structure of enterprises. However, because the hypotheses explain this correlation from different perspectives, the recommended policy measures differ. Sheppard [20] argues that market share and market efficiency together determine performance, whereas Smirlock et al. propose that a link between market share and monopoly power cannot be demonstrated and that the relationship between the two Sheppard et al.'s blurry [21–23]. Most domestic and international studies on the relationship between market structure, efficiency, and performance focus on the banking, insurance, and logistics industries. Empirical research on PV cell enterprises is virtually non-existent [24–28].

2.2. Data

2.2.1. Data sources

The selected sample of Chinese solar cell companies consists entirely of listed companies. Although listed companies only represent the market competition and performance of certain products, the use of data from listed companies for analysis is feasible. Because China's solar cell companies were listed late, to compensate for the deficiency of annual data and to reflect as much as possible the relationship between market structure and performance during the dynamic development of China's solar cell industry, this paper uses nine solar cell companies that were first listed on the stock exchange between 2008 and 2014. The sources for the specific data are the 2008–2014 panel data obtained from the financial statements of these listed companies and the *China Statistical Yearbook* [29].

2.2.2. Variables

This paper selects return on assets (ROA) of China's solar cell companies as the dependent variable, and market share, market concentration, and efficiency as the independent variables to conduct an empirical analysis of the correlations between various variables.

2.2.3. Descriptive statistical analysis of different variables

1. Market performance

The dependent variable in this paper is ROA, which is an index that measures how much net profit per unit of assets is created. A higher ROA indicates more effective resource allocation on the part of solar cell enterprises. ROA is also the basis that affects the continuing operation and rapid development of enterprises.

2. Market structure

This paper uses market concentration and market share as independent variables for an empirical analysis of the market structure of China's solar cell enterprises.

The measurement indicators of market concentration include the market concentration rate. Concentration Ratio (CRn) indicators have the advantages of easy data collection, practicality, and common use. The market concentration rate index adopted in this paper refers to the proportion-related variables in the n largest

enterprises in the industry in terms of the entire industry. The formula is as follows:

$$CRn = \sum_{i=1}^{n} \frac{X_i}{X} = \sum_{i=1}^{n} S_i \quad (1)$$

Where X is the total scale of the market, Xi is the scale of the i-th enterprise, Si=Xi/X is the market share of the i-th enterprise, and n is the number of top n enterprises. In this paper, enterprise scale is calculated via yield. A greater CRn represents a higher degree of market concentration and monopoly.

Market share is a variable that reflects the intensity of competition among solar cell enterprises. The relative market power hypothesis regards market share as a factor that affects the market power of solar cell enterprises. The efficiency structure hypothesis holds that the level of efficiency of solar cell enterprises affects market share and that enterprises with higher efficiency can increase market share by decreasing product prices. In this paper, each enterprise's market share is calculated by dividing the total output of the country's solar cell industry by the output of a single solar cell company.

3. Efficiency variable

X-efficiency is an index that measures production efficiency from the perspective of cost. Scale efficiency indicates the impact that a change in the scale of operation on the part of solar cell enterprises has on total cost. Using the Banker, Chames and Cooper (BCC) model from the DEA method, the paper identifies the X-efficiency and the scale efficiency of China's solar cell industry. The input indicators chosen for this paper include fixed assets and operating costs, and the output indicator is total sales revenue. To eliminate price effects, the input and output indicators are converted into constant prices with 2008 as the base period.

4. Control variables

The control variables are the variables that affect the performance of solar cell enterprises in addition to the efficiency variable and market structure. To investigate the relationship between market structure and performance, the paper introduces additional control variables. Based on the actual situation of China's solar cell enterprises and data availability, the paper selects the debt-to-assets ratio (OR) and enterprise total assets (AS) as control variables. These two variables reflect business operation risk and the impact of the scale of business assets on the market performance of solar cell enterprises, respectively. The business assets scale is converted into constant prices with 2008 as the base period.

5. Random variables

ε is a random error term that represents the factors that have less impact on the performance of the solar cell industry.

2.2.3. Descriptive statistical analysis of different variables

In light of the specific circumstances of the different variables, the paper conducts a descriptive statistical analysis of all the variables. The results are shown in Table 1.

Table 1 shows that the market performance of PV cell enterprises is poor and that the average ROA is negative. The average industry concentration rate reaches 44.28%, which indicates an oligopoly market. The mean and median of most variables are similar to one another, which indicates that the sample data mainly follow a quasi-normal distribution with the high in the middle and the low at the two ends. The data are suitable for regression analysis.

2.2.3.1. Model.

According to the previously described variable setting, the paper adopts ROA as the dependent variable, and market concentration, market share, and the control variables as independent variables to investigate market structure's separate impact on performance. It establishes model (1) as follows [30]:

$$ROA_{it} = \alpha_0 + \alpha_1 MS_{it} + \alpha_2 CR4_{it} + \alpha_3 Z_{it} + \varepsilon_{it} \quad (2)$$

In the model, ROA is the market performance of the sample enterprises, MS is the market share of the enterprises, CR4 is market concentration, and Z represents the control variables, i.e., a series of variables that may affect the market performance of solar cell enterprises. ε is a random error term, and α_0,α_1, α_2, and α_3 are the regression coefficients of determination.

Sheppard et al. [20] hold that market share cannot represent efficiency but can only reflect market power. Thus, this study refers to the regression equation proposed by Berger [31] to establish a test model based on solar cell enterprises to test the market power hypothesis and the efficiency structure hypothesis. Model (2) is as follows [31]:

$$ROA_{it} = \beta_0 + \beta_1 MS_{it} + \beta_2 CR4_{it} + \beta_3 XE_{it} + \beta_4 SE_{it} + \beta_5 Z_{it} + \varepsilon_{it} \quad (3)$$

In the model, XE is X-efficiency, SE is scale efficiency, and β_0, β_1, β_2, β_3, β_4, and $\beta_5$are the regression coefficients of determination.

To validate the efficiency structure hypothesis, it must also be demonstrated that market efficiency determines the level of market share, i.e., that a positive correlation exists between the efficiency variable and the market share variable. Therefore, the study establishes mathematical model (3) with efficiency as the independent variable and market share as the dependent variable as follows:

$$MS_{it} = \gamma_0 + \gamma_1 XE_{it} + \gamma_2 SE_{it} + \gamma_3 Z_{it} + \varepsilon_{it} \quad (4)$$

In the model, γ_0, γ_1, γ_2, and γ_3 are the regression coefficients of determination.

According to formulas (2) and (3), the bases for determining the four hypotheses are as follows:

When $\beta_1>0$ and β_1 is significant while the other coefficients of determination are 0 or not significant, the relative market power hypothesis is verified, which indicates that solar cell enterprises with a high market share can freely use their monopoly power to set prices and thus earn higher profits.

When $\beta_2>0$ and β_2 is significant while the other coefficients of determination are 0 or not significant, the conspiracy hypothesis is verified, which indicates that in a highly concentrated market solar cell enterprises with monopoly power can obtain monopoly profits through collusion.

When $\beta_3>0$ and $\gamma_1>0$ and both variables pass the significance test, the X-efficiency structure hypothesis is verified, which indicates that when an enterprise has high X-efficiency, it will have the advantage of low costs and high profits and thus significantly increase its market

Table 1
Descriptive statistical analysis of different variables.

Variable	Observations	Mean	Median	Maximum	Minimum	Std. Dev.
ROA	63	−0.002793	0.000170	0.357100	−0.144730	0.090701
MS	63	0.064355	0.065941	0.170000	0.000314	0.049754
CR4	63	0.442814	0.442900	0.636300	0.317400	0.107596
XE	63	0.879571	0.865000	1.000000	0.631000	0.095730
SE	63	0.935381	0.968000	1.000000	0.631000	0.073958
OR	63	0.621962	0.620865	1.122276	0.111629	0.203274
AS	63	812174823.54	508993916.7	2866480747	1115170.989	838818112.91

share and increase market concentration.

When $\beta_4>0$ and $\gamma_2>0$ and the variables pass the significance test, the scale efficiency hypothesis is verified, which indicates that when an enterprise has the advantage of scale it can obtain high profits through low costs, its market share will expand, and market concentration will increase.

2.2.3.2. Results. Panel data models can be divided into three types: mixed regression models, fixed effects models, and random effects models. To select a panel data model, in this study, a choice is first made between the mixed regression model and the fixed effects model using the F-test [32,33]. Then, the mixed regression model and the random effects model are compared using the LM test. Finally, a choice is made between the fixed effects model and the random effects model based on the Hausman test. The F-test results for models (1) and (2) are 1.2061 (F1=1.2061) and 1.4543 (F2=1.4543), respectively, both of which are below the critical value, given the significance level of α. It is found that models (1) and (2) do not reject the null hypothesis and that the mixed regression model should be selected. Because the P value result of model (3) obtained from the Hausman test rejects the null hypothesis, the model is set as a fixed effects model. To reduce the impact of heteroskedasticity and serial correlation in error terms, the estimation of models (1)–(3) uses the method of panel corrected standard errors. The final model estimation results are shown in Table 2.

The empirical results reveal that the goodness of fit of model (1) is 0.322928 (R^2=0.322928). Thus, the regression analysis of performance is conducted with market structure as the independent variable, and the efficiency factor is not considered. The goodness of fit of model (1) is insufficient, and the degree of fit is unacceptable. Because the F-statistic=6.915751 and Prob (F-statistic)=0.000127, the relationship between the explained variables and the explanatory variables in the model is not significant. According to the regression results, the market share is positively correlated with ROA, but not statistically significant, while the market concentration is negatively correlated with ROA, not statistically significant either. which reveals that the relationship between the market performance of China's PV cell enterprises and market structure is not significant. This further indicates that, in the current environment, the market structure does not have obvious promoting effect on the performance of photovoltaic cells industry in China, even the higher the concentration of the market, the lower the performance is, so we should encourage competition and reduce the degree of monopoly, in order to improve the performance of the PV battery market in china.

Model (2) adds X-efficiency and scale efficiency. The goodness of fit R^2=0.691588 indicates an excellent goodness of fit and acceptable degree of fit. Because the F-statistic=20.92920 and Prob (F-statistic) =0.000000, the relationship between the explained variables and the explanatory variables in the model is significant. According to the regression results, the market share is positively correlated with ROA, while the market concentration is negatively correlated with ROA, The results reveal that market share and market concentration do not have a significant impact, which is consistent with the conclusions from model (1). Thus, the relative market power hypothesis and the conspiracy hypothesis with respect to China's PV cell enterprises are unsupported. The barriers to entry and exit of China's PV cell industry are low. Affected by the European debt crisis in 2011, the prices of PV cells have sharply decreased, and the cost of PV power generation has significantly declined. However, in the context of China's economic transformation and new energy strategy over the past two years, many PV cell enterprises have still not been eliminated from the industry. A nd due to the lack of competition, photovoltaic battery enterprises lack the motivation to pursue higher performance. Thus, one can conclude that there is an insignificant relationship between China's PV cell performance and market structure.

The scale efficiency of the model (2) were negatively correlated with the performance, which doesn't pass the test of significance. Thus, to improve the efficiency of corporate assets through the expansion of the scale is not very effective, and the photovoltaic cell industry does not have the characteristics of the scale efficiency hypothesis. Model (2) only passes the test of significance when X-efficiency is at the significance level of 1%. The coefficient of X-efficiency is positive, namely, an increase in X-efficiency can improve business performance, which indicates that China's PV cell enterprises exhibit the characteristics predicted by the X-efficiency structure hypothesis.

That X-efficiency has a significant positive impact on ROA does not determine that China's PV cell industry reflects the X-efficiency structure hypothesis. To determine the consistency, we must also verify the relationship between efficiency and market share. Therefore, we conduct regression analysis on model (3). When only the efficiency factor is introduced, the model's goodness of fit is 0.895486 (R^2=0.895486). The goodness of fit is excellent, and the degree of fit is acceptable. Because the F-statistic=35.70030 and Prob (F-statistic)=0.000000, the relationship between the explained variables and the explanatory variables in the model is significant, which indicates that efficiency improvement is key to enhancing the performance of China's PV cell industry. The results reveal that the coefficient of X-efficiency is positive and significant. Based on these determining criteria of the four hypotheses, models (1)–(3) validate the X-efficiency structure hypothesis of China's PV cell enterprises. It shows that compared to competitors, it is easier for photovoltaic battery enterprises to obtain high profits with low costs, enhance market concentration by increasing market share through promoting the management level and production technology.

In light of the regression results for the control variables, the

Table 2
Final model estimation results.

Variable	Model (1)	Model (2)	Model (3)
CONS	0.153294** (0.044117)	−0.306068** (0.089755)	0.043123 (0.026118)
MS	0.156015 (0.173657)	0.143033 (0.116085)	
CR4	−0.093055 (0.082621)	−0.082030 (0.053911)	
XE		0.540869** (0.071006)	0.047974*** (0.018226)
SE		−0.061535(0.092469)	−0.024672 (0.025785)
OR	−0.216798** (0.042528)	−0.168005** (0.028220)	−0.010435 (0.012856)
AS	2.91e−12 (1.13e−11)	1.01e−11 (7.18e−12)	1.06e−11 (7.96e−12)
R-squared	0.322928	0.691588	0.895486
Adjusted R-squared	0.276234	0.658544	0.870402
F-statistic	6.915751	20.92920	35.70030
Prob (F-statistic)	0.000127	0.000000	0.000000

* Represent significance at the levels of 10%. The numbers in brackets are standard errors.
** Represent significance at the levels of 1%.
*** Represent significance at the levels of 5%.

coefficient of the debt-to-assets ratio OR is negative and passes the significance test at the level of 1%, which demonstrates that enterprises with a low debt-to-assets ratio have a higher level of business performance. Due to the European debt crisis, the PV cell industry has developed slowly in recent years, and most enterprises are losing money, with a high corporate debt rate and substantial business risk. Thus, reasonable control over the debt-to-assets ratio of PV cell enterprises and a decrease in business operation risk can effectively create more revenue. The coefficient of AS is positive, but it does not pass the test of significance, which shows that the relationship between total assets and performance is not significant.

2.2.3.3. Conclusions and suggestions. This paper primarily uses related data from nine companies in China's PV cell industry between 2008 and 2014 to analyse the relationship between the market structure, efficiency, and performance of China's PV industry. Previous studies on the relationship between market structure, efficiency, and performance primarily focus on the banking and insurance industries. There is little empirical research on the PV cell industry. This study finds that the relationship between market share, market concentration, and performance of PV cell enterprises is not significant. Therefore, our results do not support the relative market power hypothesis and conspiracy hypothesis. Scale efficiency and performance efficiency do not exhibit a significant relationship and in fact are negatively correlated, which indicates that with an increase in the scale of PV cell enterprises, profits decrease. This outcome does not support the scale efficiency hypothesis. Only X-efficiency and performance are significantly and positively correlated. They are significantly and positively correlated with market share, which indicates that the market structure and performance of China's PV cell industry can be explained by the X-efficiency structure hypothesis. China's PV cell products are too homogeneous. The country's PV cell enterprises lack innovation, their products vary only slightly, and competition among enterprises is not based on product differentiation. Therefore, China's PV cell enterprises can only achieve low internal costs by improving their management level and production techniques, thus gaining a competitive advantage.

To improve the performance of Chinese PV cell enterprises, we propose the following recommendations:

First, the enterprises should establish a sound corporate governance structure, rationally allocate resources, tap their own internal potential, and improve staff and management quality. Second, the enterprises should emphasize technological innovation, basic research, and development capabilities as well as adopt advanced PV cell technology and improve product quality and competitiveness. In this manner, they can enhance their market share and market power. In addition, the enterprises can improve their efficiency and performance by acquiring small businesses, expanding their business scale, and achieving economies of scale and scope.

Regarding the government, the development of the PV industry should be encouraged, and PV cell enterprises should be supported in improving their market share and enhancing their market competitiveness through mergers and acquisitions. Implementing the government's development plan for the PV industry can provide a strong economic and policy environment for the development of the PV cell industry, in which large-scale enterprises with strong overall competitiveness can be fostered. In addition, while encouraging the development of PV cell enterprises and actively introducing foreign capital, the government should emphasize the regulation of non-regulated competitive behaviours. Although a monopoly caused by excessively high market concentration will reduce market performance, competition that is too fierce will also reduce performance. Thus, the government should pay attention to regulation to ensure the healthy and orderly development of the PV cell industry.

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