Review of Economics & Finance
Submitted on 25/08/2015
Article ID: 1923-7529-2016-01-01-12 Xuemei Liu

Why Has Wind Power Capacity Been Overinvested Under Uncertainty in China?

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Abstract: There are many uncertainties associated with the investment in wind power capacity in China. Nevertheless, wind capacity in China has been overinvested in the past several years and continues to be invested. This study attempts to explore the reasons why overinvestment has occurred under uncertainty. The analytical result implies that it would be optimal to invest more under uncertainty than in the corresponding risk-free world if an increase in the capital stock of wind capacity can significantly reduce the risk of wind abandonment. Since the majority of the investors are SOEs, it is very likely that the investors believe that higher wind capital stock can help to significantly reduce the risk, and thus have incentives to invest more under uncertainty. This belief is mainly backed up by the fact that SOEs play a special role in the economy. Therefore, overinvestment in wind capacity can hardly be avoided.

Keywords: Wind power capacity, Investment, Uncertainty
JEL Classifications: Q42, Q43, Q48

1. Introduction

There are a lot of uncertainties associated with the return on investment in wind power capacity in China. The uncertainties mainly come from four sources: technology, grid system, market and policy.

It is intuitive and has been shown in a number of economic studies that investments are likely to be discouraged by uncertainty. For examples, Becker et al. (1977) argues that the uncertainty of divorce discourages the investment in marriage-specific capital; Bond and van Reenen (2007) shows that the responsiveness of investment to any given policy stimulus may be much weaker in periods of high uncertainty.

Therefore, it is reasonable to expect that the investment in wind capacity would be discouraged by the uncertainties. However, the Chinese reality has proven to be the complete opposite to that expectation. The wind capacity has far exceeded the grid and transmission capacities, and wind abandonment has become a common problem across the country, but new wind farms continue to be invested.

To the best knowledge of the authors, it has rarely been addressed or discussed why uncertainty has not discouraged the investment in wind capacity. This paper contributes to the economic and energy policy literature by making the first attempt to explore the reasons why overinvestment has occurred under high uncertainty in China.

We conduct a theoretical analysis by using the approach of dynamic and stochastic optimal control, which can well capture the dynamic nature of investment in wind capacity and the stochastic nature of uncertainty. This paper is organized as follows. Section 2 presents literature review. Section 3 describes the framework and setup of the model. Section 4 discusses the implications of the model. Conclusions are presented in Section 5.

2. Literature Review

The uncertainties associated with the return on investment in wind power capacity in China come from several sources. One major source is the technology. Without sufficient and accurate wind resource assessments, many wind farms built in China cannot generate as much electricity as anticipated (Zhang et al., 2009). In addition, although Chinese enterprises have mastered the technology to produce small-scale turbines, the domestic technology to produce large-scale turbines is still immature (Yu and Qu, 2010). Many of the wind turbine design systems are transferred from foreign companies, with no databases and know-how. As a result, wind turbines cannot be customized to meet the specific requirements of the wind resources in China, so they do not operate as well as expected (Zhang et al., 2009). Thus, at the time of making investment, it is uncertain how much electricity will be generated.

The second major source of uncertainty is the limited grid capacity and transmission technology. Given the current status of the grid network, it is difficult for the wind-powered electricity to be connected to and transmitted by the grid network. Energy demand is concentrated in the eastern and southeastern areas, but wind power resources are most abundant in the northern and northwestern parts of the country. A large proportion of the wind electricity must be transmitted from the northwest to the southeast. However, current grid network does not have enough capacity to accommodate and transmit much of the wind-powered electricity. In addition, current grid system is unable to accommodate the intermittent nature of wind and the erratic fluctuations of large scale wind power. As a result, only 62.51% of the wind capacity installed in 2009 was connected to the grid (Fang et al., 2012). By 2009, about 28% of installed wind turbines could not send electricity onto the grid network (Yu et al., 2011). By 2010, about 30% of the total installed capacity had not been integrated with grid (Zhao et al., 2012). Because the investment cost for transmission infrastructure is high and grid companies do not have financial incentives to undertake the investment in transmission infrastructure (Liu and Kokko, 2010), it is not expected that the grid system will be improved significantly in near future. Therefore, the difficulty of connecting to the grid network will continue to be a serious concern for the wind capacity investors.

The third source of uncertainty is the electricity market and price. China is currently in early stages of developing electricity markets. The markets are far away from being complete. So far there are only limited markets in the generation sector, but there is no market for the transmission, distribution and consumption sectors (Jaccard and Mao, 2001). The electricity price is strictly controlled by the central government. The on-grid power prices and final sale power prices must be approved by the National Development and Reform commission (NDRC) (Zhao et al., 2012). There are two channels for the government to control prices: bidding pricing and fixed benchmark pricing. For wind power concession projects, the bid winners were promised a guaranteed market demand and a fixed electricity tariff. For other projects, the pricing decisions must be based on a benchmark that is determined by the unit price for local coal-powered electricity generation (Liu and Kokko, 2010). The feed-in tariff for wind power in 2009 was in the range of 51 cents and 61 cents RMB/kWh, which is much higher than the price for coal powered electricity, which is 31 cents RMB/kWh (Qiu and Anadon, 2012). The huge price difference between the wind-powered electricity and coal-powered electricity makes it very difficult to predict how the wind-powered electricity price will evolve in the future. The price evolvement is also complicated by its influences on society and the economy and thus is affected by many factors (Qiu and Anadon, 2012).

The fourth source of uncertainty is the energy policy. The “Renewable Energy Law”, issued in 2005, states that 15% of national energy consumption is to be sourced from renewable energy by 2020; in addition, large state-owned power companies will be obliged to ensure that wind power accounts for at least 5% of their total energy output by the same year (Lema and Ruby, 2007). Nevertheless, the law is very abstract and does not have details on how it will be implemented in 2020. Since the political and economic changes in China have been enormous in the past thirty years, and are expected to continue in the future, it is uncertain whether the obligation of wind power will be really imposed on power companies by 2020. In case it will be imposed, it is uncertain whether the government will adopt stringent policy instrument such as quota or incentive-based instrument such as tradable quota. Since different policy instruments will have very different impacts on the companies, the uncertainty of the government policy is one of the main concerns for the investors of wind capacity.

Nevertheless, the uncertainties have not discouraged the investment in wind capacity. By the end of 2011, the total installed wind capacity in China reached 62.73 GW (Wu, Li, Ba) and ranked first in the world (NDRC, 2011)(Fang et al., 2012)(Hu et al., 2013). The installed wind capacity in China has far exceeded the grid and transmission capacities. As a consequence, about 30% of the capacity sits idle (Chinese News, 2012), and many wind farms cannot generate energy in accordance with their wind power capacity (Fang et al. 2012). Currently about 20GW generating capacity cannot be absorbed (Wu et al., 2013). Wind abandonment, which is wind energy waste due to failure of wind turbines, power grid congestion or other reasons, has become a serious problem in China. Recent Chinese news shows that the wind abandonment rate has reached about 20% in many areas in China (Chinese News, 2012).

Even though the wind capacity has far exceeded the grid and transmission capacities, and wind abandonment has become a common problem across the country, new wind farms continue to be invested. The reasons behind this interesting phenomenon have not been studied in the literature. There are few studies about the drivers behind rapid investment in wind capacity. Chen et al. (2011) concludes the high return rate is the chief cause because the energy payback time of a wind farm is only 0.94 year. This conclusion, which is drawn from a case study, cannot explain the general drivers behind the investment in wind capacity in China, because wind power is still a money-losing business in China. By contrast, there are many studies discussing the difficulties and barriers of getting good returns on the investment in wind capacity, such as inadequate grid infrastructure, waste in wind power development, wind farm outages, low capacity factors and low quality turbines (Cyranoski, 2009; Han et al., 2009; Li, 2010; Liao et al., 2010; Liu and Kokko, 2010; Rutkowski, 2010; Wang, 2010; Young et al, 2010; Yu et al. 2009).

3. The Model

We use the approach of dynamic and stochastic optimal control. Our model studies the investment behavior from the perspective of investors. The majority of investors in wind capacity in China are State Owned Enterprises (SOEs). By the end of 2008, nearly 90% of installed wind capacity was invested by SOEs, and 97% of the wind concession projects were developed by SOEs (Wang et al., 2010). We assume the investor’s objective is to maximize the net benefit derived from wind capacity, by choosing the investment level.

It is noted that this model is not a profit maximization model; instead, it is a benefit optimization model. The benefit includes both monetary benefit and non-monetary benefit. Since renewable energy is still a money-losing business even though it is supported by many favorable government policies[1], profit cannot be the major objective for SOEs to invest in wind capacity. Thus the driving force for investing in wind capacity must be non-monetary benefit. In addition to the goal of increasing employment, production, tax revenue and growth rates, as addressed in Liu and Kokko (2010), the non-monetary benefit also includes but not limited to the following tangible and intangible benefits:

(1) The investors can avoid future loss from not being able to fulfill obligations if stringent quota is imposed by 2020. It is not clear how the SOEs will be punished for not being able to fulfill the obligation. The punishment may take the form of monetary penalty as well as non-monetary punishment. For example, the chief executives of SOEs, who are actually government officials and can move freely back and forth into government positions, are likely to be punished in the form of losing their future promotion opportunities or even losing their current positions. Job security and promotion are the key concerns for government officials, thus the avoided uncertain loss is one of the major non-monetary benefits of investing in wind capacity.

(2) Another non-monetary benefit is the future value of occupying scarce resources. Wind-rich sites are scarce resources. If one day the SOEs are obliged to generate wind power, it would be more beneficial for them to take quick and early action to occupy the scarce wind-rich resources. In fact, occupying the sites with rich wind resources and convenient locations has been the focus of investing in wind capacity for some companies (Zhao et al. 2012).

(3) Investing in wind capacity may help to secure the whole company. These SOEs are large companies with core business on traditional coal-fired power plants, hydropower or nuclear power stations. Wind power has been and will be only a small part of their business. Investing in wind capacity can help to ensure their traditional energy power business stable in the future by reducing the chance that the company is punished by the government for not being able to fulfill the obligations about renewable energy.

The model studies how uncertainty affects the investment behavior. Because uncertainties come from different sources, the underlying outcome distribution is unknown. In other words, at the time of making investment, the investors do not know the probability of getting no return on investment. In our model, for simplicity's sake, we assume that the investor knows the probability of getting no return. Wind abandonment is one possible outcome of receiving no return. In this paper, we use wind abandonment to proxy the overall risk of receiving no return on investment.

The analysis in this section follows the approach developed by Clarke and Reed (1994), which studies how uncertainty about environmental catastrophe affects the optimal social choice of

[1] Since 2005, the central government has issued a number of policies, including the Renewable Energy Law (NPC, 2005), Renewable Energy Pricing and Cost Sharing Management and Trial Methods (NDRC, 2006), and the Mid- and Long-Term Development Plan for Renewable Energy (NDRC, 2007). These policies use instruments, such as favorable pool purchase pricing of wind power, tax exemption and reduction, and financial subsidies (Fang et al., 2012) to stimulate the investment in wind power.

consumption. We study a completely different problem. In our model, the choice variable is the level of the investment in wind capacity in each period. The investment includes not only the monetary investment in wind capacity, but also the non-monetary effort spent on obtaining the approval from the government through bidding in the wind concession program or lobbying the local governments. Let $z(t)$ denote the investment in period *t*, where *t* represent time period. Let *S* denote the capital stock of wind capacity, and $g(S)$ denote the decay function of the capital, which describes how the capital wears out. The decay function is assumed to be continuous and twice differentiable in *S*. Let $\dot{S}(t)$ represent the change in the capital stock in period *t*, which is given by

$$\dot{S}(t) = z(t) - g(S(t)) \text{, given } S(0) = S_0,$$

where S_0 is the initial capital stock of wind capacity at the beginning, which depends on the past accumulation of wind capacity investment.

Let $B(t)$ represent the benefit function, which is assumed to be continuous, concave and twice differentiable in *S*. The benefit in each period is a function of the stock of wind power capital:

$$B(t) = B(S(t)).$$

Let $C(t)$ represent the total cost of the investment, including the explicit cost and opportunity cost of the investment. This function is assumed to be continuous, convex and twice differentiable in investment,

$$C(t) = C(z(t)).$$

The investor maximizes the integration of net benefit from the wind capacity by choosing the investment in each period of time:

$$\max_{z(t)} \int_0^\infty e^{-rt} [B(S(t)) - C(z(t))] dt$$

subject to $\dot{S}(t) = z(t) - g(S(t))$ and $S(0) = S_0$.

where *r* is the discount rate that indicates the investor's time preference.

The current value Hamiltonian is

$$H = B(t) - C(t) + \lambda(z(t) - g(S(t))) \quad (1)$$

where λ is the current value costate variable associated with the state variable *S*.

In the future, if the wind abandonment occurs, the investor will no longer be able to derive benefit from the wind capacity. The probability of wind abandonment is characterized by the hazard rate function:

$$h(t) = \lim_{\Delta \to 0} \left\{ \Pr\left(\text{abandonment occurs in } (t, t+\Delta] \,\middle|\, \text{no abandonment in } [0,t] \right) / \Delta \right\} \quad (2)$$

The hazard rate of wind abandonment can be influenced by the size of the capital stock of wind capacity in either a positive way or a negative way. The influence will be discussed in details in next section. Thus the wind abandonment hazard function $h(t)$ is a function of $S(t)$:

$$h(t) = h(S(t)).$$

Let τ be a random variable denoting the time at which wind abandonment occurs. Let $F(t)$ represent the probability that $\tau \le t$. Then $F(t)$ is the c.d.f. of τ and $F'(t)$ is the associated density. The hazard function is defined to be

$$h(S(t)) = \frac{\dot{F}}{1 - F(t)}.$$

Since *B* and *C* are both monotone functions of *z,* the net benefit function $V(z,S)$ can be expressed in terms of *z*:

$$V(z,S) \equiv B(t) - C(t) \tag{3}$$

Let *E* denote the expectation with respect to τ . The investor maximizes the expected discounted flow of net benefit from the wind capacity before the wind abandonment occurs at time period τ :

$$E\left\{ \int_0^{\tau} e^{-rt} V(z,S) dt \right\}.$$

The above maximand can be written as $\int_0^{\infty} \left[\int_0^{\tau} e^{-rt} V(z,S) dt \right] \frac{dF}{d\tau} d\tau$.

By integrating by parts, we obtain

$$F(\tau) = \int_0^{\tau} e^{-rt} V(z,S) dt \Big|_0^{\infty} - \int_0^{\infty} F(t) e^{-rt} V(z,S) dt .$$

Since $F(0) = 0$ and $F(\infty) = 1$, then the maximand becomes

$$\int_0^{\infty} (1 - F(t)) e^{-rt} V(z,S) dt.$$

To simplify the problem, we define $R(t) = 1 - F(t) = \Pr\{\text{no abandonment in } [0,t]\}$, which is related to the hazard function by $\frac{\dot{R}(t)}{R(t)} = -h(t)$. Let $y(t) \equiv -\ln R(t)$, so that $e^{-y(t)} = R(t)$ and $\dot{y}(t) = -\frac{\dot{R}(t)}{R(t)} = h(S(t))$. By replacing $1 - F(t)$ in the maximand by e^{-y}, the maximand becomes $\int_0^{\infty} e^{-rt-y(t)} V(z,S) dt$. Then the optimization problem becomes

$$\underset{z(t)}{Max} \int_0^{\infty} e^{-rt-y(t)} V(z,S) dt$$

$$\text{Subject to} \quad \dot{S}(t) = z(t) - g(S(t)) \tag{4}$$

$$S(0)=S_0, \quad \dot{y}=h(S(t)), \quad y(0)=0.$$

Suppressing *t*, the current value Hamiltonian is

$$H=e^{-y}V(z,S)+\mu_1(z-g(S))+\mu_2 h(S),$$

where μ_1 and μ_2 are the current value co-state variables associated with states *S* and *y*.

Since wind abandonment is legally possible, $\dot{y}$ cannot be zero. However, there is a limiting value of *S*. Then a conditional steady state is defined to be a steady state at which the state variable *S* stops changing ($\dot{S}(t)=0$) conditional upon wind abandonment not having occurred.

The necessary conditions that must be satisfied on an optimal time path are:

$$\frac{\partial H}{\partial z}=e^{-y}V_z+\mu_1=0 \tag{5}$$

$$\dot{\mu}_1=(r+g'(S))\mu_1-e^{-y}V_S+\mu_2 h'(S) \tag{6}$$

$$\dot{\mu}_2=r\mu_2+e^{-y}V(z,S) \tag{7}$$

Totally differentiating Equation (5) with respect to time, using Equations (6) and (7), and then using Equation (5) to eliminate μ_1 , and collecting terms, we obtain

$$\dot{z}=\Gamma(z,S)+\Psi(z,S,\rho_2;h) \tag{8}$$

where $\rho_2\equiv e^y\mu_2$, $\Gamma\equiv\left[(r+g'(S))V_z+V_S-V_{zS}(z-g(S))\right]/V_{zz}$, $\Psi\equiv\left[h(S)V_z-h'(S)\rho_2\right]/V_{zz}$.

In Equation (8), $\dot{z}$ is decomposed into two functions: Γ is the time derivative of *z* when there is no risk of wind abandonment ($h=0$) and Ψ collects all the terms that involve the risk term *h*.

The conditional steady state requires $\dot{S}(t)=0$. Then Equation (4) implies at the conditional steady state

$$z(t)=g(S(t)) \tag{9}$$

which means that at the conditional steady state, the investment is equal to the wear-out of the capital stock. The capital stock *S* is constant if and only if *z* is constant. In order for *z* to be constant, equation (8) requires that $\Gamma+\Psi$ = 0. If both z and *S* are constant, then ρ_2 must be constant. Using the definition of ρ_2, we have $\dot{\rho}_2=0$ if and only if

$$\rho_2=-\frac{V}{r+h(S)} \tag{10}$$

Equation (10) is used to eliminate ρ_2 in the function Ψ , then we can write $\dot{z}=0$ if and only if

$$\left[r+g'(S)+h(S)\right]V_z+V_S=-\frac{h'(S)V(z,S)}{r+h(S)} \tag{11}$$

We can analyze the effect of the existence of uncertainty by examining the comparative statics of the deterministic steady state, using the stability condition. The deterministic system is given by $\dot{S}(t) = z(t) - g(S(t))$ and $\dot{z} = \Gamma(z, S)$. The linearization of this system is

$$\begin{pmatrix} \dot{S} \\ \dot{z} \end{pmatrix} \approx \begin{bmatrix} -g' & 1 \\ \Gamma_S & \Gamma_z \end{bmatrix} \begin{pmatrix} S \\ z \end{pmatrix} = A \begin{pmatrix} S \\ z \end{pmatrix}.$$

If we have a steady state in the deterministic problem, it must be a saddle point, and therefore the determinant of A must be negative.

Now we can consider the stochastic system of equations $\dot{S}(t) = z(t) - g(S(t))$ and $\dot{z} = \Gamma(z,S) + \Psi(z,S,\rho_2;h)$. If $\Psi() = 0$, the equations are for the deterministic steady state. If $\Psi() \neq 0$, the equations are for the steady state under uncertainty. The impact of Ψ on the steady state can be analyzed by totally differentiating the system treating Ψ as a constant parameter, using Cramer's rule,

$$\frac{dS}{d\Psi} = \frac{1}{|A|} < 0 \tag{12}$$

Due to the fact that the determinant of A is negative, Equation (12) shows how the steady state of S depends on the sign of Ψ ; that is, if $\Psi > 0$, the conditional steady state is lower than the deterministic steady state. On the other hand, if $\Psi < 0$, then the conditional steady state is higher than the deterministic steady state.

Using the definition of Ψ and Equation (10), we see that $\Psi > 0$ if and only if

$$\frac{V_z}{V} > -\frac{h'(S)}{(r+h)h} \tag{13}$$

If Inequality (13) holds true, Ψ will be positive, then the investment under uncertainty will be lower than the deterministic steady state.

On the other hand, Ψ is negative if and only if

$$\frac{V_z}{V} < -\frac{h'(S)}{(r+h)h} \tag{14}$$

If Inequality (14) holds true, Ψ will be negative, then the investment under uncertainty will be higher than the deterministic steady state.

Therefore, the inequality sign of Inequality (13) determines whether the investment under uncertainty is higher or lower than deterministic steady state. Both V and V_z are positive, so the left side of Inequality (13) must be positive. Then the inequality sign depends on the sign and value of the right side, which is determined by three factors: the time preference r, the hazard rate h and the marginal hazard rate of capital stock $h'(S)$. The time preference and hazard rate are positive for sure. The sign of the third factor $h'(S)$ depends on how the increase in capital stock of wind capacity influences the hazard rate of wind abandonment. It is positive if larger size of capital stock increases the hazard rate of wind abandonment, and is negative if larger size of capital stock reduces the hazard rate of wind abandonment. Therefore, depending on the sign of $h'(S)$ and the magnitudes of the three factors, *r*, *h* and $h'(S)$, there are two possible situations:

(1) Investment is lower under uncertainty

This situation occurs if $h'(S)$ is positive. When *r*, *h* and $h'(S)$ are all positive, the right side of Inequality (13) is negative. Since the left side is positive, then the left side must be greater than the right side. As Inequality (13) holds true, Ψ will be positive, as a result, the investment under uncertainty will be lower than the deterministic steady state. A positive $h'(S)$ means an increase in capital stock will increase the risk of wind abandonment. In the case when more investment in wind capacity leads to higher risk, an investor would have less incentive to make the investment. It is noted here that a positive $h'(S)$ is a sufficient condition for underinvestment under uncertainty.

(2) Investment is higher under uncertainty

This situation occurs if $h'(S)$ is negative and the magnitude of $h'(S)$ is significantly large relative to the magnitudes of *h* and *r* to make the right side positive and greater than the left side, so the Inequality (14) holds true. As a result, Ψ is negative, which implies that the investment under uncertainty will be higher than the deterministic steady state. A negative $h'(S)$ means an increase in capital stock will reduce the risk of wind abandonment. In the case when the magnitude of $h'(S)$ is significantly large relative to the magnitudes of *h* and *r*, an investor will have an incentive to invest more in wind capacity under uncertainty than in a risk-free environment. It is noted here that a negative $h'(S)$ is a necessary condition but not sufficient condition for overinvestment under uncertainty. However, combining a negative $h'(S)$ with a significantly large value of $h'(S)$ will be a sufficient condition for overinvestment under uncertainty.

4. Discussions

The analytical result in Section 2 implies that a negative $h'(S)$ is a necessary condition but not sufficient condition for overinvestment under uncertainty; that is, only if $h'(S)$ is negative, the overinvestment under uncertainty may occur. In other words, if we observe investment is more under uncertainty than in a certain world, then it must be true that $h'(S)$ is negative. In addition, combining a negative $h'(S)$ with a significantly large value of $h'(S)$ is a sufficient condition for overinvestment under uncertainty. Therefore, the key factor that can explain the overinvestment is a negative $h'(S)$ with a large value. Since the investment is made before the investors observe how the wind capital stock affects the risk, $h'(S)$ actually depends on the investor's prediction. If investors predict that higher capital stock of wind capacity will reduce the risk of wind abandonment, and the influence is significantly large, then they would have incentives to invest more under uncertainty than in a corresponding certain world.

There are several possible reasons why investors believe that $h'(S)$ is negative and the value of it is large; that is, a higher wind capital may significantly reduce the risk of wind abandonment and in turn to secure and enforce the wind farms and SOE's core business: First, since wind-rich sites are scarce resources, increasing the investment in wind capacity helps to increase the chance of occupying good sites with rich wind resource and good locations. Good sites can certainly help to reduce the risk of wind abandonment. Second, larger capital stock of wind capacity will help the SOEs to gain more market power. After the SOEs procure the ownership of the rich wind sites, other companies, including those private and foreign companies that have better technology and lower cost, will no longer be able to enter and compete in this market. The higher market power will further secure the SOEs' wind farms and core business. Third, larger capital stock of wind capacity will help the SOEs to gain more bargaining power with the government and state-owned grid companies. The "Approach of Grid Enterprises Purchasing Renewable Energy Electricity" issued in 2007 states that grid enterprises are required to purchase renewable energy at the benchmark prices. In addition, if a renewable energy generating company suffers economic losses because of problems of connecting to the grid, the grid company should take the responsibility to bear the losses. Nevertheless, there are few specific regulations and instructions on how to connect wind power to the grid (Liu and Kokko, 2010). Then it is up to the power generation company to negotiate with the two giant state-owned grid companies. Only large power generation companies have the capability and bargaining power to negotiate with the grid companies and the government who plays an important role in the negotiation. The SOEs have strong influences on employment, GDP, and tax revenue. Thus, as they grow bigger, the government will have more incentive to help them to negotiate with grid companies. Therefore, being bigger will help the investors to improve the capability of getting connection to the grid system, and in turn secure wind farms and reduce the risk.

For the above reasons, it is very likely that SOEs believe that larger capital stock of wind capacity will significantly reduce the risk of wind abandonment and in turn secure the wind farms and whole company. This belief meets the sufficient condition for overinvestment under uncertainty. Therefore, it provides a reasonable explanation why wind capacity has been overinvested rather than underinvested under high uncertainty in China.

5. Conclusion

It is intuitive and has been shown in the literature that investments are likely to be discouraged by uncertainty. There are a lot of uncertainties associated with the investment in wind capacity in China. However, the investment in wind capacity in China has not been discouraged by uncertainties. The wind capacity has far exceeded the grid and transmission capacities, and continues to be invested. This paper explores the reasons why wind capacity has been overinvested under uncertainty. We conduct a theoretical analysis by using a dynamic and stochastic control model. Our model shows that the impact of uncertainty on investment depends on three factors: time preference, the level of the risk and how the increase in the capital stock of wind capacity affects the risk of wind abandonment. The third factor is the key element that determines whether investment will be encouraged or discouraged by uncertainty. There are two possibilities: if the increase in wind capital stock increases the risk, then the investment in wind capacity will be lower under uncertainty than in a certain world; that is, risk will discourage investment; if the increase in wind capital stock can reduce the risk, and the marginal effect is large enough relative to the magnitudes of time preference and the value of risk, then the investment in wind capacity will be higher under uncertainty than in a certain world; that is, risk may encourage investment.

Our analysis implies that it would be optimal to invest more under uncertainty than in the corresponding risk-free world if an increase in the capital stock of wind capacity can significantly reduce the risk of wind abandonment. At the time of making investment, investors do not know how the capital stock will affect the risk, so their decisions depend on what they believe and how they predict about the impact of capital stock on risk. Since the majority of the investors are SOEs, it is very likely that the investors believe that higher wind capital stock can help to significantly reduce the risk. This belief is mainly backed up by the fact that SOEs play a special role in the economy – higher level of wind capital stock may help these SOEs to gain more market power and also bargaining power with the government and grid companies, and thus reduce the risk and further secure the whole companies in the future. Therefore, given the ownership of the energy companies and their special role in China, overinvestment in wind capacity can hardly be avoided.

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