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Optimal policy design for photovoltaic power industry with positive externality in China

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ABSTRACT

China's photovoltaic power (PV) power industry currently faces a challenge in excessive production capacity. The aim of this study is to determine how the Chinese government should regulate this industry with positive externalities in order to achieve equilibrium and maximize social welfare in a market economy. This paper formulates an investment model in corporate government theory that includes government, bank systems, and private- and state-owned enterprises. Using the model developed, the relationships between the government's preferred investment strategy and its budget constraints, and the related tax rate or subsidy level are analyzed in the context of China's PV power sector. Main findings of this study are as follows: Firstly, both types of enterprises can achieve optimal social investment if the budget constraints are not excessively binding as the government will have sufficient financial resources to subsidize both types regardless of how funds are obtained. Secondly, state-owned enterprises will choose a higher investment level when government budget constraints are binding because the government lacks money. Thirdly, if the tax rate is so low that the government cannot raise adequate tax to ensure production, raising funds from profits is a better choice. Due to the fact that the positive externality and incremental cost of the PV power technology compared to the local grid's mainstream power technology vary spatially and temporally, which type of enterprises is favored depends on the local real-time situation. This paper also finds that assigning PV power production to a state-owned enterprise is always the favored strategy in areas where the solar resource is not abundant and the PV sector is in its early stage, which helps to accomplish strong positive externality as early as possible in a few years. In areas where solar resource is abundant, private enterprises are supported to develop PV power. Furthermore, as the incremental cost of PV over conventional power to grid decreases with China's grid electricity becoming cleaner and more expensive, subsidy to PV power sector should be decreased and a wider range of private enterprises should be encouraged to make investment in this industry.

1. Introduction

Fossil fuel deposits are limited and are expected to be substantially depleted this century (Kim et al., 2015). Moreover, severe haze problem blanketed China in recent years and tends to getting worse, which is directly related to fossil fuel combustion (Yang and Teng, 2016). Clean energy technologies, by contrast, represent a promising solution to the global warming challenge (Choi et al., 2016), and solar energy is the kind of clean resources, which can be converted into power by using photovoltaic (PV) technology. In the past few years, PV technologies have experienced considerable growth rates of up to 70% and photovoltaics has been considered as an appropriate example for the implementation of resource availability considerations into technology development strategies (Zuser and Rechberger, 2011). Besides, the solar PV technology remains, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity (e Silva et al., 2014). According to the European Photovoltaic Industry Association, photovoltaic energy has the potential to contribute up to 13% to the global electricity supply by 2040 (Marwede and Reller, 2012).

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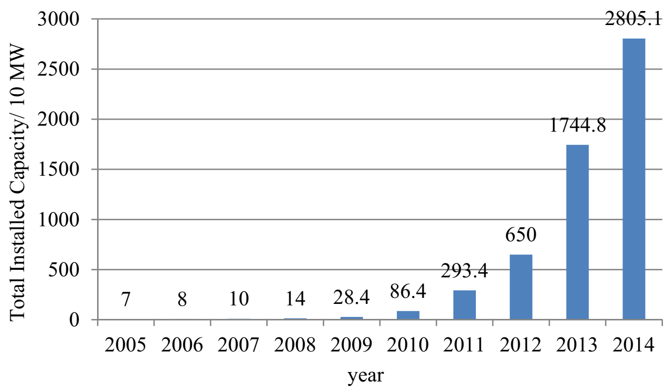

Fig. 1. The total installed capacity in the PV power industry in China.
Data Source: (Renewable Energy, 2015).

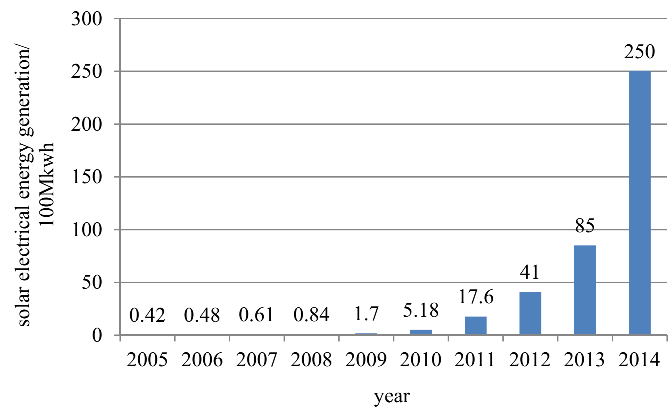

Fig. 2. The solar electrical energy generation in China.
Data Source: (The Renewable Energy Industry Development Report, 2015).

China has abundant solar energy resources, and the average annual solar energy in China is equivalent to 1700 billion tons of standard coal. At the present stage, China has 1.308 million square kilometers of land resources, including desert Gobi and desert land. Besides, the existing urban available construction area has reached 20.02 billion square meters, including the roof and south elevation. The above resources have the capacity of 500 million kilowatts and 20 million kilowatts, respectively. Therefore, the solar power will become the most large-scale and industrial development potential of renewable energy in China after the hydropower and the wind power (The Renewable Energy Industry Development Report, 2015). It therefore offers great potential for solar power utilities. This is particularly true for PV solutions, which could meet much of the global power demand by directly transforming solar energy into electricity (Grau et al., 2012; Kreiger et al., 2013).

The PV power industry has undergone dramatic changes over the past decade, growing at an average rate of 48% per year, and global PV power installations reached 40 million kW in 2014 (Zheng and Kammen, 2014; International Renewable Energy Development Report, 2015). Because of the rapid growth of solar energy, when faced with an accelerating energy crisis, both Europe and the United States drafted new government policies to promote the development of the PV power field (including subsidies) to deal with increased energy demand.

Recent years have witnessed remarkable development of the PV power industry in China, with joint promotion of the market and policies (Yang et al., 2003; Sun et al., 2014; Yang, 2015). PV power industry in China started late, which was entering the market in 2001. However, China's PV power industry grew rapidly from 2005 onwards, with annual growth exceeding 100% over the past 5 years. The total installed capacity and generating capacity in the PV power industry for 2005–2014 in China are shown in Figs. 1 and 2, respectively.

The PV power generation is clean, and has positive externality on the power grid. But according to the optimal investment decision theory in real option theory, it is easy to cause the result of inadequate investment, due to the high cost of power generation. At present, the China government has taken a series of incentive measures; including implementing the fixed feed-in-tariff (FIT) policy or paying a high proportion of subsidy to the project investment. Although it has expanded the scale of PV power generation, but it also brings overcapacity in some areas and individual sessions. A case study of "Abandon of the PV power generation" in China, the most serious areas mainly concentrated in Jiuquan, Dunhuang, and Golmud, which has excessed 20% in the local area (Energy Research, 2016).

For the investment structure of PV power generation in China, it has the feature of diversification. Four types of enterprises have invested in PV power plants, including state-owned enterprises (SOEs), private enterprises (PEs), foreign enterprises and sino-foreign joint venture. Among them, the SOEs have occupied half of the development of PV power plants. According to the statistical data of the end of 2014, there are 23.38 million kW cumulative grid connected PV power plant in China and the share of the SOEs is more than 50%, as shown in Fig. 3 (The Renewable Energy Industry Development Report, 2015).

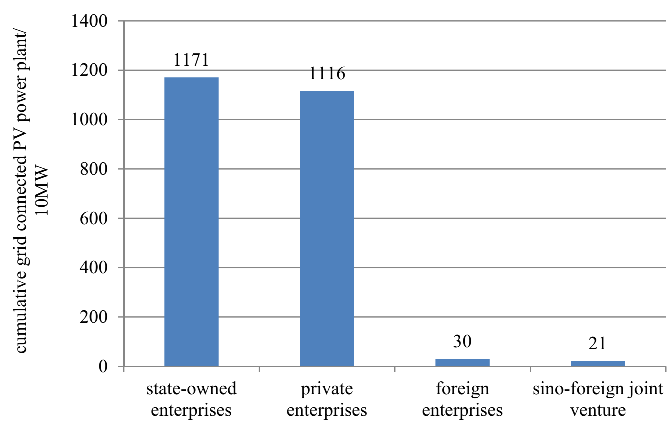

Fig. 3. The cumulative grid connected photovoltaic power plant capacity of various types of enterprises in China.
Data Source: (The Renewable Energy Industry Development Report, 2015).

With regard to the characteristics of PV power, the ratio of the coal generation ratio is relatively high, and the cost is also high, but it has large positive externality. In the future, the externality will gradually reduce, and the production cost may also decrease due to the learning curve and scale effects.

As many earlier literatures do, this paper tries to understand the problem of over-supply of green power from solar resources, which is a good with positive externality and should face the fate of supply shortage. In fact, green power supply and private provision of public goods have been a quite big topic in the energy and environmental economics and have grown extensively for the past two decades, and scholars have almost reached an agreement in framing it as a "green product" that individuals increasingly face a new option: consumption of impure public goods through joint production of a private good (electricity supply) and an environmental public good (CO_2 mitigation). In other words, green power is neither public goods nor private goods, but combination of the two (e.g., Kotchen, 2006). What's more, this paper aims to determine how government should regulate industries that have positive externalities to achieve equilibrium and maximize social benefit in Chinese