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# Technological progress and industrial performance: A case study of solar photovoltaic industry

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ABSTRACT

In order to find out the driving factors that affect the performance of PV industry in China, this article analyzes the panel data of 17 photovoltaic cells enterprise from 2008 to 2014. The total factor productivity growth is decomposed to test the performance of the photovoltaic industry and the level of technological progress. The empirical results show that the growth in output of Chinese PV industry mainly relies on technological progress, while the relative frontier technology efficiency does not change with time, and the allocation efficiency and scale economy function contributes little to the change of total factor productivity. Analysis shows that the way to obtain the future development of China PV industry is to rely on technological progress and market competition mechanism.

## 1. Introduction

Photovoltaic technology in China rose in the 1970s and was initially used in aerospace, then expanded to the ground, which led to the emergence of Chinese photovoltaic industry, after which Chinese photovoltaic industry had been growing at an annual rate of 400% [1]. Until 2009, Chinese polysilicon production has exceeded twenty thousand tons, solar cell production had exceeded 4000 MW. At that time, China had become the world's largest solar cell producer for three consecutive years [2]. After 2000, benefited from the huge market demand in Europe and the United States and Chinese policy incentives, Chinese solar photovoltaic industry had experienced rapid development. As a result, the production capacity and output has ranked the first in the world. However, the developing mode of Chinese PV industry that the raw materials and the final product market are both abroad has not changed. Followed with the rapid development in the industry, overcapacity problems also became increasingly prominent. Before 2011, external dependence of Chinese PV industry has reached more than 90% [3]. Suffered from “double-anti” (the "anti-dumping and anti-bribery" investigation) in Europe and America, Chinese PV products had experienced a rapid decline in export data. In 2013, Chinese solar photovoltaic cells and modules exported to Europe for $ 3.72 billion, going down sharply by 61.98% [2]. In addition, series of Chinese government subsidies for photovoltaic industry has also led to repeated construction problem and reluctant expansion in industrial scale, which further exacerbated the overcapacity problem in Chinese photovoltaic industry. In the first half of 2013, Chinese polysilicon industry was fully exhausted, only 6 polysilicon enterprises were still in production, while there are 43 in total which have been invested. Others have all stopped their production lines [3]. In 2014, China had more than 1 thousand enterprises engaged in the production of polysilicon and photovoltaic module, and 2/3 of them were PV module manufacturers. Total PV module capacity reached 70 GW, but the average capacity utilization dropped below 50%, more than half of the components manufacturers are still at a loss [4]. Chinese photovoltaic industry, experienced explosive development during the 10 years, but also suffered from the overcapacity problem and the impact of foreign trade protection. Therefore, it is the common concern of Chinese government and enterprises to find out the driving factors behind the development of Chinese PV industry for more than ten years, so that the development method of PV industry could be improved.

Concerning the source of economic growth, varieties of domestic and foreign scholars mainly carried on research in two aspects: factor input and technology progress. That means whether the economic growth was driven by factor input or by productivity improvement. This method is also useful in estimating industry performance. Industry Performance is one of the core issues of industrial organization economics. William and Joanna summarized the multiple meanings of performance, including the efficiency of resource allocation, technological progress, equitable distribution and competition process [5]. In practical computation, most of the literature utilizes indicators concerning profitability or productivity to measure the level of performance [6]. In this paper, we use the growth accounting equation to decompose the total factor productivity of the PV industry. The change

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of the total factor productivity is used as performance indicator in order to measure the development in PV industry and the dependence of the PV industry on technology. Conclusively, we are trying to find out the driving force of such development and the shortcomings of which, so as to provide advices for further progress in Chinese photovoltaic industry.

The structure of this paper is organized as follows. Section 2 provides a brief review on the research on the performance and technological progress of Chinese PV industry; Section 3 introduces the model to be used, the principle of model accounting and the economic meaning of each variables; Section 4 provides the data selection criteria and numerical results as well as the analysis of the results; Finally, Section 5 concludes with policy implications.

## 2. Literature review

With the rapid development of PV industry in China, the research on Chinese PV industry has made great progress, including the research on PV industry chain, the discuss of the influence of government policy effect, the analysis of international trade development competition and the strategic research on the sustainable development of PV industry and so on. Tian Hang [7] carried out a comprehensive analysis for all sectors of the photovoltaic system links, including energy consumption and social effects, noted that the problem in Chinese PV industry chain is "put both ends of the production process (the supply of raw materials and the marketing of products) on the world market." Chun-qi [8] analyzed the low end overcapacity problem from the perspective of the value chain, supply chain, technology chain, spatial chain in the PV industry, pointed out that Chinese PV industry is too much depended on technology transfer. To seize the market, low labor and land costs and environmental protection cost of China have been overused. He proposed to build an energy evaluation system to adjust the energy structure rely on the market condition. Xu [9] analyzes the problem of resource consumption and environmental pollution in Chinese photovoltaic industry from the perspective of economic cycle, and put forward some suggestions on the adjustment of industrial structure. Li [10] used the principal-agent model to study the impact of behavior of government incentives and R & D uncertainty on enterprise development, which provide a way to maximize the benefit of expenditure. Jie, etc. [11] attempted to quantify the impact of Chinese PV policies through event analysis. Conclusions show that government should subsidize the end-users rather than the producers. Yuan et al. [12] used the state space model to describe the actual effect of Chinese PV industry policy, and pointed out the problems of excessive regulation in PV industry and imperfection in industrial standards, then put forward a strategic plan from the perspective of research and development and fiscal policy to enhance the international competitiveness of Chinese PV industry. Xiong Yan [13] started from the cost advantages, stressed the government should use tax mechanisms and the price mechanism to reduce the cost of photovoltaic products. Liu [14] built the logistics model to fit the development path of the photovoltaic industry, and combined the concept of industry and the system, so as to give advice on improving the industrial system. Cui [15] empirically analyzed the performance of Chinese PV industry, determined the factors based on DEA model, and give some suggestions on the development of the policy and technology.

To perform a comprehensive and thorough analysis of the development of Chinese PV industry, you have to computing the factors that affect the performance, as well as measuring the contribution of technological progress on the development. Then analyzing which factor drives progress in the industry. For the decomposition and accounting of industrial performance and technological progress, the previous scholars had done a lot of researches. The concepts and methods provided by these researches are of great significance to this paper though they were not based on the photovoltaic industry. Simon [16] analyzed the business situation under the limited rationality and satisfactory behavior from the microscopic point of view. Leibenstein [17] presented that the company's internal incentives, information system, monitoring mechanism and agency problem would necessarily lead to low production efficiency, called "X inefficiency." In 1950s, Koopmans [18], Debreu [19] and Shephard [20] proposed a definition of technical efficiency: Production is technically efficient if and only if it is not possible to increase the yield of a certain product without reducing the output of other products or increasing the cost of inputs. Farrell [21] uses empirical method firstly to decompose the cost efficiency into technical efficiency and allocation efficiency to measure productivity. Cong [22] used the traditional learning curve model and technology diffusion model to analyze the maximum capacity and structure of renewable energy. Alani [23] used an improved C-D production function to analyze the economic development of Uganda from 1970 to 2009, and tested the effect of technology and productivity on economic growth. The same model was also adopted by Banerjee et al. [24] to explain the long-term development of India.

The calculation of economic growth was initially based on endogenous growth theory. AK model is the earliest and the most representative model [25]. According to endogenous growth theory, human capital and technological progress are the most important driving factors to promote economic growth [26]. After that, economic growth estimates involved in all aspects of economic activity, Lin etc. [27] estimate the impact of distortions in factor market on energy efficiency in mainland China. Sun and Wang [28] and Liu [29] respectively studied the influence of property rights change and market structure change on industrial performance of Chinese Industrial Enterprises. Lu etc. [30] studied the impact of government subsidies and output results from the perspective of government subsidies in emerging industries. Su etc. [31] based on international trade perspective, discussed the relationship between knowledge commerce, technological progress and economic growth. At present, scholars have recognized the factors that promote economic growth−−capital and human resources investment, policy support and a good investment environment [32].

Galor and Moav pointed out that the early industrial revolution can rely on capital investment to bring about economic growth, while modern people rely more on human capital and technological progress [33]. Path of technological progress is not singular, Hicks [34] firstly proposed that technical progress can be divided into 3 types: capital-saving, labor-saving and neutral technical progress. Neutral technological progress does not change the proportion of elements. Song etc. [35] used the time series data of China during 1978–2007 to examine the existence of skill biased technological progress in China. Wang etc. [36] built up a model of neutral technological progress and biased technological progress, and calculated the factor bias of technological progress of different sources in Chinese industries among 1999–2010. Kwack and so on [37] decomposed the source of the economic growth among 1969–2000 in South Korea, find out the contribution of scale economic function and factor input to economic growth. Molinari etc. [38] analyzed the economic development of a group of Pacific rim countries among 1980–2006, computed the contribution of capital and labor to technological progress.

There are two main methods to decompose the total factor productivity−−the growth accounting method and the regression analysis method. Durlauf [39] gave a detailed review of these two methods. Bosworth and Collins [40] further proved that the growth accounting method and regression analysis method is consistent with the results. For the decomposition of total factor productivity, the parameter method attracts more and more attention, because it can avoid the blindness of the internal process of economic development that will not appear by non-parametric method. Xu [41] constructed a stochastic frontier model to analyze the performance change of large and medium sized industrial enterprises in China during 1995–2002, they put that the productivity growth could be divided into four parts: