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On the impact of FIT policies on renewable energy investment: Based on the solar power support policies in China's power market

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ABSTRACT

In 2013, the feed-in tariff (FIT) policy was issued in China to promote the investment in renewable technology, but then it was revised because this policy brought a heavy financial burden to the government. By considering the intermittence of renewable resources, we model the implemented Chinese FIT policies and analyze their impact on renewable energy investment in the power market. The open-loop model is employed to simulate the China's power market organized with Power Purchase Agreement, and the closed-loop game is used to characterize the spot power market. Meanwhile, the strategic capacity choices of power generators in two games are compared under four different policy schemes: (i) *free competition,* (ii) *FIT via fixed subsidy,* (iii) *FIT via price premium and* (iv) *Chinese FIT by cross control (CFCC).* The results show that the *CFCC* policy is a good alternative to well control the investment in renewable technology, as it can be seen as a comprise between *free competition* and *FIT via fixed subsidy* policy. Furthermore, compared with the other three policy schemes, the *CFCC* policy is capable of keeping renewable power generators from deviating the equilibrium, which implies higher robustness in regulating the electricity spot market.

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1. Introduction

The consumption of fossil fuel resources such as coal, oil and gas has increased fiercely since the Industrial Revolution, and all of the world's leaders are striving to seek effective measures against energy crisis and environment pollution [1–3]. The power generation from renewable sources, without using fossil fuel resources and producing little or no harmful emission, becomes a strategic choice to ensure energy security, environmental protection and structure adjustment in the power market.

However, the high cost of renewable power generation always hinders its wide use in the commercial environment. To remedy this situation, FIT policies have been implemented in most countries to subsidize the generators employing renewable technology. The 2000 German Renewable Energy Act was the first to work out the FIT policy, which prescribed the on-grid price of solar power and a decline ratio of 5% each year. But along with the decreasing installation cost, the decline ratio was adjusted to 9% in 2012. Spain introduced a generous FIT policy in 2007 that triggered its first boom in solar projects with an installed capacity of 2.7 GW. However, in the next year, Spain revised its solar PV legislation and issued the New Royal Degree 1748/2008, which made a sudden decrease in the tariff. As a result, Spain's installed capacity of solar power was only 96 MW in 2009 [4]. US support for the solar market began with a 30% investment tax credit, and now the FIT policy as well as renewable portfolio standards has become the country's major measures to increase the market share of renewable energy. Japan's renewable energy policy focuses more on research and development, and the country has implemented measures ranging from investment subsidy to net metering and finally to a FIT policy. Facts show that the renewable energy policy is never constant: it is always in a process of constant revision and improvement.

The FIT policy has proven to be the most effective government incentive aimed at promoting installed capacity [5,6]. For example, an FIT policy option offers the purchase price of renewable power with a premium payment added to the market price [7]. A fixed premium (*FIT via fixed subsidy*) or a percentage of retail price (*FIT via price premium*) above the average retail price generally represents the environmental and social contributions of renewable energy [8]. The guaranteed payment structure ensures a high degree of investment security and helps the participation of encourages the risk-averse investors for developing renewable energy. In the economic literature, many scholars have structured these different FIT policies and analyzed their advantages and disadvantages with a

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Nomenclature

Parameters

N	number of power generators adopting traditional technology;
M	number of power generators adopting renewable technology;
v^T	unit production cost for traditional technology;
v^R	unit production cost for renewable technology;
k^T	unit investment cost for traditional technology;
k^R	unit investment cost for renewable technology.

Variables

$y_i^T, (i = 1\ldots, N)$	electricity output generated by generator i using traditional technology;
$y_j^R, (j = 1\ldots, M)$	electricity output generated by generator j using renewable technology;
$x_j^R, (j = 1\cdots, M)$	investment capacity of generator i on traditional technology;
$x_j^R, (j = 1\ldots, M)$	investment capacity of generator j on renewable technology.

focus on the implications, either for investors or for society [7,9,10]. But in practice, an effective renewable energy policy should be the one that can facilitate the installation of the desired capacities within a controlled level of expenditures. To some extent, it is challenging to find such a policy because of the lack of a common definition of FIT policy and the spectrum of political systems that occur among different nations.

The introduction of FIT policy accelerates the development of the green power market in China and has positioned China to lead in the solar industry. In early 2013, a *FIT via fixed subsidy* policy was instituted by the National Development and Reform Commission (NDRC) to promote the application of solar energy. The commission proclaimed that all solar power would be bought up by the grid company at the market price and the generators would be able to receive a subsidence of a fixed price of 0.42 Yuan/kWh. Such a “favorable policy” pushed China's worldwide rank in photovoltaic generation to the top in 2013 with an installed capacity of 18.1 GW (far above the government target of 10 GW). However, the rapid growth beyond expectations not only resulted in a heavy financial burden on the government but also affected the stability of the power system. To ensure the stable and smooth construction of photovoltaic projects, the Chinese government proposed the *CFCC* policy in late 2013. According to this policy, the installed capacity of solar energy in every province each year had to be pre-arranged in line with the national goal. Solar power derived from the pre-arranged capacity would be subsidized with a fixed subsidy, whereas the excessive amount would no longer be subsidized. Herein, we focus on whether the revised policy can control the renewable investment effectively to ease the government's financial burden and investigate its robustness in the electricity spot market.

With the intermittence of renewable resources into consideration, we model the FIT policies implemented in China in a mathematical representation of power market, which extends the investment model of power market reported by Murphy and Smeers (2007). In contrast to the analysis of Murphy and Smeers (2007), we add the renewable technology using intermittent resources to the power market. Based on the transaction mode of power market (open-loop or closed-loop model), we investigate the strategic capacity choices of power generators under the *FIT via fixed subsidy* policy and the *CFCC* policy. In addition, the *free competition* mechanism without incentive renewable policies and the *FIT via price premium* policy are also modified and submitted to the comparative analysis. Therefore, we model four policy schemes in the open-loop or closed-loop power market. Since there are multiple rational generators monopolizing the power market, some of them employ traditional technology whereas others employ renewable technology using intermittent resources, we assume that Cournot competition exists among the power generators. This assumption mirrors the power market in China, where five state-owned power plants have formed a long-term monopoly of the electricity supply since 2002.

This paper mainly refers to the literature on the investment strategy of power generators. Unlike most papers concerning the optimal technology selection [11] and coordination in the electricity industry [12], we concentrate on the impact of FIT policies on the renewable energy investment of power generators. In the electricity spot market, most studies have used a two-stage decision model to simulate the strategic capacity choices of power generators. For example, Tishler et al. constructed a two-stage model of the power market to examine the interdependence of equilibrium capacity, market price level, market price volatility and supply shortage caused by price capping [13]. Milstein and Tishler followed the aforementioned work and indicated that the introduction of renewable technology amplified market price volatility [14], and rational electricity generators' profit-seeking behavior was cited as a major reason for supply shortage [15]. Fred and Smeers studied the effect of forward markets on investment capacity by extending the two-stage model to three stages in an oligopolistic power market [16]. Gurkan et al. studied generation capacity investments and strategic generation capacity choice under perfect competition by assuming that the open-loop equilibrium and closed-loop equilibrium coincided [17,18]. Garcia et al. analyzed the impact of FIT policy and renewable portfolio standards on technology investment in a two-stage model [19]. In this paper, we also formulate a two-stage decision model of power generators in the electricity spot market. As the reform of power market deepens in China, we employ the closed-loop model to structure its future power spot transaction mode, and apply the open-loop model to formulate its existing power transaction mode organized by a Power Purchase Agreement.

Given the profound FIT policy implications, it is hardly surprising that it has attracted academic attention. Much of this work was in the economic analysis of the support projects using the net present value [20–22] or real options analysis [23,24]. But they do not allow for market power and competition from the traditional power generators. Over the past few decades, in power market field, the highly stylized models of electricity pricing and investment were formulated and have experienced relatively little progress [25], which fails to give sufficient thought to the difference between the traditional and renewable power-generation technology. In order to fill this gap, in this paper, we formulate an investment model of power market with intermittent resources. With the integration of power generation from renewable energy into the power market, we compare the impact of four policy schemes on the strategic capacity choices of power generators in the open-loop and closed-loop games, and get some instructional results for managers and policy makers.

In the open-loop game, equilibrium solutions exist under each policy scheme. We show that the *FIT via fixed subsidy* and *price premium* policy can effectively promote the renewable energy investment in theory compared with *free competition* mechanism. We then analyze the solutions in the closed-loop game under the four policies. A key result is that in the closed-loop game, generators

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