Game Analysis of the China Wind-farm Investment Market

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Abstract

The global electricity supply from non-hydro renewable energies, such as wind and solar, has being growing at a high rate, and it is expected that this trend persists. In China, Wind power is one of the most mature renewable energy technologies and it is possible to be utilized in large-scale. However, in the long run, the malicious competition will break the rule of the monopoly wind power market under control of electricity utilities in China and prevent the development of Chinese wind power. Reasonable competition of the investment market is a key to promote healthy development of the wind power industries in China. Based on game theory, this paper investigates competitive behavior of the wind-farm investment companies. The competition mechanism and malicious competition behavior of the investment market of the non-asymmetric enterprisers, and the wind-farm investment market are discussed by the Stacklberg model and the Cournot-Nash model, respectively, and moreover, the theoretic analysises are verified to be effective by an example. Furthermore, some policy advices are put forwards to the Chinese wind power investment market.

Keywords: Wind-farm investment, Competition analysis, Game analysis

1. Introduction

Availability of energy is a key element to achieve the interrelated economic, social and environmental goals of sustainable development in modern human society. However, about 84% of the total energy consumption is based on non-renewable forms of energies today (OECD/IEA, 2007). Since the rebuilding rate of fossil energy reserves is approximately 10^6 times slower than the present rate of tapping, the current use of fossil energies is far from being sustainable (Hans, 2006). Furthermore, the gases from the burning of fossil fuels contribute to global climate change and local pollution, and the dependence on oil and gas raises concerns about supply security. For these reasons, countries seek renewable sources of energy for generating electricity.

China, characterized by the largest population, is one of the most rapidly growing countries and the second largest energy consumer, just behind the United States. Its annual GDP growth rate recorded about 10% during the last two decades, and the primary energy consumption in 2009 is more the 2132 Mtoe, equivalent to 12.6% of the world total. At the same time, China is also one of the worst polluters with the largest SO_x emissions and the second largest CO_2 emissions. Therefore, renewable energy in China continues to play an increasingly important and strategic role in the country's energy development. China has a large area with long coastline, so its wind energy resource has tremendous development potential. About 20% areas of the country are abundant wind energy resource and Chinese government has been paying much attention to the development of wind power. Chinese government has increased the input on wind energy development over the recent years. And wind is now the fastest growing renewable energy source for generating electricity in China.

Because of its huge potential impact, the study of China's wind energy issues is vital not only for China itself but also for the rest of the world. A lot of studies have been done on it, including those conducted by IEA, EIA/DOE/USA, World Bank, and The Energy Research Institute of China. A number of recent policy analysis have suggested further important necessary policy changes for wind energy development to continue its growth in China (Wang, 2010; Cherni, 2007; Zhang, 2009). In 2009, China revised its basic target for renewable energy share for 2020. The differences between share of primary and final energy consumption are discussed by Martinot (2007). Electricity storage technologies of wind power on large scales were investigated before (Hall, 2008; Ibrahim,2008; Hadjipaschalis, 2009; International Energy Agency, 2008). Related technologies problems such as wind farm, wind turbines, gird-connected and stability of wind power system were analyzed (Xing, 2009;

Huang, 2009; Lund, 2007; Ni, 2004). The investment cost and tariff were discussed and some proposals were given by Zheng (2004) and Zhang (2001). In fact, the Chinese down-stream enterprises (here it means wind-farm investment enterprises) of wind energy development landscape are also dominated by state-owned utilities, or developers, with five such firms (the "Big Five") claiming 60% of this market in 2009. Even beyond the Big Five, most developers are state-owned; private developers and international entities each represent less than 10% of the market. Here, experienced foreign players have become integral partners in pre-development tasks such as wind resource assessment. SOEs are dominating the wind development market due to a number of factors working in their favor, governmental intervention chief among them. The central government maintains a great deal of influence over all large development projects (over 50 MW), including approval authority for pricing. SOEs have won almost every single project of this type by out-bidding private firms and foreign players, often below cost. The enclosure movement of SOEs made them able to control the market. Furthermore, in order to barrier other to entry, they do not hesitate to sacrifice their own interests. Those behaviors have prevented emitters such as top quality private or foreign enterprises from entering the downstream market of wind power, this behavior also wasted resources seriously. In the long run, the malicious competition will break the rule of market and prevent the development of Chinese wind power. However, there are few studies that focus on the wind energy market for investment.

This paper investigates the competitive behavior of wind investment downstream market in China. At first, a stackelberg model is constructed to analyze the situation, in which the largest firm plays the role of leader, and the medium-sized firms are treated as Cournot followers. And moreover, the malicious competition behavior of the monopolist is disused. Secondly, based on Cournot-Nash game, duopolistic market is considered. To verify our viewpoints, a numerical example is given at last.

2. The Stackelberg Model

The Stacklberg game was first proposed in 1934, and the formulation is especially appropriate for studying a game with a sequential move or a leader-follower relationship. Examples can be found in Fudenberg and Tirole (1991); Gibbson (1992); Tirole (1998). The standard backward induction procedure to solve such games initially fixes the decisions made by the leader in the first stage and then derives the best response of each follower. The optimal decisions for the leader are then found by solving an optimization problem with constraints for the derived response of the followers. Firms' status is asymmetry in downstream market of China wind energy investment. The leader in the Stackelberg game, usually the largest companies, such "Big Five", or other big SOEs, the follower is some private or foreign enterprises which capital or technologies lag behind that of the largest companies. Under this condition, the leader maximizes its profit subject to capacity constrains and subject to the condition that the followers act optimally given the strategy chosen by the leader.

2.1 Some Assumptions

We now give some assumptions.

Assumption 2.1 There are two investors in a regional downstream market of wind energy. They are Firm 1 and 2, respectively, and can be considered as such without loss of generality. Firm 1 is leader and Firm 2 is follower, and wind power output of Firm 1 is y_1, as reaction, Firm 2 chose y_2 as its output. Note that these are non-negative ($y_i \geq 0$). The total wind power output is $Q = y_1 + y_2$.

Assumption 2.2 Suppose that the inverse demand function is expressed as $p = a - b(y_1 + y_2)$, where p is the equilibrium price of wind power. Each firm has generation cost $C_i(y_i) = c_i y_i$, with strictly positive marginal cost of generation, that is, $c_i \geq 0$, furthermore, $a > c, i = 1,2$.

2.2 A Maximum Profit Model of Follower

Follower that is Firm 2 chooses output in order to maximize profits

$$\max_{y_2 \geq 0} R_2(y_1, y_2) = \{a - b(y_1 + y_2)\}y_2 - c_2 y_2 \qquad (2.1)$$

The output level of Firm 2 depends on the production strategies of Firm 1, and it is a reaction function of Firm 1's output, holding Firm 1's output level constant. The solution of the first order conditions of (2.1) yields Firm 1's equilibrium output

$$y_2 = \frac{1}{2b}(a - by_1 - c_2) \qquad (2.2)$$

2.3 A Maximum Profit Model of the Leader and the Stackelberg Price

The Stackelberg leader maximizes profits by selecting an output level to withhold given the responses of the

followers:

$$\max_{y_1 \geq 0} R_1(y_1, y_2) = \{a - b(y_1 + y_2)\}y_1 - c_1 y_1 \tag{2.3}$$

Based on (2.2), it yields that

$$R_1(y_1, y_2) = \{a - b(y_1 + \frac{a - by_1 - c_2}{2b})\}y_1 - c_1 y_1 \tag{2.4}$$

The solution of the first order conditions of (2.3) yields Firm 1's equilibrium output:

$$y_1^* = \frac{1}{2b}(a - 2c_1 + c_2) \tag{2.5}$$

Combining (2.5) with (2.2) leads to the Firm 2's Stackelberg equilibrium output:

$$y_2^* = \frac{1}{4b}(a + 2c_1 - 3c_2) \tag{2.6}$$

According to (2.5), (2.6) and the inverse demand function, we conclude the wind power Stackelberg equilibrium price is $p^* = \frac{1}{4}(a + 2c_1 + c_2)$. The total wind energy generation of this region is $Q^* = \frac{1}{4b}(3a - 2c_1 - c_2)$, the profit of Firm 1 is $R_1^* = \frac{1}{8b}(a - 2c_1 + c_2)^2$ and the profit of Firm 2 is $R_2^* = \frac{1}{16b}(a + 2c_1 - 3c_2)^2$.

2.4 A Extended Model of Stackelberg Game

On the current situation of China, the large investor usually preemptively entries some region and to be a monopolist, which set as Firm 1. Here we consider the entry of other firms. As we all known that, it need a lot of entry cost to invest wind-farm, it is denoted as K, and $K > 0$. Under the condition of increasing returns to scale, investing of wind-farm on the small scale is not possible to make profit. We set Firm 2 is a potential entrant.

Under the assumptions 2.1 and 2.2, Firm 2's output is derived from maximizing the following profit function:

$$\max R_2(y_1, y_2) = \{a - b(y_1 + y_2)\}y_2 - c_2 y_2 - K \tag{2.7}$$

The solution to (2.7) yields a best-response output for Firm 2: $y_2 = \frac{1}{2b}(a - by_1 - c_2)$. Moreover, we can obtain the maximum profit of Firm 2: $R_2^* = \frac{b}{4}(y_1 + \frac{2(c_1 - c_2)}{b})^2 - K$. Obviously, when $y_1 = \frac{2}{b}(c_2 - c_1)$ holds: $\min R_2 = -K$.

Once Firm 1 grasps the information of the marginal cost and entry cost of Firm 2's, we notes that Firm 1 can control the wind energy prices by deciding the production of the wind power according to those costs, so it can implement first-move advantages to attain entry deterrence to other potential entrants. When Firm 1 employs entry deterrence to Firm 2, its output will lower than optimal level and the price will deviate from the competitive price level. In order to obtain a higher profit through returning to its action, Firm 1 sets $p^* = 2c_1$, based on the marginal profit equal to its marginal cost: $\partial R_1 / \partial y_1 = \partial(c_1 y_1) / \partial y_1$. Table 1 lists the strategies of Firm 1 and Firm 2 when the marginal costs and entry cost change in different scope.

The first column of Table 1 to the left lists the relation of marginal cost of Firm 1 and Firm 2. The second column is the entry cost for Firm 2 to invest wind-farm in this region. According to the change scope of and together with Firm 2's reaction function, Firm 1 decides the amount of wind power produced as shown in the third column. The fourth column shows the profits of Firm 2, and Firm 2's strategies is listed in the last column.

From the Table 1, we can see that Firm 1's profit will reduce, even to be zero. Obviously, these are dominated strategies, and it is showed more clearly in Table 2. Once Firm 2 entries the market, Firm 1 chooses Stacklberg leadership action, and the other responds according to the Cournot reaction function.

In Chinese wind-farm investment market, the first-mover advantage is very important for enterprises, so, every one wants to entry a region first, and in order to achieve the goal, many SOEs take the way of "Enclosure Movement", and even to loss. Though it is obvious that to set entry barriers is a bad strategy for preemptive firms, it exists everywhere in China's wind-farm investment market.

3. The Cournot-Nash Game

Indeed, in some situations, the competition in Chinese wind-farm investment market is oligopolistic, for instance there are Huaneng, Huarun and Guodian Power Development Company and other large companies participating in the wind-farm investment market in Liaoning Province, each has the similar competitive strength. The

approach used in this study is to calculate an economic equilibrium concept known as the Cournot-Nash equilibrium. In Cournot-Nash equilibrium, each firm considers the output of all the other firms and sets its own output in a way that maximizes its profits when selling to a price-responsive demand curve. In equilibrium, each firm is producing at its profit-maximizing output, given the output of all the other firms. The following assumptions provide a further definition of equilibrium under the economic circumstances it addresses.

Assumption 3.1 N regulated firms are engaged in a regional wind-farm investment market, and each is "rational man". Furthermore, there are big barriers of entry for other potential entrants. In this market, all the firms are price taker, that is, they produce a certain quantity, and the price is determined by the market demand. The firm's strategy is based on quantity rather than price. Firm i set its power produced quantities y_i, $i = 1, 2, \cdots, N$. $Q = \sum_{i=1}^{N} y_i$, which is the total production in the market.

Assumption 3.2 We assume that inverse demand function is a linear function of the form: $p = a - b\sum_{i=1}^{N} y_i$. Suppose that fixed costs are zero and that marginal costs (the costs for generate a single added wind power) are constant, with value c. This assumption means that costs are linear in y_i. So the cost function is of the form $C(y_i) = cy_i, c \geq 0, i = 1, 2, \cdots, N, a > 0, b > 0, a > c$, where p is the equilibrium price.

3.1 Cournot Nash Model

Firm i maximizes profit by selecting an output level:

$$\max_{y_i} R_i(y_1, y_2, \cdots, y_n) = (a - b\sum_{i=1}^{n} y_i)y_i - cy_i \tag{3.1}$$

To find Firm i's production, we take the derivative of its profit function with respect to firm i's quantity and set it equal to zero:

$$\frac{\partial R_i}{\partial y_i} = a - 2by_i - b\sum_{k \neq i}^{N} y_k - c = 0 \tag{3.2}$$

Evidently, (3.2) is equivalent to the following:

$$by_i = a - c - b\sum_{k=1}^{N} y_k \tag{3.3}$$

Obviously, the right side of (3.3) is independent with Firm i. We find that all firms chose the same production strategy given the assumption 3.1 and 3.2. We denote equilibrium output is y^* and (3.3) can be rearranged as $by^* = a - c - Nby^*$, this means that

$$y^* = \frac{a-c}{b(N+1)} \tag{3.4}$$

According to assumption 3.1 and (3.4), we conclude the total power produced quantities, price of wind power and the profit of Firm i as following:

$$Q^* = \sum_{i=1}^{N} y_i = Ny^* = \frac{N(a-c)}{b(N+1)} \tag{3.5}$$

$$p^* = a - \frac{N(a-c)}{N+1} < a \tag{3.6}$$

$$R_i^* = \frac{(a-c)^2}{(N+1)^2 b} \tag{3.7}$$

By virtue of (3.5), (3.6) and (3.7), we have the deviation of the market price from the marginal cost is:

$$p^* - c = \frac{a-c}{N+1} > 0 \tag{3.8}$$

If there is a single firm, that is $N = 1$, in a regional wind-farm investment market, then the deviation will be largest. On the other hand, when $N \to \infty$, $\lim_{N \to \infty} \frac{a-c}{N+1} = 0$. This implies that the competitive equilibrium price will be reach to marginal cost.

4. Numerical Examples

Suppose one region consists of two wind energy firms, they are Firm 1 and Firm 2. The former is larger and entries the market first. The inverse demand function is defined by $p = 1 - 10^{-9}(y_1 + y_2)$, where y_1, y_2 are the production quantities, respectively (kWh). They have different marginal cost, denoted by and c_1, c_2, respectively.

The entry cost of Firm 2 is constant, denoted by K. Once Firm 2 entries into the market and action as Stacklberg follower, and K will be ignored in the total cost. The profits for both firms are R_1 and R_2, respectively. The total output is denoted as Q, and p is the equilibrium wind power price. Furthermore, in the first column of Table 2, A represents Stacklberg game, B represents the extend model of Stacklberg game and C represents Cournot game. The output, profits of each firm, the total equilibrium output, equilibrium price and the strategies of Firm 2 are reported in the Table 2 under the different cost levels. Where the units of each variable is: $c_i(yuan/kW)$, $K(10^5 yuan)$, $y_i(10^8 kWh)$, $R_i(10^8 yuan)$, $Q(10^8 kwh)$, $p(yuan/kW)$.

Three results can be concluded from the example:

(1) In a duopoly wind energy investment market, if the preemptive leader permits other rival firms to entry, the Stacklberg action of them will be "win-win" strategies. We then consider the scenario where Firm 1 hope to guarantee monopoly state by regulating it's output strategies according to the entry cost of Firm 2. In this case, Firm 1 will lose comparing with the case of Stacklberg profit although it can make the rival firm withdraw from market in certain cases, even though Firm 1 can reduce loss by raising price.

(2) When the marginal cost of Firm 2 is lower or the entry cost is small, Firm 1 will lose more to employ entry deterrence, on the other hand, deviation of the monopoly price from the marginal cost will farther, that is, the low-cost firm always leads due to its dominant competitive advantage.

(3) When two oligopolies with the same marginal cost act as Cournot players, both firms are price takers. The firm's strategy is based on quantity rather than price. As is the case with any firm, both firms choose their quantity of production so as to maximize its own profits no matter its rival's decision. Region government should encourage to completing in wind-farm investment market.

5. Conclusion

Combing the current situation in China, we have presented the results of simulations of the wind-farm investment market where some firms act strategically. These strategic firms were assume to follow Stacklberg, the extend Stacklberg and Cournot strategies. The followings are the main suggestions of this study.

(1) From the viewpoint of long-term sustainable development, wind power has to depend on the improvement of its economic performance in order to be independent from government support in the future. Thus, it would be much better to establish a competitive incentive mechanism to push for cost reduction in utility purchasing price of wind power.

(2) In China, some remedies to current institutional framework need to be done to support wind-farm investment market and to make wind-farm investment market much competitive. One is to eliminate monopoly, punish the behavior of malicious competition and introduce a market competition mechanism so as to reduce wind generation cost. Another is to set up a specific and effective investment policy to attract private investment.

(3) Since wind power industry is more like a monopoly market under control of electricity utilities in China, it blocks the entry of private and foreign investors, though there is a regulation about management of gird-connected wind-farms. Unless a clear and effective investment policy or regulation was established to reduce the risk of investment and to eliminate malicious competition, wind-farm projects will not be able to attract enough investment. The "Enclosure Movement" in wind-farm investment markets must be forbidden by making strict entrance policies and perform seriously.

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Table 1. Stacklberg competition between wind-farm investment enterprises when entering cost exists

c_i	K	y_1	R_2	Firm 2's strategies
$c_2 > c_1$	$K < \dfrac{(c_2 - c_1)^2}{b}$	$-\sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}} \leq y_1 \leq \sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$	$R_2 = 0$	Withdraw from market
		$y_1 > \sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$ or $0 < y_1 < -\sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$	$R_2 > 0$	Entry into the market and action as Shacklberg follower
	$K \geq \dfrac{(c_2 - c_1)^2}{b}$	$0 \leq y_1 \leq \sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$	$R_2 = 0$	Withdraw from market
		$y_1 > \sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$	$R_2 > 0$	Entry into the market and action as Shacklberg follower
$c_2 \leq c_1$	$K > \dfrac{(c_1 - c_2)^2}{b}$	$0 \leq y_1 \leq \sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$	$R_2 = 0$	Withdraw from market
		$y_1 > \sqrt{\dfrac{4K}{b} + \dfrac{2(c_2 - c_1)}{b}}$	$R_2 > 0$	Entry into the market and action as Shacklberg follower
	$K \leq \dfrac{(c_1 - c_2)^2}{b}$	$y_1 \leq 0$ (delete)	$R_2 > 0$	Entry into the market and action as Shacklberg follower

Table 2. Gaming between two firms under the different cost levels

	c_i	K	y_i	R_i	Q	p	Firm 2's strategies
A	$c_1 = 0.40$ $c_2 = 0.45$	-	$y_1 = 3.25$ $y_2 = 1.125$	$R_1 = 0.53$ $R_2 = 0.28$	4.375	0.56	Entry into the market and action as Shacklberg follower
B	$c_1 = 0.40$ $c_2 = 0.45$	30	$0 < y_1 \leq 0.1$ $y_2 = 0$	$R_1 = 0.04$ $R_2 = 0$	0.10	0.80	Withdraw from market
			$y_1 > 0.1$	$R_1 = 0.53$ $R_2 = 0.28$	1.09	0.56	Entry into the market and action as Shacklberg follower
		2	$0.11 < y_1 \leq 1.89$ $y_2 = 0$	$R_1 = 0.756$ $R_2 = 0$	1.89	0.80	Withdraw from market
			$y_1 \geq 1.89$ or $0 < y_1 \leq 0.11$	$R_1 = 0.53$ $R_2 = 0.28$	1.09	0.56	Entry into the market and action as Shacklberg follower
	$c_1 = 0.40$ $c_2 = 0.35$	30	$0 < y_1 \leq 0.10$ $y_2 = 0$	$R_1 = 0.04$ $R_2 = 0$	0.10	0.80	Withdraw from market
			$y_1 = 2.75$ $y_2 = 1.875$	$R_1 = 0.41$ $R_2 = 0.35$	4.625	0.54	Entry into the market and action as Shacklberg follower
		2	$y_1 = 2.75$ $y_2 = 1.875$	$R_1 = 0.41$ $R_2 = 0.35$	4.625	0.54	Entry into the market and action as Shacklberg follower
C	$c_1 = 0.40$ $c_1 = 0.40$	-	$y_1 = 2.0$ $y_2 = 2.0$	$R_1 = 0.4$ $R_2 = 0.4$	4.0	0.60	Cournot Nash game