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ABSTRACT

Due to the incentive policies of governments, renewable energy plays an increasingly important role in the global energy supply system. Among the subsidy schemes, the one-off subsidy is mainly applied in the projects with a long investment period where the time value of money cannot be ignored due to the long payback period. In this article, a microeconomic model of enterprises with a discount factor is established. The impact of the one-off subsidy by the government is discussed in different periods. The results show that only when the investment period is long enough, the government would give the enterprise one-off subsidy and the given subsidy is positively correlated with the investment period. Besides, the enterprise is more willing to invest in the project when getting close to the end of the investment period and the subsidy increases with the growth of capital-output elasticity. This article analyzes the optimal period of giving the one-off subsidy under the condition of different internal rates of return (IRRs). Based on the extended framework of subsidy analysis by game theory, it is found that if IRR of the enterprise is larger than that of the government, the subsidy is suggested to be given at the beginning of the project.

I. INTRODUCTION

Currently, the world renewable energy is in the rapid development stage (Zou *et al.*, 2018). Some technologies have reached the level of commodification (Lin *et al.*, 2018), and the renewable energy will enjoy a large-scale development soon from the perspective of resource, technology, and industry (Bresser *et al.*, 2018).

Countries in the world take different strategies for the promotion of renewable energy due to the different motivations. Promotions of renewable energy by developed countries are mainly for reducing air pollution and lowering greenhouse gases, in order to protect the environment and to deal with climatic changes. Besides, the aim includes diversifying the energy resources, ensuring energy security, maintaining technological advantages, and expanding exports as well. However, developing countries promote renewable energy mainly for solving the energy supply problem in rural areas, in order to expand energy supplies and to relieve the pressure of energy shortages (Chen *et al.*, 2018).

The investment scheme of renewable energy projects is different from that of the traditional project (Miranda *et al.*, 2017; Gómez-Márquez *et al.*, 2011) due to its subsidy way (Chen *et al.*, 2017). First, renewable energy programs are of good flexibility resulting from the market factors, such as the market fluctuation of renewable energy prices, the initiative considerations (e.g., the managerial motivation) (Nie *et al.*, 2018), and the government factors (e.g., the uncertainty of the policy) about the renewable policy. Second, the benefit of renewable energy programs is diversified, which is of the externality like other environmental programs. Non-economy achievements, such as improving the environment quality and saving energy, would occur with the economic efficiency of normal investment. The environmental and energy issues could be relieved only by protracted and unremitting efforts because the non-economy achievements are of distinct indirectness and hysteretic nature obviously. Third, the investment of renewable energy programs makes contribution to solving the problems of sustainable development since it changes the situation of the single dependence on the unsustainable resources. According to the above-mentioned particularity of renewable energy programs, the subsidies and investment schemes of traditional projects (Foo *et al.*, 2018) are not suitable for the subsidy of renewable energy programs and cannot maximize the benefits of both the government and the enterprises which undertake the renewable energy programs.

Subsidy policies of the government for promoting renewable energy programs are like each other to a certain extent. The similarity includes the government direct subsidy policy before and during the project implementation and the indirect subsidy from the society capital as well as the support provided after the project implementation. For example, the electricity price stimulation policies include the fixed feed-in tariff scheme and the quota system of tradable green certificates for the power generating projects, which take the lead in applying the technology (Nie and Yang, 2016). In recent years, countries in the world have expanded the related policies from the single promotion for renewable energy projects to the comprehensive solution system including the establishment of incentive policy exit paths.

The internal rate of return is the discount rate when the total present value of capital inflow is equal to the total present value of capital flow and the net present value is equal to zero. It is the rate of return that an investment is eager to achieve. Meanwhile, the internal rate of return also indicates the ability to resist risks in the course of project operation. In addition, if a loan is needed in the project operation, the internal rate of return (IRR) can represent the maximum tolerable interest rate. If the loan interest is included in the project economic calculation, the maximum floating value of the loan interest is in the future project operation.

Currently, investment for renewable energy projects, such as hydropower projects, photovoltaic power projects, and wind power projects, is large with a long capital recovery period, leading to weak willingness of enterprises to invest in these projects. In this research, the internal rate of return (IRR) is introduced as an index to measure the investment of renewable energy projects, and the subsidy of renewable energy projects under different circumstances is studied. Based on the game theory, this article takes the renewable energy projects with a long investment cycle as an example, expanding the study of the subsidy supply scheme in the implementation process of long-term renewable energy projects.

There are two main contributions of this research. Theoretically, this article qualitatively discusses the subsidy scheme for renewable energy projects based on the game theory. The research extends the framework which only considers a single subsidy in previous studies and makes the results more targeted and practical. Practically, the research on the subsidy scheme for the renewable energy projects with a long period contributes to solving the investment shortage issue of some renewable energy projects and improving the efficiency of government subsidies.

The rest of this paper is organized as follows. Section II shows the literature review. Section III shows the model and its solution. Section IV discusses the analysis on fixed subsidies. Section V presents the discussion on different types of fixed subsidies. Section VI shows the concluding remarks.

II. LITERATURE REVIEW

Governments around the world introduce diverse policies for the development of renewable energy at present for energy structure transformation, energy saving, and emission reduction in the industry (Lai *et al.*, 2016), which caused widespread concern in academic circles. The policies for promoting renewable energy could be divided to direct subsidy and indirect promotion. Direct subsidy policies refer to financial contributions to enterprises provided by the government or any public authorities and the related support to prices or incomes (Yang *et al.*, 2016). Yang and Nie (2016) divided the government subsidies into three categories and conducted comparative analysis. Meanwhile, there are a great variety of indirect promotion policies which mainly include the quota of carbon emission permits (Jiang *et al.*, 2016), carbon taxes (Chen and Nie, 2016) and so on.

Direct subsidy to the renewable energy program means that the government gives financial support or the equivalents (Sovacool, 2017), among which FIT is the most widely applied to renewable energy companies (Solangi *et al.*, 2011; Carl and Fedor, 2016; Charnovitz and Fischer, 2015). The Spanish scholar González (2008) affirms FIT's active role in promoting the renewable sources of power in Spain and analyzes the difference of three fixed FITs and their improvements. Ritzenhofen *et al.* (2016) analyzed the renewable energy standards and structural influences of feed-in tariffs on the electricity market. Some scholars analyzed FIT at the regional level. Romano *et al.* (2016) analyzed the possibility of OPEC countries to accept FIT based on the panel Probit model. Based on the example of the European photovoltaic industry, Pyrgou *et al.* (2016) carried out the inspection about FIT. There are other similar research studies including the analysis about the influence of FIT in Portugal on its environment, economy, and society (Behrens *et al.*, 2016) and the comparative study of South Africa's renewable energy auction and FIT (Eberhard and Kaberger, 2016). For the influence of direct subsidy, Andor and Voss (2016) compared the capacity subsidy and the power generation subsidy and proved that some incentive instruments widely applied would cause shrinking benefits. Adkins and Paxson (2016) analyzed the renewable energy subsidy scheme with uncertainties. Scholars worldwide conducted research studies on the application and influence of the renewable energy subsidy, which includes the research about the influence of small direct subsidy schemes of renewable energy in Brazil's Amazon regions (Gomez *et al.*, 2015), the analysis of the influence of European Union's renewable energy policy to Czech (Marousek *et al.*, 2015), and so on.

Research on direct subsidies for renewable energy projects includes case studies of photovoltaic and geothermal projects. Xue (2017) took China's photovoltaic greenhouse project as an example based on the IRR and proposed that the construction of greenhouse projects needs to consider the investment capacity, investment scale, investment area, photovoltaic power generation subsidy policy, and other factors. Dû *et al.* (2015) found that carbon taxes and subsidies have a less impact on the construction of ground-source heat pump systems in Halifax and Montreal but have a certain impact in Toronto and Vancouver. Rodrigues *et al.* (2015) took Tahira Island as an example to analyze the feasibility of wind power generation based on GIS and cost-effectiveness.

As the supplementation of direct subsidy, indirect subsidy refers to a series of good policies provided by the government such as the RPS, TGC system, and below-market interest loans for renewable energy companies besides the direct financial assistance for the development of renewable energy companies. Current research studies attach importance to the development policies of renewable energy and the role of market mechanisms. At the policy level, Carley (2011) analyzed that the US power sector insists on investing policy instruments of diversification, decentralization, and de-carbonization from the aspects of renewable quantity standards, public welfare fund, and energy efficiency standards. Howarth (2012) demonstrated that the marketization of renewable energy technology is hard to be achieved through the single price mechanism. Hua *et al.* (2016) made comparative studies about China's and Australia's policies of promoting renewable energy, finding that Australia attaches more importance to the development of renewable energy than China and the renewable energy certificate policy could be implemented more effectively in Australia. In terms of market mechanism, Menanteau *et al.* (2013) proved that the government plays a very important role in promoting the innovation of renewable energy technology and accelerating learning the technology with the choice of both the FIT and quota system. According to their study, FIT is superior to the quota system. However, Sun and Nie (2015) believed that both existing policies have their own advantages and disadvantages with different government goals and framework conditions after the comparative analysis of FIT (Feed-in Tariff) and RPS (Renewable Portfolio). There are no policy instruments with inborn superiority (Sun and Nie, 2015). Delmas and Montes-Sancho (2011) compared renewable energy's RPS and MGPO in America. According to their results, RPS causes a negative effect on investment and private investment is more responsive to RPS than public investment while MGPO (Mandatory Green Power Option) has a more positive effect on the install capacity of renewable energy.

Some scholars proved the advantages of direct financial subsidies through the comparison of it and indirect subsidies and other policies. For example, Eichner and Runkel (2014) analyzed the relationship of carbon tax and green energy subsidies through the establishment of a multi-country model which includes renewable energy and traditional energy. This study shows that it is of low efficiency to take only one measure of imposing carbon tax without green subsidies and the reason is that all countries neglect capital outflow caused by the environmental externality.

The existing research studies on the development of renewable energy policies mainly concentrate on the regional impact of various subsidies on the environment and economy and the comparison of subsidies and other government strategies. On the one hand, there are almost no research studies on direct subsidies with incomplete information. On the other hand, improvements should be made in the research studies of comparing various direct subsidies with specific types of renewable energies considered.

III. MODEL AND SOLUTION

In this section, the model for renewable energy projects is established. The variables in the model are listed in the Nomenclature section.

Since the period to build equipment for the power plant is very long, we assume that there are k periods to build this generator. In these k periods, the capital investment at each period is $K_t, t = 1, 2, \ldots, k$. The total capital investment is $K = \sum_{t=1}^{k} K_t$ from the $(k+1)$ period. In this article, a simplified Cobb-Douglas function is introduced to characterize the production function of renewable energy projects because the Cobb-Douglas function is a basic production function. Moreover, since renewable energy projects are capital-intensive rather than labor-intensive, capital K is considered only in the production function. Considering that investment in different periods has different impacts on the output, the production function of the power plant at each period is

$$Q_t = K_t^{\alpha}. \tag{1}$$

Due to few labor inputs for the project during the production period, the impact of labor on production is not considered in this article. k is the period to build this generator. α in formula (1) is capital-output elasticity, and $0 < \alpha < 1$. Therefore, the profit function of the enterprise is

$$\pi = -\sum_{t=1}^{k} \delta^t K_t + \sum_{t=k+1}^{\infty} \delta^t \left[\left(\sum_{t=1}^{k} K_t^{\alpha} \right) \right]. \tag{2}$$

The energy price is assumed to be 1. Besides, during the first k period, the construction period, of the project, the enterprise could not get profits. Since the output in each period of payback, which means the period starts from the $k+1$ period, is $\sum_{t=1}^{k} K_t^{\alpha}$, the profit of the enterprise in each period is $\sum_{t=k+1}^{\infty} \delta^t [(\sum_{t=1}^{k} K_t^{\alpha})]$, where δ is the discount factor of the project.

Seeking the partial derivative of formula (1)

$$\begin{aligned} \frac{\partial \pi}{\partial K_1} &= -\delta + \alpha K_1^{\alpha-1} \sum_{t=k+1}^{\infty} \delta^t \\ \frac{\partial \pi}{\partial K_2} &= -\delta^2 + \alpha K_2^{\alpha-1} \sum_{t=k+1}^{\infty} \delta^t \\ \frac{\partial \pi}{\partial K_3} &= -\delta^3 + \alpha K_3^{\alpha-1} \sum_{t=k+1}^{\infty} \delta^t \\ &\vdots \\ \frac{\partial \pi}{\partial K_t} &= -\delta^t + \alpha K_t^{\alpha-1} \sum_{t=k+1}^{\infty} \delta^t. \end{aligned} \tag{3}$$

According to formula (2), the Hessian determinant of the profit function is

$$H(\pi) = \begin{bmatrix} \alpha(\alpha-1)MK_1^{\alpha-2} & 0 & \cdots & \cdots & 0 \\ 0 & \alpha(\alpha-1)MK_2^{\alpha-2} & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & 0 \\ 0 & \cdots & \cdots & 0 & \alpha(\alpha-1)MK_k^{\alpha-2} \end{bmatrix}. \tag{4}$$

where $M = \sum_{t=k+1}^{\infty} \delta^t = \frac{\delta^{k+1}}{1-\delta}$. Since $\alpha < 1$, the Hessian determinant is negative semidefinite. Thus, the profit function is a concave function. Order formula (2) equals to 0, the optimal investment of the enterprise in each period is

$$\begin{aligned} K_1^* &= \left(\frac{1-\delta}{\alpha \delta^k} \right)^{\frac{1}{\alpha-1}} \\ K_2^* &= \left[\frac{1-\delta}{\alpha \delta^{k-1}} \right]^{\frac{1}{\alpha-1}} \\ K_3^* &= \left[\frac{1-\delta}{\alpha \delta^{k-2}} \right]^{\frac{1}{\alpha-1}} \\ &\vdots \\ K_t^* &= \left[\frac{1-\delta}{\alpha \delta^{k+1-t}} \right]^{\frac{1}{\alpha-1}}. \end{aligned} \tag{5}$$

In formula (5), δ is the discount factor of the project and α is the capital-output elasticity.

Proposition 1. The enterprise is more willing to invest the project when getting close to the end of the investment period.

According to (5), optimal investment of an enterprise would increase with the higher t level when the project investment period moves on and other conditions stay the same. In other words, enterprises tend to invest on the power project with small investment schemes. It illustrates why the establishment of large-scale power stations basically is led by the government. As the investment in the earlier stage of the power industry is enormous and its payback period of investment after being up and running is long, common enterprises are cautious about investing on the industry. One reason is that common enterprises are not able to provide such a great amount of fund in the earlier stage, while another reason is that enterprises will be faced with the risk of fund chain breaking during the long process of the payback of investment.

The subsidies from the government lower the fixed cost of the enterprises effectively. At present, the financing model for projects with a high venture and long period is not mature enough and only the projects with a small fund requirement could be satisfied. Excessive opportunity cost would directly decrease the innovation will of enterprises and then the development of the renewable energy sector would slow down and even stop if the government does not provide subsidies for these projects. Meanwhile, the low cost of traditional energy would also bring the pressure to renewable energy and decreasing profits would further hinder the implementation of similar projects.

The total investment of the enterprise on the project under the condition of optimal investment of the enterprise is

$$K^* = \frac{\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}} - \left(\frac{1-\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}}{1-\delta^{\frac{1}{\alpha-1}}}. \tag{6}$$

Substituting formula (5) into formula (3), the profit function under optimal investment of the enterprise is

$$\pi^* = \frac{\delta^{k+1}\left[\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1-\delta}{\alpha\delta}\right)^{\frac{\alpha}{\alpha-1}}\delta^{\frac{\alpha}{\alpha-1}}\right]}{(1-\delta)\left(1-\delta^{\frac{\alpha}{\alpha-1}}\right)} - \frac{\delta\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}} - \delta^k\left(\frac{1-\delta}{\alpha\delta}\right)^{\frac{1}{\alpha-1}}\delta^{\frac{\alpha}{\alpha-1}}}{1-\delta^{\frac{\alpha}{\alpha-1}}}. \tag{7}$$

Proposition 2. Total investment of the enterprise rises with the growth of the project investment period and capital output elasticity.

Proof: see the Appendix.

According to (6), the gross investment of enterprises increases with the longer investment period k when other conditions stay the same. The longer the investment period is, the larger the project scale is. Large-scale projects demand greater investment, and the gross investment of enterprises growing with new investment is the passive action based on the requirement of the projects. Increasing investment at different periods may lead to the failure for projects to continue with the increase in the project scale, while it tends to be an independent choice of the enterprise that the gross investment goes up with the increasing capital-output elasticity. The high capital-output elasticity means that there is higher capacity for projects with the same amount of investment, and more profits could be created in the payback period of investment in the project. Therefore, these types of projects are more favored by enterprises and they will enjoy stronger investment willingness.

IV. ANALYSIS ON THE FIXED SUBSIDY

Considering the huge investment in the earlier stage of power industry, most enterprises and people involved need to keep operating with debts. What is more, the long payback period of investment of the industry leads to its low capital profit margins especially in the pre-production period. If the capital profit margin of the enterprise is higher than the interest rate of borrowing money, the equity of the shareholder will increase due to operating with debts. Similarly, if enterprises are too dependent on debt management, it will damage the interests of shareholders and the debt is unprofitable when the interest rate exceeds the rate of return on capital. Therefore, when investing on projects such as hydropower projects, photovoltaic power projects, and wind power projects, companies tend to take into consideration the existence of long-term unpredictable risks and the existence of opportunity costs for making capital to pursue higher profits.

Therefore, only when formula (8) is satisfied, the enterprise would invest in the project

$$\frac{\pi}{\sum_{t=1}^{k} K_t} \geq \gamma. \tag{8}$$

In formula (8), γ is the threshold of capital profit margin. Only when the value of capital profit margin of the enterprise is larger than or equals to γ, the enterprise has the motivation of investment. Considering the feature of the renewable energy industry, it is usually hard for enterprises to reach the profit margin without subsidies. In this article, it is assumed that the one-off subsidy by the government is S. When tightening the constraint of formula (7)

$$\frac{\pi^* + S}{\sum_{t=1}^{k} K_t^*} = \gamma. \tag{9}$$

Substituting formula (5) and formula (6) into formula (8)

$$S^* = \frac{\gamma\left[\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}} - \left(\frac{1-\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\right]}{\left(1-\delta^{\frac{1}{\alpha-1}}\right)} - \frac{\delta^{k+1}\left[\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1-\delta}{\alpha\delta}\right)^{\frac{\alpha}{\alpha-1}}\delta^{\frac{\alpha}{\alpha-1}}\right]}{(1-\delta)\left(1-\delta^{\frac{\alpha}{\alpha-1}}\right)} + \frac{\delta\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}} - \delta^k\left(\frac{1-\delta}{\alpha\delta}\right)^{\frac{1}{\alpha-1}}\delta^{\frac{\alpha}{\alpha-1}}}{\left(1-\delta^{\frac{\alpha}{\alpha-1}}\right)}. \tag{10}$$

Proposition 3. The enterprise with a higher value of the capital-output elasticity would get more government subsidies.

According to Figs. 1–3, the greater the capital-output elasticity is the more subsidies the enterprises could gain. Meanwhile, with the increase in the elasticity of capital output, the increase in the elasticity of unit capital output will increase the rate of subsidy growth. This

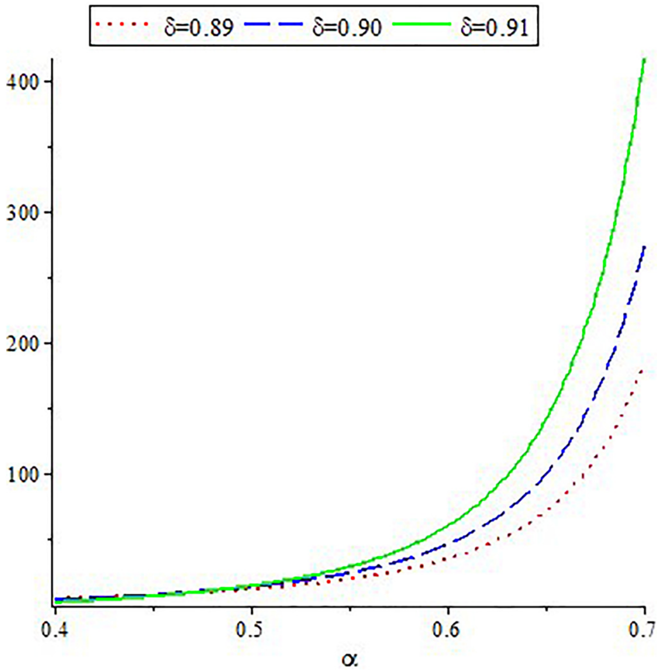

FIG. 1. Relation between the subsidy and capital-output elasticity for $\gamma = 0.2$, $k = 30$.

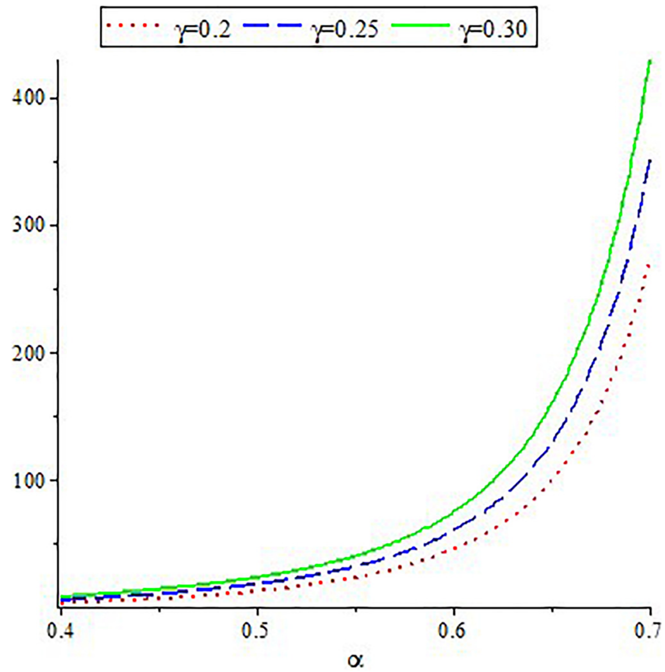

FIG. 3. Relation between the subsidy and capital-output elasticity for $k = 30$, $\delta = 0.9$.

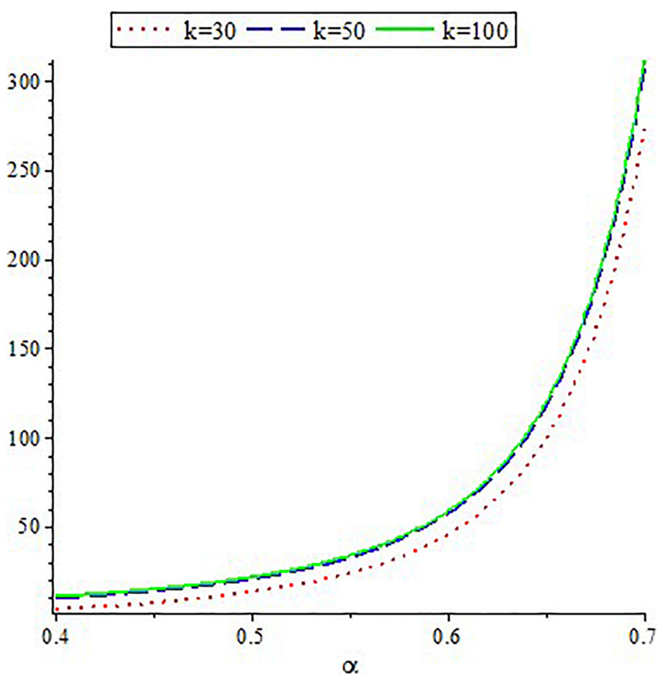

FIG. 2. Relation between the subsidy and capital-output elasticity for $\gamma = 0.2$, $\delta = 0.9$.

article considers such a subsidy to be reasonable. The greater the elasticity of capital output, the greater the increase in the output resulting from the increase in unit capital investment. In this case, this paper argues that subsidies should increase with the increase in the production of unit capital inputs. The reason is that the higher capital-output elasticity means the higher productivity in the industry and more output or higher energy efficiency could be achieved with the same capital input if the level of management and the technical level of energy enterprises are higher. The enterprises deserve more financial subsidies whether for conserving social resources or for achieving government's goal of energy saving and emission reduction. Therefore, the financial subsidies could help enterprises by promoting the enhancement of the management level and the improvement of the productivity. According to the comparison of Figs. 1–3, subsidies and the trend of capital-output elasticity do not change with the changes of the discount factor of the project δ, the expected rate of return γ and the investment period k and then the result is of stability.

According to Fig. 1, under the premise that γ, k and other conditions remain the same, more subsidies are needed when the capital-output elasticity α is the same and the discount factor of the project δ is higher. The difference of subsidies needed gradually increases with the increase in α and different levels of δ. It means that projects rely on government subsidies in a higher degree with a higher discount rate and the degree keeps increasing with the rise of capital-output elasticity. Figure 2 shows that more subsidies are needed and a marginal declining trend occurs with the premise that γ, k and other conditions remain the same when the capital-output elasticity α is the same and k is higher. The added value of the subsidy would decline with the increase in the project cycle, and it is in line with the actual situation of declining marginal cost. According to Fig. 3, under the premise that δ, k and other conditions remain the same, more subsidies are needed when the capital-output elasticity α is the same and γ is higher. The difference of subsidies needed gradually increases with the increase in α and different levels of γ. Generally speaking, a higher expected return of projects presents better quality and enterprises would be more willing to take risks. Therefore, it is reasonable for the government to give higher one-off subsidies to projects of enterprises when the expected return is high.

Proposition 4. Only if the investment period is long enough, the government would give the enterprise one-off subsidy. Otherwise, the enterprise would not get the subsidy. Besides, the longer the investment period is more subsidies the enterprise would get.

According to (9), Figs. 4 and 5, subsidies from the government to enterprises are negative when the period of investment k is small. In this case, the negative value of subsidies is meaningless, and the government does not provide subsidies when the period of investment is short. Government subsidies for the renewable energy industry are mainly for avoiding the lack of investment as enterprises take risks because of huge investment in the earlier stage. As a result, similar risks decrease sharply when the period of investment is short, and it is not necessary for the government to provide similar projects with subsidies. When the period of investment reaches a certain value, investment by the enterprise will decrease, and the government must provide subsidies for promoting the development of renewable energy such as hydropower. The longer the period of investment, the bigger the risk enterprises face. Then, higher subsidies would be provided to enterprises by the government. According to the comparison of Figs. 4 and 5, subsidies and the trend of capital-output elasticity do not change with the changes in the discount factor of the project δ and the expected rate of return γ, and then, the value is stable.

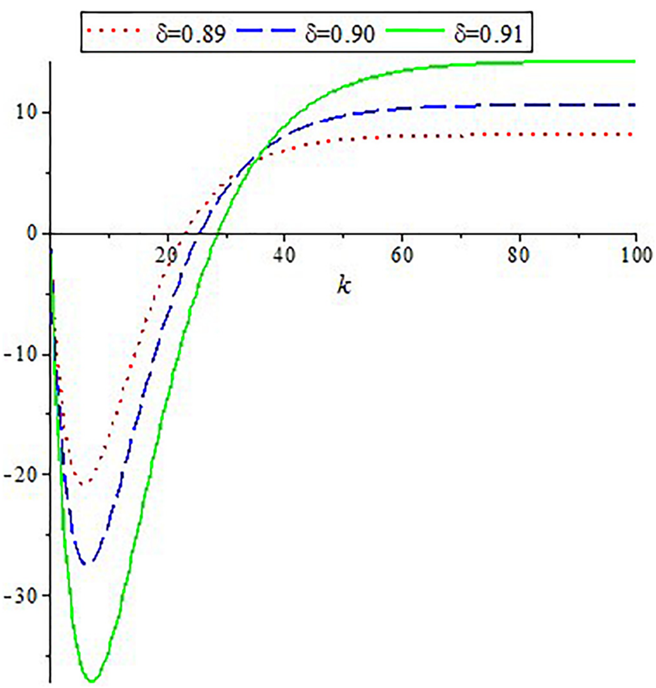

FIG. 4. Relation between the subsidy and the investment period for $\gamma = 0.2$, $\alpha = 0.4$.

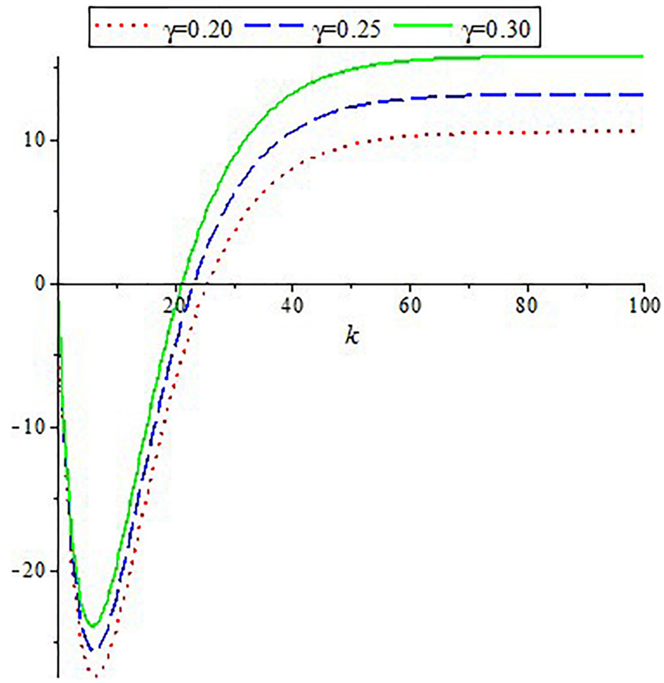

FIG. 5. Relation between the subsidy and the investment period for $\delta = 0.9$, $\alpha = 0.4$.

According to Fig. 4, under the premise that γ, k, and other conditions remain the same, subsidies increase with the fluctuation of the period of investment k and the increase in the discount factor of the project δ. The higher the discount rate of projects is, the greater the difference of the investment amount needed in different period is. Then it is in line with the actual situation that subsidies increase with the fluctuation of the period of investment. Meanwhile, according to Fig. 5, when the discount factor of the project δ, α, and other conditions remain the same, more subsidies in the same period of investment are needed as a result of higher expected rate of return. The reason is that enterprises would be more willing to take risks as a result of high expected return and high quality of projects. Therefore, the expected rate of return is increasingly higher, and it is reasonable for enterprises to gain higher financial subsidies from the government.

It should be noted that funds of these projects not only come from government subsidies, but also could be gained through financing such as invests. One form of equity capital investment means that the angel investor offer helps to small start-ups or original projects with specific technology or unique concepts for one-off investment in the earlier stage. The investment is one off, and its amount is small. In addition, its review for venture business is not strict. However, traditional investment is not suitable for projects which have a long-term and large demand for funds as it is invested by one person and is an individual or small business practices. Therefore, it is necessary for the government to provide subsidies for projects with more periods of investment. For projects with less periods of investment, enterprises could gain funds through other ways and government does not have to provide subsidies. This is good for the more effective use of government resources.

V. DISCUSSION ON DIFFERENT TYPES OF FIXED SUBSIDIES

If the government gives the fixed subsidy to the enterprise at the beginning of the project, then

$$\frac{\pi^* + S^*}{\sum_{t=1}^{k} K_t^*} = \gamma. \tag{11}$$

The subsidy for the enterprise under this condition is

$$S^* = \gamma \sum_{t=1}^{k} K_t^* - \pi^*. \tag{12}$$

If the government gives the fixed subsidy to the enterprise at the end of the project, then

$$\frac{\pi^* + \delta^k S^{**}}{\sum_{t=1}^{k} K_t^*} = \gamma. \tag{13}$$

The subsidy for the enterprise under this condition is

$$S^{**} = \frac{\gamma \sum_{t=1}^{k} K_t^* - \pi^*}{\delta^k}. \tag{14}$$

If the internal rate of return (IRR) of the enterprise is r_1 and the internal rate of return (IRR) of the government is r_2, $r_1 > 1$, $r_2 > 1$. If the enterprise gets the subsidy at the beginning of the project, the profit of the subsidy during the project belongs to the enterprise. Then, the total profit of capital of the government and the enterprise is

$$S^* r_1^k + 0. \tag{15}$$

If the enterprise gets the subsidy at the end of the project, the profit of the subsidy during the project belongs to the government. Then, the total profit of capital of the government and the enterprise is

$$0 + S^{**} r_2^k. \tag{16}$$

Proposition 5. When $r_1 < r_2 < \frac{r_2}{\delta}$, the subsidy at the end of the project is better, while the subsidy at the beginning of the project is better when $r_1 > \frac{r_2}{\delta}$.

Proof: see the Appendix.

When the internal rate of return (IRR) $r_1 < \frac{r_2}{\delta}$, the subsidy at the end of the project by the government contributes to the optimal total profit. Besides, $r_2 < \frac{r_2}{\delta}$ since the discount factor $\delta < 1$. Otherwise, when the internal rate of return (IRR) $r_1 > \frac{r_2}{\delta}$, the subsidy at the beginning of the project contributes to the optimal total profit.

This article assumes that large and medium-sized enterprises have higher probability to get high returns compared to small businesses. The reason for the assumption is that the business efficiency of large and medium-sized enterprises is better than that of small enterprises and large and medium-sized enterprises have a higher internal rate of return and more projects while small enterprises have fewer projects. Therefore, this paper believes that providing subsidies in the end of projects for large and medium-sized enterprises is beneficial for achieving the maximal total revenue while providing subsidies in the early stage of projects for small enterprises is beneficial for achieving the maximal total revenue.

There is certain policy support for small renewable energy projects. The local government should be responsible for the construction funds of projects in which renewable energy takes the place of fossil fuel, while the central government would provide subsidies. Take China as an example, the total proportion of subsidies from the government differs. In western regions, the total proportion would reach 45%, while in the eastern regions, the proportion is 15%. This paper believes that subsidies should be provided in the early stage of projects for promoting the smooth flow of corporate cash and then achieving the maximal total profit in the projects.

VI. CONCLUDING REMARKS

Based on the consideration of capital, time, and value, this article establishes a microeconomic model which introduces the discount factor of the enterprise and discusses the influence of the government on one-off subsidies of enterprises in different stages. Then, the best stage for the government to provide one-off subsidies for enterprises is taken into consideration when enterprises and governments have different internal rates of return. The main results of this article are as follows. First, enterprises will be more willing to invest in the later stage of a project. Second, enterprises can get higher subsidies with the increase in their capital-output elasticity. Besides, large and medium-sized enterprises are of higher probability to get high returns than small enterprises.

The government would be motivated to provide one-off subsidies for enterprises only when the period of investment is long enough, and the amount of subsidy is positively related to the length of the project investment period. The investments are of long period and high input in the early stage so that short-term cost recovery is impossible. As a result, it is necessary for the government to provide subsidies for projects with a long period of investment. As for projects of a few periods of investment, enterprises could gain funds through other ways and the government does not have to offer subsidies. It is good for the more effective use of government resources.

The government should provide subsidies at the end of the investment period when the internal rate of return of enterprises is smaller than that of government and subsidies should be provided in the early stage of the investment period conversely. Large and medium-sized enterprises are of higher management efficiency of funds than small enterprises, who have weaker ability to resist risks. Small enterprises, in contrast, are of smaller investment scale and less investment channels, so that their ability of achieving short-term appreciation of funds is relatively weak. Therefore, the government should provide subsidies in the early stage of investment period for large and medium-sized enterprises, which could promote effectively the appreciation of state-owned property, make effective use of laid-up capital and increase the total social assets. As for small enterprises, subsidies should be provided in the end of the investment period so that the government could evade the loss of state-owned assets effectively caused by enterprise bankruptcy or ethical risk.

Based on game theory, this paper conducts a micro model about the subsidy issue before and during the implementation of renewable energy projects from the aspects of the government and enterprises, which enriches the research studies on the provisioning solution of subsidies during the implementation of renewable energy projects. Meanwhile, in practice, the laws of economics about renewable energy project subsidies could be concluded according to the model results of this article, enlightening for policy-making and are of practical significance.

Since the subsidies of renewable energy projects are difficult to obtain, this article makes the qualitative analysis on the impact of subsidies on renewable energy projects based on the optimal model. Empirical research based on data of renewable energy projects will further quantify the impact of the subsidies, which is also the future direction of this research.

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NOMENCLATURE

r_1	Internal rate of return (IRR) of the enterprise
r_1	Internal rate of return (IRR) of the government
k	Project investment period
K	Investment of the enterprise on the project
Q	Output of the enterprise
S	One-off subsidies for the project by the government
α	Capital-output elasticity
δ	Discount factor of the project
γ	Expected return of the project
π	Profit of the enterprise

APPENDIX

Proof of Proposition 2. Partial derivative of formula (6)

$$\frac{\partial K^*}{\partial \alpha}=\frac{\left[\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}}\right]\left[-\frac{\ln\left(\frac{1-\delta}{\alpha\delta^k}\right)}{(\alpha-1)^2}-\frac{1}{\alpha(\alpha-1)}\right]-\left(\frac{1-\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\left[-\frac{\ln\left(\frac{1-\delta}{\alpha}\right)}{(\alpha-1)^2}-\frac{1}{\alpha(\alpha-1)}\right]}{1-\delta^{\frac{1}{\alpha-1}}}-\frac{\delta^{\frac{1}{\alpha-1}}\left[\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}}-\left(\frac{1-\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\right]\ln\delta}{\left(1-\delta^{\frac{1}{\alpha-1}}\right)^2(\alpha-1)^2}. \tag{A1}$$

In formula (A1), $0<\alpha<1, 0<\delta<1$. Generally, the value of discount factor is larger than the investment of the enterprise on the project, which means $\alpha<\delta$. Therefore, in formula (A1), $\left[\left(\frac{1-\delta}{\alpha\delta^k}\right)^{\frac{1}{\alpha-1}}\right]>0$, $\frac{\ln\left(\frac{1-\delta}{\alpha\delta^k}\right)}{(\alpha-1)^2}<0$ and $\frac{\ln\left(\frac{1-\delta}{\alpha}\right)}{(\alpha-1)^2}<0$.

Therefore, $\frac{\partial K^*}{\partial \alpha}>0$.

Proof of Proposition 5. According to formula (11) to formula (16)

$$S^{**}=\frac{S^*}{\delta^k}. \tag{A2}$$

Therefore, when $S^*r_1^k>S^{**}r_2^k$, $r_1>\frac{r_2}{\delta}$.

Otherwise, when $S^*r_1^k>S^{**}r_2^k$, $r_1<r_2<\frac{r_2}{\delta}$.

REFERENCES

Adkins, R. and Paxson, D., "Subsidies for renewable energy facilities under uncertainty," Manchester School **84**(2), 222–250 (2016).

Andor, M. and Voss, A., "Optimal renewable-energy promotion: Capacity subsidies vs. generation subsidies," Resour. Energy Econ. **45**, 144–158 (2016).

Behrens, P., Rodrigues, J., Brás, T., and Silva, C., "Environmental, economic, and social impacts of feed-in tariffs: A Portuguese perspective 2000–2010," Appl. Energy **173**, 309–319 (2016).

Bresser, D., Hosoi, K., Howell, D., Li, H., Zeisel, H., Amine, K., and Passerini, S., "Perspectives of automotive battery R&D in China, Germany, Japan, and the USA," J. Power Sources **382**, 176–178 (2018).

Carl, J. and Fedor, D., "Tracking global carbon revenues: A survey of carbon taxes versus cap-and-trade in the real world," Energy Policy **96**, 50–77 (2016).

Carley, S., "The era of state energy policy innovation: A review of policy instruments," Rev. Policy Res. **28**(3), 265–294 (2011).

Charnovitz, S. and Fischer, C., "Canada-renewable energy: Implications for WTO law on green and not-so-green subsidies," World Trade Rev. **14**(2), 177–210 (2015).

Chen, Y., Nie, P., and Yang, Y., "Energy management contract with subsidy," J. Renewable Sustainable Energy **9**(5), 055903 (2017).

Chen, Z., Huang, Z., and Nie, P., "Industrial characteristics and consumption efficiency from a nexus perspective-based on Anhui's empirical statistics," Energy Policy **115**, 281–290 (2018).

Chen, Z. and Nie, P., "Effects of carbon tax on social welfare: A case study of China," Appl. Energy **183**, 1607–1615 (2016).

Miranda, O., Brandão, L. E., and Lazo, J. L., "A dynamic model for valuing flexible mining exploration projects under uncertainty," Resour. Policy **52**, 393–404 (2017).

Delmas, M. and Montes-Sancho, M., "US state policies for renewable energy: Context and effectiveness," Energy Policy **39**(5), 2273–2288 (2011).

Dû, M. L., Dutil, Y., Rousse, D. R., Paradis, P. L., and Groulx, D., "Economic and energy analysis of domestic ground source heat pump systems in four Canadian cities," J. Renewable Sustainable Energy **7**(5), 053113 (2015).

Eberhard, A. and Kaberger, T., "Renewable energy auctions in South Africa outshine feed-in tariffs," Energy Sci. Eng. **4**(3), 190–193 (2016).

Eichner, T. and Runkel, M., "Subsidizing renewable energy under capital mobility," J. Public Econ. **117**, 50–59 (2014).

Foo, N., Bloch, H., and Salim, R., "The optimisation rule for investment in mining projects," Resour. Policy **55**, 123–132 (2018).

Gomez, M., Tellez, A., and Silveira, S., "Exploring the effect of subsidies on small-scale renewable energy solutions in the Brazilian Amazon," Renewable Energy **83**, 1200–1214 (2015).

Gómez-Márquez, I., Alejano, L. R., and Bastante, F. G., "Mining compatibility with other projects in Spain: Solutions and benefits," Resour. Policy **36**(1), 22–29 (2011).

González, P., "Ten years of renewable electricity policies in Spain: An analysis of successive feed-in tariff reforms," Energy Policy **36**(8), 2917–2929 (2008).

Howarth, N., "Clean energy technology and the role of non-carbon price-based policy: An evolutionary economics perspective," Eur. Plann. Stud. **20**(5), 871–891 (2012).

Hua, Y., Oliphant, M., and Hu, E., "Development of renewable energy in Australia and China: A comparison of policies and status," Renewable Energy **85**, 1044–1051 (2016).

Jiang, M., Yang, D., and Chen, Z., "Market power in auction and efficiency in emission permits allocation," J. Environ. Manage. **183**(3), 576–584 (2016).

Lai, P., Du, M., Wang, B., and Chen, Z., "Assessment and decomposition of total factor energy efficiency: An evidence based on energy shadow price in China," Sustainability **8**(5), 408 (2016).

Lin, J., Chen, L., Liu, T., Xia, C., Chen, C., and Zhan, Z., "The beneficial effects of straight open large pores in the support on steam electrolysis performance of electrode-supported solid oxide electrolysis cell," J. Power Sources **374**, 175–180 (2018).

Marousek, J., Haskova, S., Zeman, R., Váchal, J., and Vaníčková, R., "Assessing the implications of EU subsidy policy on renewable energy in Czech Republic," Clean Technol. Environ. Policy **17**(2), 549–554 (2015).

Menanteau, P., Finon, D., and Lamy, M., "Prices versus quantities: Choosing policies for promoting the development of renewable energy," Energy Policy **31**(8), 799–812 (2013).

Nie, P., Wang, C., and Chen, Z., "A theoretic analysis of key person insurance," Econ. Modell. **71**, 272–278 (2018).

Nie, P. and Yang, Y., "Renewable energy strategies and energy security," J. Renewable Sustainable Energy **8**(6), 065903 (2016).

Pyrgou, A., Kylili, A., and Fokaides, P., "The future of the Feed-in Tariff (FiT) scheme in Europe: The case of photovoltaics," Energy Policy **95**, 94–102 (2016).

Ritzenhofen, I., Birge, J., and Spinler, S., "The structural impact of renewable portfolio standards and feed-in tariffs on electricity markets," Eur. J. Oper. Res. **255**(1), 224–242 (2016).

Rodrigues, A., Silva, V., Barcelos, E., Silva, C., and Dentinho, T., "Geographical information systems and cost benefit analysis-based approach for wind power feasibility: A case study of Terceira Island," J. Renewable Sustainable Energy **7**(5), 053115 (2015).

Romano, A., Scandurra, G., and Carfora, A., "Probabilities to adopt feed in tariff by OPEC countries using a panel probit model," Energy Syst.-Optim. Model. Simul. Econ. Aspects **7**(3), 449–468 (2016).

Solangi, K., Islam, M., Saidur, R., Rahim, N., and Fayaz, H., "A review on global solar energy policy," Renewable Sustainable Energy Rev. **15**(4), 2149–2163 (2011).

Sovacool, B. K., "Reviewing, reforming, and rethinking global energy subsidies: Towards a Political Economy Research Agenda," Ecol. Econ. **135**, 150–163 (2017).

Sun, P. and Nie, P., "A comparative study of feed-in tariff and renewable portfolio standard policy in renewable energy industry," Renewable Energy **74**, 255–262 (2015).

Xue, J., "Economic assessment of photovoltaic greenhouses in China," J. Renewable Sustainable Energy **9**(3), 033502 (2017).

Yang, D., Chen, Z., and Nie, P., "Output subsidy of renewable energy power industry based on asymmetric information," Energy **117**, 291–299 (2016).

Yang, D. and Nie, P., "Influence of optimal government subsidies for renewable energy enterprises," IET Renewable Power Gener. **10**(9), 1413–1421 (2016).

Zou, C., Zhang, L., Hu, X., Wang, Z., Wik, T., and Pecht, M., "A review of fractional-order techniques applied to lithium-ion batteries, lead-acid batteries, and supercapacitors," J. Power Sources **390**, 286–296 (2018).