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Is RPS Any Better Than FIT? Analysis of Policy Effects in a Deregulated Power Market

Cengceng Liu[1,*], Nan Li[2], Qin Zhang[2]

[1]*School of Management Science & Engineering, Nanjing University of Finance & Economics, No. 3 Wenyuan Road, Xianlin University City, Nanjing, 210023, China*
[2]*College of Economics and Management, Nanjing University of Aeronautics and Astronautics, 29 Jiangjun Avenue, Nanjing 211106, China*
**Corresponding author. Email: liu_cengceng2016@163.com*

ABSTRACT
China implemented the Feed-in Tariff (FIT) policy in 2013, but now the Renewable Portfolio Standard (RPS) policy is in place in its deregulated power market. The FIT and RPS policy, as two most widely used renewable energy price policy, they both have successful and failure cases. This paper is aimed at presenting the function mechanism of these two renewable energy price policies in theory as well as the comparison of their policy effects. These two policies are modelled and introduced into the deregulated power market. The equilibrium results show that the government subsidy for renewable power with the FIT policy is more effective to promote the investment of renewable power and restrain the investment of traditional power. However, with the RPS policy, setting of the renewable power quota may be a challenge because it not only inhibits the investment of renewable but also the traditional power. In the comparison of the two policies in policy effects, we show that follow the FIT policy, the implementation of RPS policy will lead the power price increase, consumer surplus and social welfare decrease.

Keywords: *Renewable Energy Price Policy, Power Generators, Capacity Investment, Policy Effects.*

1. INTRODUCTION

China's energy structure adjustment has been achieved remarkable results during the 12th and 13th Five-Year period. By the end of 2020, China's renewable power generation capacity stood at 930 million kW, ranked the first in the world. There were 370 million kW installed capacity from hydropower, 280 million kW installed capacity from wind power, 250 million kW of installed capacity from solar power, and 29.52 million kW of installed capacity from biomass power. These achievements are mainly attribute to the implementation of FIT policy.

The FIT policy has been proved to be the most effective government incentive aimed at promoting installed capacity in a short time[1; 2]. The 2004 German Renewable Energy Act was an embryonic form of FIT policy. Its implementation has successfully raised German's renewable power capacity, investment quota and social employment[3]. As a result, the FIT policy was issued by 18 European Union countries in the next year. However, in light of their questions encountered and experiences accumulated in the development process of renewable energy, the FIT policy was emending and perfecting perpetually in different countries. In the development initial period, government aimed at a rapid application of renewable power, a higher feed-in tariff was generally adopted. As the investment cost changed of renewable power and technology innovation evoked by learning effects, the feed-in tariff was set decrease with time[4-6]. And to avoid overcompensation, a stepped or progressive feed-in tariff policy was also applied in some countries. Although a serious revision policies appeared in its implementation process, many scholars held a positive attitude about the incentive function of the FIT policy[7]. The effectiveness of FIT policy proved in European and American countries from the actual effect,, a definite feed-in tariff lowered the risk premiums of generators and volatility in energy prices[8-10].

In order to promote the development of marketing of renewable energy, mandatory quota policy i.e. RPS policy was issued in 2019 in China. The RPS policy, like the FIT policy, is one of the most widely used renewable energy price policies in energy field[8]. The RPS policy has been implemented over ten years in England, America and many other European countries. Now, it becomes an important market mechanism for promoting the development of renewable energy in lots of countries and regions[11]. Under the RPS policy, the quota of renewable power is the generators' legal obligation mandated by the government, and the market price of renewable power is decided by regulating action of power market in the market transaction[12]. Compared with the FIT policy, the RPS policy with a lower policy cost in Texas [13]. Berry and Jaccard proposed the implementation of RPS policy had a positive function in playing the function of market regulation and achieving the minimal government intervention[14].

Studies have differed on the effectiveness of the FIT and RPS policy. Generally, the countries with FIT policy have a higher renewable power generation efficiency than that with RPS policy. Which is corroborated by the successfully implemented FIT policy in Denmark, Germany and Spain. However, the FIT policy in Taiwan decreased the social welfare because renewable power generators bought traditional power to get more subsidies[15]. In the study of Garcia et al., neither of the FIT and RPS policy was capable of inducing the socially optimal levels of investment[16]. Considering the latency time, FIT policy is applicable for the initial exploration stage and RPS policy is applicable for the visicalc stage of renewable energy project[17; 18]. In practice, there are some successful and failure cases about the FIT and RPS policy. But both of them performed well only in limited countries. Sawin et al. compared these two policies used the case analysis and the results showed that for the FIT policy, Spain was a successful case but it was not effective in Italy, and for the RPS policy, Texas was a pioneer but they did not get the same or even better results in other American states[19]. Therefore, the debate about the superiority between the FIT and RPS policy is still an open problem.

This paper chooses the Chinese implemented FIT policy and the RPS policy at the early stage as the research objects. China implemented the FIT policy in 2013, and switched to the RPS policy in its deregulated power market. This is different with some European countries, who decided to transfer the RPS policy to FIT policy. It is necessary to clarify the policy effects and the resulting problems whatever the implementation order of the FIT and RPS policy. To predict the policy effects after implementation, empirical and theoretical research are commonly used methods. The case study or empirical analysis, from phenomenon to essence, requires an enormous amount of data to effectively support conclusion. This paper will use the theoretical analysis to reveal the function mechanism, policy effects of the FIT and RPS policy in the essence. By a theoretical derivation of generators' capacity investment, we get some issues that need concerns to government. Our analysis shows that although the government subsidy for renewable power with the FIT policy is more effective to promote the investment of renewable power and restrain the investment of traditional power. Interestingly, the renewable power quota with the RPS policy not only inhibits the investment of renewable, but also shows a negative correlation with the traditional power. In the comparation of the two policies in policy effects, we show that follow the FIT policy, the implementation of RPS policy will lead the power price increase, consumer surplus and social welfare decrease.

The structure of this paper is as follows. In the next section, we present the power market investment model with multiple power generators. The power market consists of several power generators employing traditional technology and several generators employing renewable technology with intermittent resources. Section 3 is the model equilibrium under three policy schemes. The policy effects are analyzed in section 4. The models in section 2 and 3 and policy effects in section 4 are characterized by experiment data in section 5. The paper is concluded in section 6.

2. MODEL

Assuming that there is M and N power generators respectively adopting renewable and traditional technology in the oligopoly market. Each generator only use one technology. Let p, Q respectively denotes the price and demand of power, the power demand function is

$$\mathrm{p} = \mathrm{a} - \mathrm{bQ}. \tag{1}$$

Under the assumption of market clearing, $\mathrm{Q} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{y}_{\mathrm{i}}^{\mathrm{T}} + \sum_{\mathrm{j}=1}^{\mathrm{M}} \mathrm{y}_{\mathrm{j}}^{\mathrm{R}}, (i = 1 \cdots N; j = 1 \cdots M)$. Where $\mathrm{y}_{\mathrm{i}}^{\mathrm{T}}$ denotes the power output of the i_th traditional generator and $\mathrm{y}_{\mathrm{j}}^{\mathrm{R}}$ denotes the power output of the j_th renewable generator. Parameters a, b are two known constants greater than zero.

According to Smeer's study, the spot power market is simulated by a two-stage model strictly in proper order, and the power market oriented by agreement is adapted to a one-stage model[20]. As China's power market mainly institutes Power Purchase Agreement, in the following we will formulate generators' decision model using the spirit of one-stage model.

At present, the main characteristic of fuel-burning power generators is that the cost of fuel-burning weights heavily in the total cost. This fact makes traditional generators with a relatively lower investment cost and higher operational cost. When the operational cost and investment cost of traditional technology, v^{T} and k^{T}, are all known, the i_th generator using traditional technology decides on the capacity investment $\mathrm{x}_{\mathrm{i}}^{\mathrm{T}}$ and power output $\mathrm{y}_{\mathrm{i}}^{\mathrm{T}}$ to maximize its profit. Given the power outputs and capacities of the other $\mathrm{N} + \mathrm{M} - 1$ generators, the profit of generator i is

$$
\begin{aligned}
&\text{Max} \quad \pi_i^T = (p^T - v^T)y_i^T - k^T x_i^T \\
&\text{s.t.} \quad y_i^T \le x_i^T \qquad (\lambda_i^T) \\
&x_i^T \ge 0 \qquad (\mu_i^T) \\
&y_i^T \ge 0 \qquad (\varpi_i^T)
\end{aligned} \tag{2}
$$

Notice that p^T denotes the sales income of each kilowatt hour of traditional power. Under the power market without energy policy and with the FIT policy, $p^T = p$, where p is the price of power. Under the RPS policy, $p^T = p - \phi\omega$, where ω is the price of green certificate, and ϕ is the renewable power quota mandated by the federal government. Traditional generators have to take a portion of their revenue to meet the government quota. With the RPS policy, ϕ of the total power output from renewable energy requires the traditional power generators to purchase an appropriate number of green certificates at a quantity of ϕy_i^T and price of ω. In addition, the first constraint condition is a reflection of the external expansion production of electrical industry. Generators' production is limited by their installation capacity. The constraint conditions $x_i^T \ge 0$, $y_i^T \ge 0$ reflect the non-negativity of the investment capacity and the power output of generators.

In terms of Chao's modeling of the intermittency of renewable power[21], the individual generation units were subjected to random failures or forced outages. Let a random variable $\tilde{x}_j^R$ denote the available investment capacity and $\psi(x)$ be a dimensionless random variable, representing the unit availability factor, distributed between 0 and 1. The stochastic dependence of the available capacity on the investment capacity x_j^R is formalized through the following integral: $\tilde{x}_j^R = \int_0^{x_j^R} \psi(x)dx$. Assuming $E\{\psi(x)\} = \tau_j$, which means the capacity of renewable technology consists of generating units with availability factor τ_j, independent of the investment capacity.

The status of renewable energy projects' construction and operation indicates the major characteristics of renewable power project are the high investment costs and low operational costs in the formal run after completion of the project. The widespread presence and free use of renewable energy in the environment make the operational costs of renewable power near zero. In realizing the cost structure, the operational cost of renewable power are far below its investment cost, i.e. $v^R < k^R$. Let p^R be the sales income of each kilowatt hour of renewable power. With the gross profit minus the total operating cost and investment cost, the objective of the j_th renewable power generator is to maximize its profit by deciding the investment capacity and power output.

$$
\begin{aligned}
&\text{Max}\, \pi_j^R(y_j^R) = (p^R - v^R)y_j^R - k^R x_j^R \\
&\text{s.t.} \quad y_j^R \le \tilde{x}_j^R = \int_0^{x_j^R} \psi(x)dx \quad (\lambda_j^R) \\
&x_j^R \ge 0 \qquad (\mu_j^R) \\
&y_j^R \ge 0 \qquad (\varpi_j^R)
\end{aligned} \tag{3}
$$

Under the power market without energy policy, $p^R = p$. Notice that with FIT policy, governments are involved in renewable power though input subsidies. Let t be the government subsidy for each unit of the renewable power, thus $p^R = p + t$. For each unit renewable power with the RPS policy, p is the operational income from power transaction and ω is the operational income from green certificates trading. Because of ϕ of the total renewable power satisfying the government quota, $p^R = p + (1 - \phi)\omega$ under the RPS policy. Additionally, the first constraint condition of model (3) reflects not only the external expansion production of electrical industry, but also the availability of renewable energy. The second and third constraint condition of model (3) is a reflection of the non-negativity of the investment capacity and power output of renewable generators.

Assuming the Cournot competition among generators, they have complete information about the entire game. With this assumption, their equilibrium investment capacity and power output are predictable, and we denote them by $x_i^{T*}, x_j^{R*}, y_i^{T*}, y_j^{R*}$. Superscripts F，E respectively identifies under the FIT and RPS policy supervised.

3. EQUILIBRIUM OF THE MODEL

Establish the Lagrange function of the optimization problem (2) and (3), and solve the differential of this Lagrange function respects to the unknown parameters, the KKT conditions are obtained of the following forms.

KKT conditions in a market without energy price policy

$$
\begin{aligned}
&x_i^{T*} \perp \left(k^T - \lambda_i^{T*} - \varpi_i^{T*}\right); \\
&y_i^{T*} \perp \left(2by_i^{T*} + b\left(\textstyle\sum_{-i}^{N} y_i^T + \sum_{j=1}^{M} y_j^R\right) + v^T + \lambda_i^{T*} - \mu_i^{T*} - a\right); \\
&\lambda_i^{T*} \perp \left(x_i^{T*} - y_i^{T*}\right);\ \mu_i^{T*} \perp y_i^{T*};\ \varpi_i^{T*} \perp x_i^{T*} \\
&x_j^{R*} \perp \left(k^R - \lambda_j^{R*} - \varpi_j^{R*}\right); \\
&y_j^{R*} \perp \left(2by_j^{R*} + b\left(\textstyle\sum_{i=1}^{N} y_i^T + \sum_{-j}^{M} y_j^R\right) + v^R + \lambda_j^{R*} - \mu_j^{R*} - a\right); \\
&\lambda_j^{R*} \perp \left(E\{\textstyle\int_0^{x_j^{R*}} \psi(x)dx\} - y_j^{R*}\right);\ \mu_j^{R*} \perp y_j^{R*};\ \varpi_j^{R*} \perp x_j^{R*}
\end{aligned} \tag{4}
$$

By solving the KKT conditions corresponded to formula (4), solutions to the model (2) and (3) under the power market without energy price policy is obtained. The equilibrium solution is as follows.

$$
\begin{aligned}
&x_i^{T*} = y_i^{T*} = \frac{a-(M+1)(v^T+k^T)+M\left(v^R+k^R/\tau_j\right)}{b(M+N+1)} \\
&E\left\{\int_0^{x_j^{R*}} \psi(x)dx\right\} = y_j^{R*} = \frac{a+N(v^T+k^T)-(N+1)\left(v^R+k^R/\tau_j\right)}{b(M+N+1)}
\end{aligned} \tag{5}
$$

Similarly, equilibrium solutions of the model (2) and (3) with FIT policy are obtained of the following form.

$$
x_i^{T*F} = y_i^{T*F} = \frac{a-(M+1)(v^T+k^T)+M\left(v^R+k^R/\tau_j\right)-Mt}{b(M+N+1)}
$$

$$E\left\{\int_0^{x_j^{R*F}} \psi(x)dx\right\} = y_j^{R*F} = \frac{a+N(v^T+k^T)-(N+1)\left(v^R+{k^R}/{\tau_j}\right)+(N+1)t}{b(M+N+1)} \quad (6)$$

Equilibrium solutions with RPS policy are

$$x_i^{T*E} = y_i^{T*E} = \frac{a-(M+1)(v^T+k^T)+M\left(v^R+{k^R}/{\tau_j}\right)-(M+\phi)w}{b(M+N+1)}$$

$$E\left\{\int_0^{x_j^{R*E}} \psi(x)dx\right\} = y_j^{R*E} = \frac{a+N(v^T+k^T)-(N+1)\left(v^R+{k^R}/{\tau_j}\right)+(N+1-\phi)w}{b(M+N+1)} \quad (7)$$

In all three cases: The equilibrium solutions show that when the generators' profit is maximized, whose investment power units are all in full load. The investment capacity and the power output is dominated by the investment cost and operational cost. The increase of investment and operational cost of traditional technology is beneficial to enhance power output/investment capacity of renewable technology. The increase of investment and operational cost of renewable technology is beneficial to enhance power output/investment capacity of traditional technology, and vise versa. The availability of renewable technology has an impact not just on the power output of renewable technology but also on the traditional technology. The higher the availability of renewable technology is, the higher the investment capacity of renewable technology is and the lower the investment capacity of traditional technology is.

By comparing the market equilibrium without energy price policy and with FIT policy (Eq. 5 and Eq. 6), the government subsidy for renewable technology increases the power output/investment capacity of renewable technology and decreases the power output/investment capacity of traditional technology. Viewing from the power industry, the implementation of FIT policy increased the power output and the increased amount is $\frac{Mt}{b(M+N+1)}$. According to the power supply and demand principle, this may cause a decline in power prices when compared to the market mechanism without energy price policy. Similarly, the comparison of equilibrium solutions without energy price policy and with RPS policy (Eq. 5 and Eq. 7), the existence of policy parameters ω, ϕ increases the power output/investment capacity of renewable technology and decreases the power output/investment capacity of traditional technology. But this effects of increased the power output/investment capacity on the power industry is uncertain, compared to the power market mechanism. It is determined by the number of power generators M, N.

4. INFLUENCE MECHANISM AND POLICY EFFECTS

In this section, we first analyze the influence mechanism of energy price policy. On this basis, we clarify the effects of renewable energy price policies when they are implemented in the order from the market mechanism without renewable energy price policy to FIT policy to RPS policy.

4.1. The Influence Mechanism of Renewable Energy Price Policy

Note from Eq. (6) that both the traditional and renewable generators' investment capacity under the FIT policy are related to the government subsidy t. Explore the first-order derivative of the investment capacity of traditional generator, renewable generator and the power industry with respect to the government subsidy t

$$\frac{dx_i^{T*F}}{dt} = -\frac{M}{b\,(M+N+1)} < 0\,;\ \frac{dx_j^{R*F}}{dt} = \frac{N+1}{b(M+N+1)\tau_j} > 0;$$

$$\frac{d(Nx_i^{T*F}+Mx_j^{R*F})}{dt} = \frac{MN(1-\tau_j)+M}{b(M+N+1)\tau_j} > 0 \quad (8)$$

In terms of formula (8), it can be concluded that with the FIT policy, the higher the government subsidy, the more investment capacity will be installed by renewable generators and the less investment capacity will be installed by traditional generators, which ultimately increases the investment capacity of the power industry.

With the RPS policy, Eq. (7) shows the generators' investment capacity associates with renewable power quota and green certificate price. Explore the first partial derivatives of the investment capacity versus renewable power quota ϕ and green certificate price w respectively.

$$\frac{\partial x_i^{T*E}}{\partial w} = -\frac{M+\phi}{b(M+N+1)} < 0;\ \frac{\partial x_j^{R*E}}{\partial w} = \frac{N+1-\phi}{b(M+N+1)\tau_j} > 0;$$

$$\frac{\partial\left(Nx_i^{T*E}+Mx_j^{R*E}\right)}{\partial w} = \frac{MN(1-\tau_j)+M(1-\phi)-N\phi\tau_j}{b(M+N+1)\tau_j}$$

$$\frac{\partial x_i^{T*E}}{\partial \phi} = -\frac{w}{b(M+N+1)} < 0;\ \frac{\partial x_j^{R*E}}{\partial \phi} = -\frac{w}{b(M+N+1)\tau_j} < 0;$$

$$\frac{\partial(Nx_i^{T*E}+Mx_j^{R*E})}{\partial \phi} = -\frac{w(N\tau_j+M)}{b(M+N+1)\tau_j} < 0 \quad (9)$$

Aiming at the green certificate price changes, the above results show that the higher the green certificate price, the more investment capacity will be installed by renewable generators and the less investment capacity will be installed by traditional generators. However, the impact of the green certificate price on the investment capacity of the power industry is not certain, whose increase or decrease is lied on the number of renewable and traditional generators (M and N). For the renewable power quota, the higher renewable power quota set by government, the less investment capacity installed by renewable and traditional generators, which ultimately results in the decrease of the whole power industry's investment capacity.

4.2. The Policy Effects between the FIT and RPS Policy

According to the applicability of energy price policy, FIT policy is suited for encouraging earlier investment.

As investment being undertaken, RPS policy creates incentives for later investment. In the analysis of policy effects of energy price policy, we will follow the implementation sequence: market mechanism without energy price policy, FIT policy and RPS policy. We define the policy effects including the changes of power price, consumer surplus and social welfare. Compared with welfare effects, the analysis of power price is added.

Scenario one: the power market shifts to implement FIT policy from market mechanism

On the basis of the equilibrium solutions under market mechanism and FIT policy, the power price under FIT policy is $p^{*F} = a - b(Ny_i^{T*F} + My_j^{R*F})$, while the power price under market mechanism is $p^* = a - b(Ny_i^{T*} + My_j^{R*})$. Take the equilibrium solutions (6) and (5) into p^{*F} and p^* and compare them, then

$$p^{*F} - p^* = b\left(Ny_i^{T*} + My_j^{R*}\right) - b\left(Ny_i^{T*F} + My_j^{R*F}\right) = \frac{-Mt}{(M+N+1)} < 0 \tag{10}$$

Hence, the implementation of FIT policy in the power market makes the power price decrease.

The consumer surplus under FIT policy is $CS^{*F} = \frac{1}{2}b(Ny_i^{T*F} + My_j^{R*F})^2$. Similarly, the consumer surplus under market mechanism is $CS^* = \frac{1}{2}b(Ny_i^{T*} + My_j^{R*})^2$. Take the equilibrium solutions (6) and (5) into CS^{*F}, CS^* and compare them, then

$$CS^{*F} - CS^* = \frac{1}{2}\left(\frac{Mt}{M+N+1}\right)\left(Ny_i^{T*F} + My_j^{R*F} + Ny_i^{T*} + My_j^{R*}\right) > 0 \tag{11}$$

This indicates the implementation of FIT policy make the consumer surplus increase.

The social welfare under FIT policy is $W^{*F} = CS^{*F} + N\pi_i^T(y_i^{*F}) + M\pi_j^R(y_j^{*F})$. The social welfare under market mechanism is $W^* = CS^* + N\pi_i^T(y_i^*) + M\pi_j^R(y_j^*)$. Take the equilibrium solutions (6) and (5) into W^{*F}, W^*. Then,

$$W^{*F} - W^* = \frac{1}{2}b\left(\frac{Mt}{M+N+1}\right)\left[(M + 2N + 2)\left(y_j^{R*F} + y_j^{R*}\right) - N(y_i^{T*F} + y_i^{T*})\right] \tag{12}$$

Clearly, when the FIT policy implements in the power market, this change will bring the power price decline and consumer surplus increase. However, the impact of this policy measure on social welfare is uncertain but determined by the parameter values. When the parameter values satisfy $(M + 2N + 2)\left(y_j^{R*F} + y_j^{R*}\right) > N(y_i^{T*F} + y_i^{T*})$, the implementation of FIT policy will brings the social welfare increase; while when the parameter values satisfy $(M + 2N + 2)\left(y_j^{R*F} + y_j^{R*}\right) < N(y_i^{T*F} + y_i^{T*})$, the implementation of FIT policy will leads the social welfare decrease.

Scenario two: the power market shifts to implement RPS policy from FIT policy.

When comparing the two policies from policy effects, it is need to establish an unified standard for comparation. As the aim of implementing energy price policy is to accelerate the application of renewable power, it is reasonable that setting to achieve the same amount of renewable power output as the premise of the comparison between the FIT and RPS policy. Through calculation to the Eq. (6) and Eq. (7), policy variables satisfying $\phi = (N + 1)\left(1 - \frac{t}{w}\right)$, $\left(\frac{N}{N+1} < \frac{t}{w} < 1\right)$ makes that premise founded, i.e. $x_j^{R*F} = x_j^{R*E}$,. $y_j^{R*F} = y_j^{R*E}$.

With the RPS policy, the power price expression is $p^{*E} = a - b\left(Ny_i^{T*E} + My_j^{R*E}\right)$. Substitute the equilibrium solution $y_i^{T*F}, y_j^{R*F}, y_i^{T*E}, y_j^{R*E}$ into p^{*F}, p^{*E}, then

$$p^{*F} - p^{*E} = \frac{[M(1-\phi) - N\phi]w - Mt}{M+N+1} \tag{13}$$

Notice that $\phi = (N + 1)\left(1 - \frac{t}{w}\right)$, thus $p^{*F} - p^{*E} = \frac{-N\phi}{N+1} < 0$. That is, $p^{*F} < p^{*E}$. It is determined that compared with the FIT policy, the implementation of RPS policy will lead to higher power price.

For the consumer surplus, its expression with the RPS policy is $CS^{*E} = \frac{1}{2}b(Ny_i^{T*E} + My_j^{R*E})^2$. Then

$$CS^{*F} - CS^{*E} = \frac{1}{2}b\{N(y_i^{T*F} - y_i^{T*E})(Ny_i^{T*F} + Ny_i^{T*E} + 2My_j^{R*E})\} \tag{14}$$

Because of $y_i^{T*F} - y_i^{T*E} = \frac{\phi w}{b(N+1)} > 0$, $CS^{*F} - CS^{*E} > 0$ is derived. Which shows that compared with the FIT policy, the implementation of RPS policy will lower the consumer surplus.

For the social welfare, its expression with the FIT policy is

$$W^{*F} = \frac{1}{2}b\left(Ny_i^{T*F} + My_j^{R*F}\right)^2 + Nb\left(y_i^{T*F}\right)^2 + Mb\left(y_j^{R*F}\right)^2 \tag{15}$$

And its expression with the RPS policy is

$$W^{*E} = CS^{*E} + N\pi_i^{T*E}(x_i^{T*E}) + M\pi_j^{R*E}(x_j^{R*E})$$
$$= \frac{1}{2}b(Ny_i^{T*E} + My_j^{R*E})^2 + Nb(y_i^{T*E})^2 + Mb(y_j^{R*E})^2 \tag{16}$$

Then, $W^{*F} - W^{*E} = Nb\left(y_i^{T*F} - y_i^{T*E}\right)\{y_i^{T*F} + y_i^{T*E} + \frac{1}{2}(Ny_i^{T*F} + Ny_i^{T*E} + 2My_j^{R*E})\}$. Because of $y_i^{T*F} - y_i^{T*E} = \frac{\phi w}{b(N+1)} > 0$, then $W^{*F} - W^{*E} > 0$. It is determined that compared with the FIT policy, the implementation of RPS policy will lower the social welfare.

Table 1. Investment capacity as a function of renewable quota

Renewable quota		0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Investment capacity (*E+09)	Coal-fired	3.306	3.300	3.294	3.288	3.282	3.276	3.270	3.264	3.258	3.252	3.246
	Solar	1.652	1.644	1.637	1.629	1.622	1.615	1.607	1.600	1.592	1.585	1.577
	Power industry	4.957	4.944	4.931	4.917	4.904	4.891	4.877	4.864	4.850	4.837	4.824

Comprehensively, with the same amount investment capacity of renewable power under the FIT and RPS policy, compared with the FIT policy, the implementation of RPS policy will raise the power price and lower the consumer surplus and social welfare. With the RPS policy, the quota of renewable power will lead to the decrease of power output of traditional generator. On the basis of the equal power output of renewable generator, the more power output with the FIT policy brings in a lower power price. Under the assumption of market clearing, purchasing the equal amounts of power, the consumer surplus with the FIT policy apparently is lower than that with the RPS policy. For the social welfare, besides the comparison of consumer surplus, the profits of generators are the other comparative factors. As government subsidy/green certificate price increase, the traditional power generators, subject to the quota of renewable power, whose power output growth always lower than that with the RPS policy. What's more, they still bear the profit output for mandatory quotas from government. With the equal investment capacity of renewable power, the profitability of renewable power generators with the RPS policy is also far below than the profitability of renewable power generators with the FIT policy. Combined with comparison results of consumer surplus, the social welfare with the FIT policy is higher.

5. NUMERICAL ILLUSTRATION

In this section, we present the numerical results to illustrate the policy effects using the following values: $\mathrm{a} = 1485$, $\mathrm{b} = 2.85 \times 10^{-7}$, $v^T = 32.94\,\$/\mathrm{MWh}$, $k^T = 45.07\,\$/\mathrm{MWh}$, $v^R \approx 0$ and $k^R = 220\mathrm{M/MWh}$. We assume $\mathrm{N} + \mathrm{M} = 8$ (if without a special request, we set $\mathrm{N} = \mathrm{M}$ for the numerical illustration).The available factor for solar energy is assumed to be 0.8. Ignoring the other forms of power generation, traditional generators utilizes coal-fired generation technologies and renewable generators utilizes solar photovoltaic technology.

Fig. 1 presents the optimal investment capacity of the power industry as a function of the government subsidy t. The FIT policy was implemented in 2013 and the premium subsidy was $\mathrm{t} = 69\,\$/\mathrm{MWh}$. Under FIT policy, the government subsidy takes 69 as the initial value and gradually goes down to 0. As can be seen in Fig. 1, a decrease in the amount of government subsidy is accompanied by some falloff of investment capacity of renewable power and an increase of investment capacity of traditional power. The increase in government subsidy higher investment capacity of the power industry. When a measure to reduce government subsidy nearly to zero, the investment capacity then is that under the market mechanism without price policy.

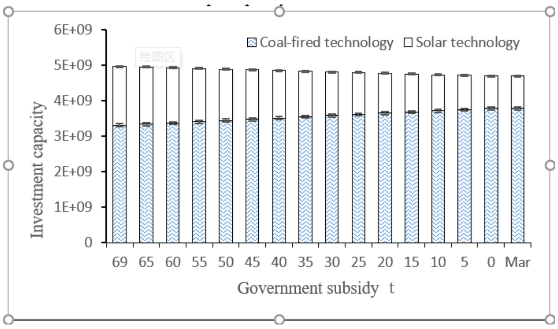

Figure 1 Investment capacity of as a function of government subsidy

Tab. 1 shows the effect of the value of renewable quota on the optimal investment capacity of each technology and the power industry, when $\emptyset \in (0{,}50\%)$. A higher value of renewable quota results in a lower investment capacity of coal-fired technology, solar technology and the power industry. That is, only elevating the renewable quota can not improve the investment capacity of renewable energy, and instead inhibits the investments on each technology and the whole power industry.

Fig. 2 presents the industry's investment capacity as a function of the price of green certificate, when $\phi = 10\%$. The increase of green certificate price higher the investment capacity of solar technology and lower that of coal-fired technology. At the same time, the increase rates of solar technology is more than the decrease rates of coal-fired technology, which eventually an increase in the total investment capacity of the power industry. When $\mathrm{w} = 0$, the whole and its composition of the industry's investment capacity nearly are approximately equal to that under the market mechanism. When $\mathrm{w} \approx \mathrm{t}$, the whole and its composition of the industry's investment capacity nearly are approximately equal to that under the FIT policy.

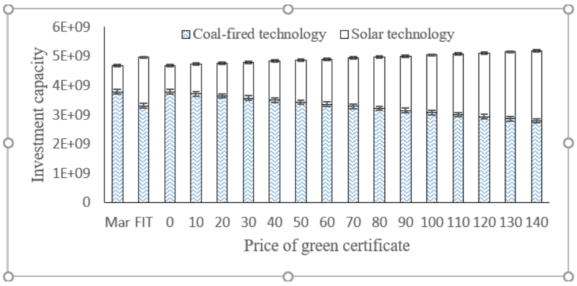

Figure 2 Investment capacity as a function of green certificate price

Tab. 1 and Fig. 2 show that under the RPS policy, the investment incentives of renewable power mainly depend on the measure of trading green certificates. Both the measures of setting renewable quota and trading green certificates will inhibit the investments on traditional power. That is, the successful implementation of RPS policy must incorporate other measures similar to trading green certificates.

Next, we will compare the policy effects under the market mechanism, FIT policy and RPS policy. Consider the comparison premise between the FIT and RPS policy, we set $w = t + 0.8$ satisfying $\phi = (N+1)\left(1 - \frac{t}{w}\right)$, $(\frac{N}{N+1} < \frac{t}{w} < 1)$ when $t \in (0{,}150)$. The power price, consumer surplus or social welfare under market mechanism, irrelevant to government subsidy/green certificate price, is plotted by a solid line parallel with the horizontal axis.

Fig. 3 displays the power price changes under the market mechanism, FIT policy and RPS policy. The power price under FIT policy is lower than that under market mechanism and RPS policy. That is, the implementation of FIT policy in the power market will decrease the power price. And with the policy transform from FIT policy to RPS policy, it will increase the power price.

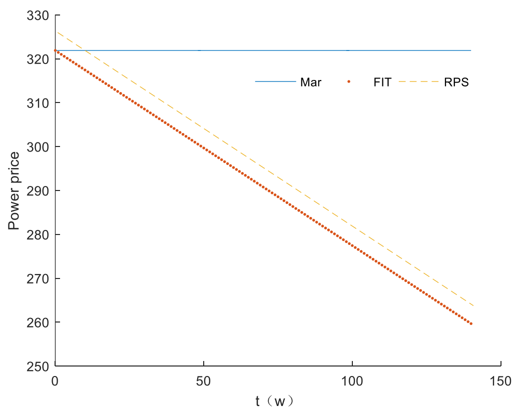

Figure 3 Power price variations

Fig. 4 shows the consumer surplus under market mechanism, FIT policy and RPS policy. Benchmarked the FIT policy, the market mechanism and RPS policy has a lower consumer surplus. That is, the implementation of FIT policy in the power market will increase the consumer surplus. And with the policy transform from FIT policy to RPS policy, it will decrease the consumer surplus.

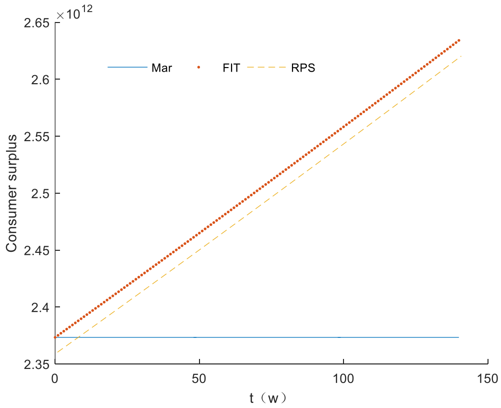

Figure 4 Consumer surplus variations

Fig. 5 presents the social welfare changes under that three cases. The effect of implementation FIT policy in the market mechanism is uncertain to the social welfare. It is determined by the value of government subsidy. When the RPS policy becomes an alternative to FIT policy and achieves the same incentive effects on renewable energy, social welfare under the RPS policy is lower than that under the FIT policy.

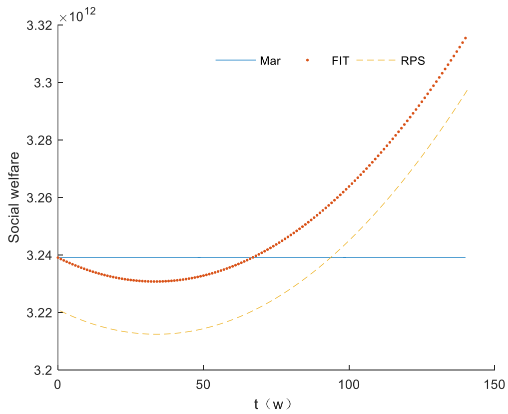

Figure 5 Social welfare variations

6. CONCLUSION

This paper mainly focuses on policy effects of energy price policy. That is how about influence mechanisms of energy price policy, and how will energy price policy change impact the power price, consumer surplus and social welfare? To answer these questions, we formulate an investment model with endogenous capacity and operations to assess the outlook and proactivity of renewable energy price policy in the deregulated power market. We start by the intermittence of renewable technology to different the traditional generators and renewable generators. Based on the determined demand function, we are able to derive the equilibrium solution under the market mechanism without energy price policy, with FIT policy and RPS policy. We then obtain the influence mechanisms of FIT and RPS policy. With the energy price policy changes from market mechanism to FIT policy to RPS policy, the impact on power price, consumer surplus and social welfare is concluded. And finally the numerical experiments are given to illustrate the validity of the analysis.

This paper shows that the government subsidy under the FIT policy is higher and higher the capacity investment in the power market. Consequently, the power price is lower and consumer surplus higher than that under market mechanism when there exists a government subsidy for renewable power. One interesting result under the RPS policy is the renewable quota regulated by the government will inhibit all the capacity investment on power technology. Compare with the FIT policy, the implementation of RPS policy will increase the power price and decrease the consumer surplus and social welfare based on the same incentive effects on renewable power.

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