Hindawi Publishing Corporation
Journal of Applied Mathematics
Volume 2013, Article ID 368296, 9 pages
http://dx.doi.org/10.1155/2013/368296

Research Article

A Comparative Study of Renewable Energy Industry Regulation on Feed-In Tariffs Based on Pricing Strategy of Value Standard Method

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Received 16 July 2013; Accepted 27 August 2013

Academic Editor: X. Henry Wang

Based on pricing strategy of value standard method, we establish a three-stage game model of energy production to compare the differences of optimal regulated price and social welfare under three regulation types of feed-in tariffs. We show that the optimal price levels under three main regulation types are different. But the choice of regulation type does not impact the optimal social welfare. So policymakers with different preferences may make regulation decisions in different ways. This successfully explains why many regulation types exist in different countries. Moreover, although it is difficult to determine the optimal price by the value standard method in practice, the conclusions of this paper also provide a judgment criterion for other pricing strategies on how to choose a suboptimal regulation type.

1. Introduction

Renewable energy sources (RES) are considered to be the best substitution energy when we face increasing energy demand and higher environmental goals. The renewable energy industry (REI) is immature yet because of the immaturity of technology, uncertainty of investment risk, and weakness of market competition. Therefore, the related regulatory policies will play a significant role in the rapid development of REI.

Feed-in tariffs (FITs) are the most widely used method to stimulate rapid development of RES and are currently implemented in 63 countries and regions worldwide [1–5]. Compared with other regulatory policies (CBP, RO/RPS, RES-E, etc.), FITs are regarded as the most effective policy to attract venture capital, stimulate innovation, and build market platform [6–10].

In this paper, we establish a three-stage game model of energy production to compare the differences of optimal regulated price and social welfare under three regulation types of feed-in tariffs. We show that the optimal price levels under three main regulation types are different. The optimal regulated price must correspond with regulation type; otherwise the social welfare surely will lead to loss. Policymakers with different preferences may make regulation decisions in different ways. That is why so many types of FITs are adopted in different countries.

The choice of regulation type and the price strategy are the two core issues of FITs. The basic pricing methods of FITs include the cost-plus method (CPM) and the value standard method (VSM). CPM is similar to average-cost method, which equals to the cost plus a certain amount of investment returns. The advantage of CPM lies in the simplicity of estimation and reasonableness of investment return. But this method cannot embody the whole value of emission reductions, environmental effects, and social preferences [11]. The VSM tries to solve these problems. It takes into account the negative externality (negative externality include climate, air and energy security, etc.) by the consumption of traditional fossil energy and solves the market failure effectively [2, 12]. This paper further employs the VSM.

In practice, there are many types of FIT policies. In general, they can be summarized as market-dependent and market-independent FIT models [1]. And the advantages and disadvantages of every type are analyzed in the existing literature. But most scholars pay less attention on the comparison of different types of FIT policies. When face with different market conditions, there is no common view of which type of FIT policies is better than others. And there is no explanation why so many types of FIT policies exist in many different countries and regions in existing researches.

That is our writing motivation. In this paper, we provide a theoretical basis on how to choose the level and type of regulated price based on the pricing strategy of value standard. Based on three main types of FIT policies, we compare their optimal regulated price, government expenditure, and social welfare.

This paper is organized as follows. In Section 2, the models of three main regulation types are established. The analysis of equilibrium solutions is presented in Section 3. In Section 4, numerical simulation and comparative analysis are addressed, including regulated price, government expenditure, and social welfare. The application conditions of different types of FITs are also investigated. Concluding remarks are offered in the final section.

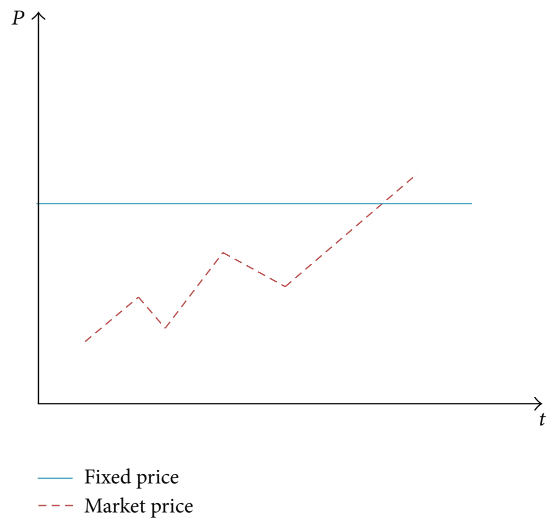

Figure 1: Fixed price model for FIT policy design.

2. The Model

There are two firms, R and D, in an industry. Firm R generates electricity by renewable energy such as wind power, solar power, and biomass power. Firm D produces electricity by fossil energy such as coal, oil, and gas. For the negative externality of fossil energy consumption, public authorities need to give a support price to the renewable energy firm R to achieve welfare maximization. In practical terms, there are three main types of FIT prices: fixed price, constant-premium price, and variable-premium price. We will build three models, respectively, to compare the differences under the three regulation types.

2.1. Fixed Price Model for FIT Policy Design (F Tool). Fixed price means that the regulated price is independent of the market price (as shown in Figure 1). Under this type, the renewable energy firm (firm R) gains constant subsidies with no risk.

The profit function of firm R is (the superscript "F" of variables represents fixed price tool (F tool), similarly hereinafter)

$$\pi_R^F = \overline{P}^F Q_R^F - c_R \left(Q_R^F\right)^2, \quad (1)$$

where Q_R^F is the electricity energy output of the renewable energy firm, $\overline{P}^F$ is the regulated price which is irrelevant with market price, c_R is a constant and stands for the cost coefficient, and $c_R(Q_R^F)^2$ is the total production cost which means decreasing returns to scale. The price of the fossil energy firm depends on market scale and electricity energy outputs of both energy firms. We assume that there exists no difference between the electricity energy products of the two energy firms. So the profit function of the fossil energy firm (firm D) is

$$\pi_D^F = \left(\alpha - Q_R^F - Q_D^F\right) Q_D^F - c_D \left(Q_D^F\right)^2, \quad (2)$$

where $\alpha - Q_R^F - Q_D^F$ is the market price and $\alpha > 0$ is a constant and represents the market size. $c_D(Q_D^F)^2$ is the total production cost of fossil energy firm. Consumer surplus contains two parts: the consumption of both firms' electricity energy subtracted by the negative externality from consuming fossil energy. That is,

$$\begin{aligned} \mathrm{CS}^F &= \left[\int_0^{Q_D^F + Q_R^F} \left(\alpha - Q_D^F - Q_R^F\right) d\left(Q_D^F + Q_R^F\right) \right. \\ &\quad \left. - \left(\alpha - Q_G^F - Q_R^F\right)\left(Q_D^F + Q_R^F\right) \right] - \gamma \left(k Q_D^F\right)^2 \\ &= \frac{1}{2}\left(Q_D^F + Q_R^F\right)^2 - \gamma\left(k Q_D^F\right)^2, \end{aligned} \quad (3)$$

where $f(Q_D) = \gamma(kQ_D^G)^2$ is pollution damage function. It is quadratic form of total pollutant emissions [13]. And we have $\partial f(Q_D)/\partial Q_D > 0$ and $\partial^2 f(Q_D)/\partial Q_D^2 > 0$, which mean the negative externality of damage increases incrementally with the increase of fossil energy consumption. kQ_D is the pollutant emissions when consuming fossil energy, $k \in [0, 1]$ is a constant and represents energy emission intensity. γ is the pollution damage coefficient. The bigger k and γ are, the higher negative externality is and the lower consumer surplus is. Government expenditure function is

$$\mathrm{GE}^F = \left[\overline{P}^F - \left(\alpha - Q_R^F - Q_D^F\right)\right] Q_R^F. \quad (4)$$

From (1)–(4), we get the social welfare function:

$$\begin{aligned} W^F &= \pi_R^F + \pi_D^F + \mathrm{CS}^F - \mathrm{GE}^F \\ &= \overline{P}^F Q_R^F - \left(c_R Q_R^F\right)^2 + \left(\alpha - Q_R^F - Q_D^F\right) Q_D^F \\ &\quad - \left(c_D Q_D^F\right)^2 + \frac{1}{2}\left(Q_D^F + Q_R^F\right)^2 - \gamma\left(k Q_D^F\right)^2 \\ &\quad - \left[\overline{P}^F - \left(\alpha - Q_R^F - Q_D^F\right)\right] Q_R^F. \end{aligned} \quad (5)$$

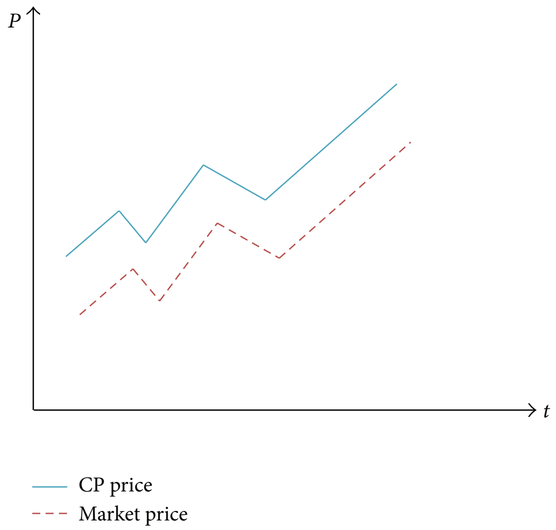

Figure 2: Constant-premium price model.

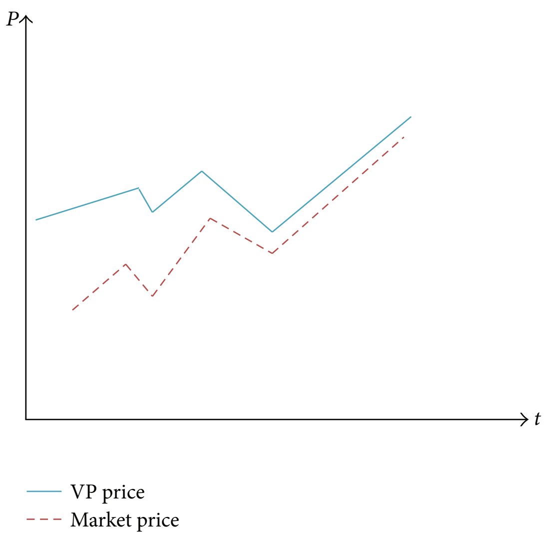

Figure 3: Variable-premium price model.

2.2. Constant-Premium Price Model for FIT Policy Design (CP Tool). If the government chooses a regulated price relevant to market price, there are two situations. One is constant-premium price (CP) (as shown in Figure 2); the other is variable-premium price (VP) (Figure 3). Under the two types, the final profits will fluctuate with the market environment. So the regulated level will be different with the F tools.

When the premium price is constant, we have the profit function of firm R:

$$\pi_R^{CP} = \left(\alpha - Q_R^{CP} - Q_D^{CP} + \varsigma\right) Q_R^{CP} - c_R\left(Q_R^{CP}\right)^2, \quad (6)$$

where ς is the level of constant-premium price. The corresponding profit function of firm D and government expenditure function are

$$\begin{aligned} \pi_D^{CP} &= \left(\alpha - Q_R^{CP} - Q_D^{CP}\right) Q_D^{CP} - c_D\left(Q_D^{CP}\right)^2, \\ GE^{CP} &= \varsigma Q_R^{CP}. \end{aligned} \quad (7)$$

Similar to (5), the social welfare function is

$$\begin{aligned} W^{CP} = {} & \left(\alpha - Q_R^{CP} - Q_D^{CP} + \varsigma\right) Q_R^{CP} - c_R\left(Q_R^{CP}\right)^2 \\ & + \left(\alpha - Q_R^{CP} - Q_D^{CP}\right) Q_D^{CP} - c_D\left(Q_D^{CP}\right)^2 \\ & + \frac{1}{2}\left(Q_D^{CP} + Q_R^{CP}\right)^2 - \gamma\left(kQ_D^{CP}\right)^2 - \varsigma Q_R^{CP}. \end{aligned} \quad (8)$$

2.3. Variable-Premium Price for FIT Policy Design (VP Tools). When the premium price is variable with the change of market, the situation is complex. For convenience sake, we just assume that the rate of change relative to market price is invariable. Assume the rate of change relative to market price is λ. The profit function of firm R is

$$\pi_R^{VP} = (1 + \lambda)\left(\alpha - Q_R^{VP} - Q_D^{VP}\right) Q_R^{VP} - c_R\left(Q_R^{VP}\right)^2. \quad (9)$$

Correspondingly, the profit function of firm D and government expenditure function are

$$\begin{aligned} \pi_D^{VP} &= \left(\alpha - Q_R^{VP} - Q_D^{VP}\right) Q_D^{VP} - c_D^{VP}\left(Q_D^{VP}\right)^2, \\ GE^{VP} &= \lambda\left(\alpha - Q_R^{VP} - Q_D^{VP}\right) Q_R^{VP}. \end{aligned} \quad (10)$$

And the social welfare function is

$$\begin{aligned} W^{VP} = {} & (1 + \lambda)\left(\alpha - Q_R^{VP} - Q_D^{VP}\right) Q_R^{VP} - c_R\left(Q_R^{VP}\right)^2 \\ & + \left(\alpha - Q_R^{VP} - Q_D^{VP}\right) Q_D^{VP} - c_D^{VP}\left(Q_R^{VP}\right)^2 \\ & + \frac{1}{2}\left(Q_D^{VP} + Q_R^{VP}\right)^2 - \gamma\left(kQ_D^{VP}\right)^2 \\ & - \lambda\left(\alpha - Q_R^{VP} - Q_D^{VP}\right) Q_R^{VP}. \end{aligned} \quad (11)$$

In order to ensure solution existence, we need to add an additional assumption.

Assumption 1. No matter what kind of regulated tool type, the precondition of government regulation is that the regulatory profit is bigger than the corresponding expenditure. That is,

(i) $\gamma(kQ_D^{F*})^2 > [(\overline{P}^{F*} - (\alpha - Q_R^{F*} - Q_D^{F*})]Q_R^{F*} > 0$ in F tool (the superscript "$*$" of variables represents Equilibrium solution. Similarly hereinafter),

(ii) $\gamma(kQ_D^{CP*})^2 > \varsigma^* Q_R^{CP*} > 0$ in CP tool;

(iii) $\gamma(kQ_D^{VP*})^2 > \lambda^*(\alpha - Q_R^{VP*} - Q_D^{VP*})Q_R^{VP*} > 0$ in VP tool.

This assumption ensures that the government gives the renewable energy firm a regulated price that is higher than market price.

In conclusion, we have built a three-stage game model that includes three parties: the government, a renewable energy firm, and a fossil energy firm. The timing of game decisions is given as follows: at the first stage, the government chooses the type and level of regulated price. Different regulation types will obtain different price levels. At the second stage, the renewable energy firm decides its production quantity of electricity. At the third stage, the fossil energy firm chooses electricity output.

3. Equilibrium Solution

The previous model is herein analyzed. We will use backward induction three times to solve three types of FIT policies and compare their differences, including regulated price level, government expenditure, and social welfare.

3.1. Equilibrium Solution of F Tool. By backward induction, the fossil energy firm is first considered. Taking derivative in (2) with respect to Q_D^F yields

$$Q_D^F = \frac{\alpha - Q_R^F}{2(1+c_D)}; \tag{12}$$

and by (1), we get

$$Q_R^F = \frac{\overline{P}^F}{2c_R}. \tag{13}$$

So (12) can be changed to

$$Q_D^F = \frac{\alpha - Q_R^F}{2(1+c_D)} = \frac{2\alpha c_R - \overline{P}^F}{4c_R(1+c_D)}. \tag{14}$$

And then through (1)–(4), we get the two firms' profits, consumer surplus, and government expenditure:

$$\begin{aligned}
\pi_R^F &= \frac{\left(\overline{P}^F\right)^2}{4c_R}, \\
\pi_D^F &= \frac{\left(2\alpha c_R - \overline{P}^F\right)^2}{16c_R^2(1+c_D)}, \\
\mathrm{CS}^F &= \frac{1}{2}\left[\frac{2\alpha c_R + (1+2c_D)\overline{P}^F}{4c_R(1+c_D)}\right]^2 - \gamma\left[k\frac{\left(2\alpha c_R - \overline{P}^F\right)}{4c_R(1+c_D)}\right]^2, \\
\mathrm{GE}^F &= \frac{\left[(4c_R + 2c_D + 4c_Rc_D + 1)\overline{P}^F - 2\alpha c_R(1+2c_D)\right]\overline{P}^F}{8c_R^2(1+c_R)}.
\end{aligned} \tag{15}$$

From (15), the social welfare is

$$\begin{aligned}
W^F = {} & \frac{(1+2c_D)\left(2\alpha c_R - \overline{P}^F\right)}{4c_R(1+c_D)} \cdot \frac{\overline{P}^F}{2c_R} - \frac{\left(\overline{P}^F\right)^2}{4c_R} \\
& + \frac{\left(2\alpha c_R - \overline{P}^F\right)^2}{16c_R^2(1+c_D)} + \frac{1}{2}\left[\frac{2\alpha c_R + (1+2c_D)\overline{P}^F}{4c_R(1+c_D)}\right]^2 \\
& - \gamma\left[k\frac{\left(2\alpha c_R - \overline{P}^F\right)}{4c_R(1+c_D)}\right]^2.
\end{aligned} \tag{16}$$

Taking derivative with respect to $\overline{P}^F$ yields the optimal regulated price

$$\overline{P}^{F*} = \frac{2\alpha c_R\left(2\gamma k^2 + 4c_D^2 + 6c_D + 1\right)}{2\gamma k^2 + 8c_R(1+c_D)^2 + (4c_D^2 + 6c_D + 1)}. \tag{17}$$

As shown in (17), the optimal regulated price under F tool $\overline{P}^{F*}$ is also the final support price by the government which depends on the values of α, c_R, c_D, γ, and k. The impact analysis of optimal price with the change of parameters will be discussed in Section 4.

3.2. Equilibrium Solution of CP Tool. Following similar lines, we achieve equilibrium solution of CP tool. From (6)–(8), we have

$$\begin{aligned}
Q_D^{\mathrm{CP}} &= \frac{(1+2c_R)\alpha - \varsigma}{4(1+c_R)(1+c_D) - 1}, \\
Q_R^{\mathrm{CP}} &= \frac{(1+2c_D)\alpha + 2(1+c_D)\varsigma}{4(1+c_R)(1+c_D) - 1}.
\end{aligned} \tag{18}$$

And the profits, consumer surplus, and government expenditure are

$$\begin{aligned}
\pi_R^{\mathrm{CP}} &= (1+c_R)\left[\frac{(1+2c_D)\alpha + 2(1+c_D)\varsigma}{4(1+c_R)(1+c_D) - 1}\right]^2, \\
\pi_D^{\mathrm{CP}} &= (1+c_D)\left[\frac{(1+2c_R)\alpha - \varsigma}{4(1+c_R)(1+c_D) - 1}\right]^2, \\
\mathrm{CS}^{\mathrm{CP}} &= \frac{1}{2}\left[\frac{2(1+c_D+c_R)\alpha + (1+2c_D)\varsigma}{4(1+c_R)(1+c_D) - 1}\right]^2 \\
&\quad - \gamma\left[k\frac{(1+2c_R)\alpha - \varsigma}{4(1+c_R)(1+c_D) - 1}\right]^2, \\
\mathrm{GE}^{\mathrm{CP}} &= \varsigma \cdot \frac{(1+2c_D)\alpha + 2(1+c_D)\varsigma}{4(1+c_R)(1+c_D) - 1}.
\end{aligned} \tag{19}$$

From (19), the social welfare is

$$\begin{aligned} W^{\mathrm{CP}} &= (1+c_D)\left[\frac{(1+2c_R)\alpha-\varsigma}{4(1+c_R)(1+c_D)-1}\right]^2 \\ &+ (1+c_R)\left[\frac{(1+2c_D)\alpha+2(1+c_D)\varsigma}{4(1+c_R)(1+c_D)-1}\right]^2 \\ &+ \frac{1}{2}\left[\frac{2(1+c_D+c_R)\alpha+(1+2c_D)\varsigma}{4(1+c_R)(1+c_D)-1}\right]^2 \\ &- \gamma\left[k\frac{(1+2c_R)\alpha-\varsigma}{4(1+c_R)(1+c_D)-1}\right]^2 \\ &- \varsigma\cdot\frac{(1+2c_D)\alpha+2(1+c_D)\varsigma}{4(1+c_R)(1+c_D)-1}. \end{aligned} \quad (20)$$

Taking derivative with respect to ς yields the optimal premium level

$$\varsigma^* = \frac{\alpha\left[2\gamma k^2(1+2c_R)-2c_R+4c_D^2+6c_D+1\right]}{2\gamma k^2+8c_R(1+c_D)^2+(4c_D^2+6c_D+1)}. \quad (21)$$

Comparing with (17), the optimal constant premium level ς^* in (21) and $\overline{P}^{F*}$ of F tool have the same denominator but different numerators. The final regulated price of CP tool is equal to market price plus premium level, that is, $\alpha - Q_R^{\mathrm{CP}*} - Q_D^{\mathrm{CP}*} + \varsigma^*$. It will be analyzed in detail in Section 4.

3.3. Equilibrium Solution of VP Tool. From (9)–(11), we have

$$\begin{aligned} Q_D^{\mathrm{VP}} &= \frac{(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}, \\ Q_R^{\mathrm{VP}} &= \frac{(1+\lambda)(1+2c_D)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}. \end{aligned} \quad (22)$$

And the profits, consumer surplus, and government expenditure are

$$\begin{aligned} \pi_R^{\mathrm{VP}} &= (1+c_R)\left[\frac{(1+2c_D)(1+\lambda)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right]^2, \\ \pi_D^{\mathrm{VP}} &= (1+c_D)\left[\frac{(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right]^2, \\ \mathrm{CS}^{\mathrm{VP}} &= 2\left\{\frac{[(1+\lambda)(1+c_D)+c_R]\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right\}^2 \\ &\quad - \gamma\left[k\frac{(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right]^2, \\ \mathrm{GE}^{\mathrm{VP}} &= \frac{\lambda(1+2c_D)(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)} \\ &\quad \cdot\frac{(1+\lambda)(1+2c_D)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}. \end{aligned} \quad (23)$$

From (23), the social welfare is

$$\begin{aligned} W^{\mathrm{VP}} &= \frac{(1+2c_D)(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)} \\ &\quad \cdot\frac{(1+\lambda)(1+2c_D)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)} \\ &\quad - c_R\left[\frac{(1+2c_D)(1+\lambda)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right]^2 \\ &\quad + (1+c_D)\left[\frac{(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right]^2 \\ &\quad + 2\left\{\frac{[(1+\lambda)(1+c_D)+c_R]\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right\}^2 \\ &\quad - \gamma\left[k\frac{(1+\lambda+2c_R)\alpha}{4(1+c_R+\lambda)(1+c_D)-(1+\lambda)}\right]^2. \end{aligned} \quad (24)$$

Taking derivative with respect to λ yields the optimal premium rate

$$\lambda^* = \frac{2\gamma k^2(1+2c_R)+4c_D^2+6c_D+1-2c_R}{4c_R(1+c_D)(1+2c_D)-2\gamma k^2-(4c_D^2+6c_D+1)}. \quad (25)$$

Comparing with (17) and (21), the difference of (25) is that the optimal variable premium rate λ^* is not relative to the market scale α. λ^* just depends on the value of c_R, c_D, γ, and k. And note that λ^* has the same numerator as ς^* in (21) except α. The final regulated price is $(1+\lambda^*)(\alpha - Q_R^{\mathrm{VP}*} - Q_D^{\mathrm{VP}*})$.

4. Numerical Simulation and Comparative Analysis

In Section 3, we obtained the optimal regulated price under three types of regulation tools. Because the expressions of optimal prices are complex, we compare the differences under the three regulation types by numerical simulation. We will give assignment to the parameters and obtain the path of numerical solution when the parameters change. All the program setting and graphic processing will be achieved by MATLAB 7.0.

4.1. The Comparison of Regulated Price. The level of regulated price reflects the government's support intensity for the renewable energy firm. The higher the regulated price is, the more quickly the REI develops and achieves energy substitution. So we compare the optimal regulated price of three tools firstly. For the sake of convenience in analysis, we just consider the changes of two parameters α (market scale) and c_R (cost coefficient of renewable firm). Other parameters will be set constant. Under the condition of Assumption 1, we stipulate that $c_D = 1, \gamma = 100$, and $k = 0.1$.

4.1.1. The Change of Market Scale α. We will consider the path of regulated price when market scale α lies in the interval of $[5, 15]$ and with $c_R = 2$.

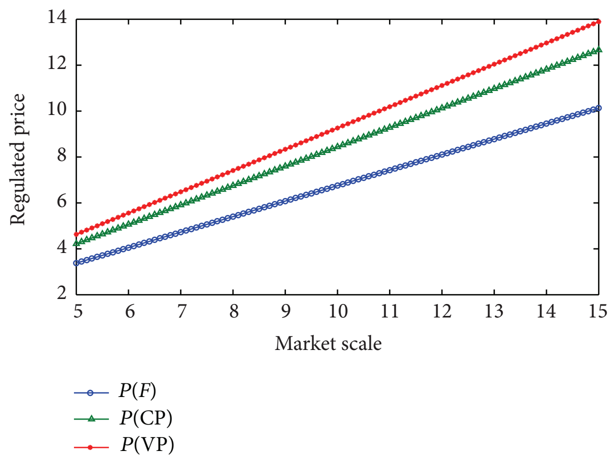

Figure 4: Three tools comparison of regulated price under the change of market scale α.

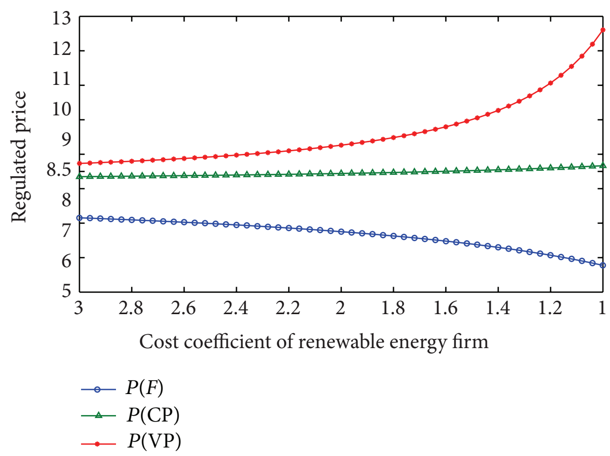

Figure 5: Three tools comparison on regulated price under the change of cost coefficient of renewable energy Firm c_R.

As shown in Figure 4, with the increase of market scale, the regulated price will increase under the three kinds of regulated price. Because when the market scale is larger, more electricity output by the fossil energy firm will be produced and more greenhouse gas (GHGs) will be discharged. It needs higher support price to renewable energy firm to achieve welfare maximization.

In addition, the optimal regulated price of VP tool is higher than the other tools. And the regulated price of F tool is the lowest. It reflects that the FITs tool of variable-premium price has the highest support intensity and REI will achieve development quickly.

Why do the three tools display different regulated prices? One possible reason is the risk difference. Under the fixed regulated price, the subsidy level of unit output is constant. The renewable energy firm will obtain stable profits and does not need to worry about the fluctuation of market price. So a relatively low regulated price will achieve welfare maximization. And under the CP and VP tools, the profits of the renewable energy firm fluctuate with market price. So the firm has to undertake the market risk when demand contracts. The VP tool has the biggest risk and need to the highest regulated price.

4.1.2. The Change of Cost Coefficient of Renewable Energy Firm c_R. The cost coefficient c_R reflects the production efficiency of the renewable energy firm. The lower c_R is, the higher production efficiency is. With the development of REI, production efficiency shows an increasing trend. So we consider the path of regulated price when cost coefficient c_R in the interval of $[3, 1]$ and with $\alpha = 10$.

As shown in Figure 5, with the decrease of cost coefficient c_R, different regulated tools show very different paths. The price of F tool decreases gradually, and the price of VP tool increases. The price of CP tool increases inapparently. Why different tools display different price paths? We show that the impact of improved production efficiency to regulated price has two opposite effects: (i) the optimal regulated price design must balance two parts of efficiency loss. One is the negative externality by the fossil energy firm; the other is low production efficiency of the renewable energy firm. With the improvement of production efficiency, the government has the trends to support the renewable energy firm more and increase the regulated price. This effect can be defined as relative efficiency effect (REE). (ii) On the other hand, the government has to pay the cost of regulated price. And the higher production efficiency is, the more profits the renewable energy firm makes. So the government has a motivation to lower the support price and reduce expenditure. It can be defined as efficiency improvement effect (EIE). The final change of regulated price depends on the two opposite effects. We find that EIE is bigger than REE under the F tool. So the regulated price drops off gradually. And the regulated price increases gradually under the VP tool because EIE is smaller than REE. Under the CP tool, EIE is close to REE. So the regulated price changes a little.

4.2. The Comparison of Government Expenditure. In practice, government expenditure of REI regulation is also a significant consideration. Noticeably, social welfare is the uppermost concern by the public and economists, but how to maximize the social welfare with the lowest expenditure is the favorite subject by government, especially when the government faces a budget constraint. So we will compare the government expenditure of the three regulation tools when parameters change.

As shown in Figures 6 and 7, government expenditure is always the lowest under the F tool and the highest under the VP tool. With the increase of market scale, government expenditure will rise under the three kinds of regulated price. Because the bigger market scale is, the more electricity outputs of the two firms and the higher expenditure are. And with the decrease of cost coefficient c_R, government expenditure also increases. The reason is that EIE is always less than REE. So the lower cost coefficient is, the higher expenditure is.

But the changes in range under the three tools are very different. The F tool is the most stable whatever the change of

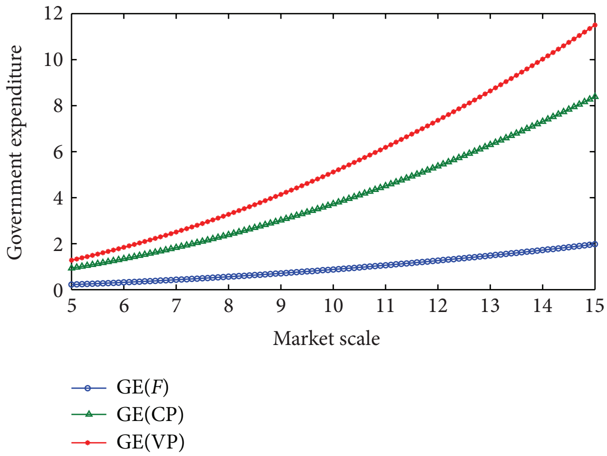

Figure 6: Three tools comparison on government expenditure under the change of market scale α.

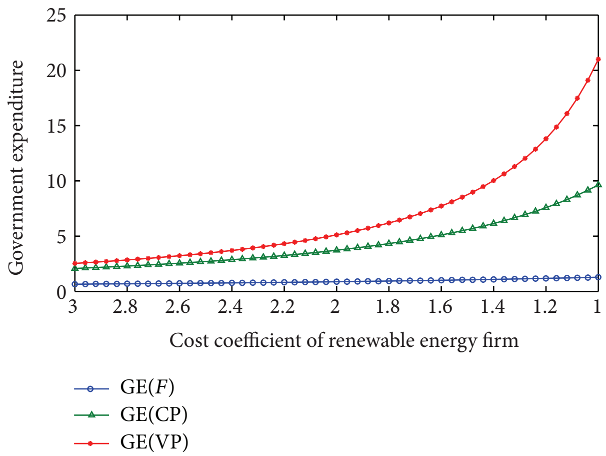

Figure 7: Three tools comparison on government expenditure under the change of cost coefficient of renewable energy firm c_R.

α or c_R and VP tool's fluctuation is the biggest. This reflects that the expenditure of F tool is low and stable and the government need not concern with the problem of budget constraint when the situation of market and/or firm changes. But under the VP/CP tool, the government has to consider the changes of expenditures in the future.

4.3. The Comparison of Social Welfare. The comparison of social welfare is herein analyzed. As shown in Figure 8, unpredictably, the welfare under the three regulation tools are exactly the same no matter how the parameters change (we just display the figure of social welfare with the change of market scale α, and the results of other parameters' change are the same). And with the increase of market scale, social welfare will improve. These results reveal that different choices of regulation tools do not impact the social welfare but just influence the optimal regulated price and government expenditure.

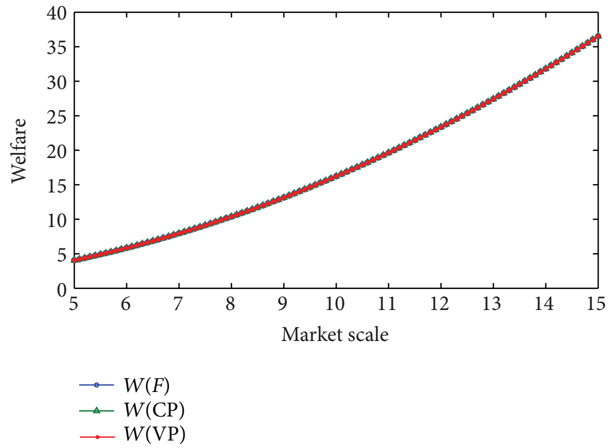

Figure 8: Three tools comparison on welfare under the change of market scale α.

Formally, we present the following proposition.

Proposition 2. *The choice of regulation type of FITs does not impact the optimal social welfare. But different tools may obtain very different optimal regulated price and government expenditure. The regulated price of F tool is the lowest and so is the government expenditure. Under the VP tool, we obtain the highest regulated price and government expenditure. Both regulated price and government expenditure under the CP tool are in the middle of three tools.*

Remarks. From the previous analysis, we show that regulation tool does not impact the social welfare. So the problem is that what is the standard for the government in choosing the regulation type in practice? Maybe governments with different preferences will make decisions in different ways. High support price inevitably accompanies with high volatility and high government expenditure. So the government must make a choice between the two aspects.

If policymakers are concerned more with the rapid but high volatile development of REI and face a loose expenditure constraint; they will choose the VP tool. With the change of market situation and/or firm efficiency, the government must undertake the risk of high and unstable expenditure at the same time. If the government wants to give a stable support price to the renewable energy firm whatever the firm efficiency or if the firm does not want change in the regulated price frequently, then maybe the CP tool is a good choice. And if the government expects a low and controllable expenditure to achieve a healthy and steady development of REI, the F tool absolutely is a good choice.

In practice, different countries and different renewable industries choose different regulation types. In initial stages of regulation, fixed price tool (F) is the most often adopted method in many countries, such as China and many European countries (Ireland, Switzerland, Austria, France, Germany, and so on). Why? Because this tool is very easy to

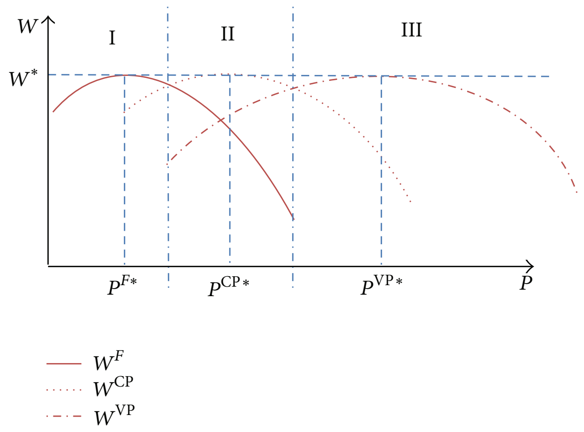

FIGURE 9: The comparison of three welfare functions.

handle and implement. And the character of stability and low risk becomes the main reason of prudent policymakers.

But with the diversified development of regulation tools, many countries begin to adopt more flexible instruments, such as Spain, Italy, Denmark, the Czech Republic, and Estonia, which had brought in the constant-premium price (CP tool). The Netherlands has introduced varied premium price. Precisely because different tools display different advantages and disadvantages, policymakers of different countries choose to change the regulation type or not.

4.4. The Choice of FIT Tools under Other Pricing Strategies. As mentioned previously, different regulation tools obtain the same optimal social welfare under different optimal prices. According to Proposition 2, we draw a diagram about the social welfare and regulated price (shown in Figure 9). The optimal prices under different regulation tools are based on the pricing strategy of value standard method which considers the common social welfare. Although it is not easy to determine exactly in practice, the previous conclusion also provides a judgment criterion when applying to other pricing strategies and help policymakers to choose a suboptimal project when they cannot obtain the optimal solution.

There are three areas in Figure 9: I, II, and III. The social welfare under the F tool is the highest in area I, CP tool in II, and VP tool in III. The optimal prices are P^{F*}, P^{CP*}, and P^{VP*}, respectively, under the three FIT types. The optimal social welfare is W^* no matter which regulation tools were applied. And we know that $P^{F*} < P^{CP*} < P^{VP*}$. So when policymakers cannot determine the regulated price exactly by using the pricing strategy of value standard method and have to apply other pricing strategies (cost-plus method, e.g.), F tool of FITs may be a good choice if the practical regulated price is relatively low. Because the lower price is, the more likely price falls into area I. Correspondingly, CP tool is better if the regulated price is modest. And if the regulated price is relatively high, VP tool will be a better choice. The wrong choice of regulation types (e.g., policymaker chooses VP tool when the regulated price is low) will lead to a deadweight welfare loss.

5. Conclusion

This paper establishes a three-stage game model including a renewable energy firm, a fossil energy firm, and the government to analyze the regulation effects of different FIT types. We find that the different regulation tools obtain different optimal price levels. The optimal price is the lowest under the F tool and the highest under the VP tool, which could be explained by risk differences. But if the regulated prices are all set appropriately under different tools, we show that the social welfares are the same under the three tools of FITs. The choice of regulation type does not impact the welfare. So we highly emphasize that government preference plays a crucial role in the choice of FIT types. If the government expects a rapid but high volatile development of REI, it will choose the variable price tool which has the highest and most unstable optimal regulated price. If the government does not want to change the regulated price frequently no matter how high the firm efficiency is, the constant price tool is a good choice. And if the government expects a healthy and steady development of REI under low and controllable expenditure, fixed price tool absolutely is a good choice.

We also point out that if policymakers cannot determine the exact regulated price in practice, the analysis of this paper also can help them to choose a suboptimal project. That means that the pricing strategy of value standard method is not only a method of optimal regulated price design which could solve the market failure perfectly, but also a judgment criterion for other pricing strategies.

How to apply the proper regulation tool to achieve both the rapid development of REI and improvement of social welfare is the issue of common concern both in theoretical and practical fields. The conclusions of this paper provide a theoretical basis on how to choose the level and type of regulated price based on the pricing strategy of value standard. The optimal regulated price must correspond with regulation type; otherwise the social welfare surely will lead to loss. Moreover, this paper successfully explains that the three tools of FITs all exist in different countries.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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