Real Options in Renewable Portfolio Standards

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1 Introduction

Recently policymakers have implemented various policies for reducing greenhouse gas emissions, due to concerns about global warming and climate change. Foremost policies for supporting and promoting renewable energy are feed-in tariff (FIT), and renewable portfolio standards (RPS). RPS scheme encourages power producers to supply a certain minimum share of their electricity from renewable energy sources. They create market for renewable energy certificates/credits.

Relationship between RPS scheme and market equilibrium is studied by Sidiqui, Tanaka and Chen [2]. Boomsma, Meade and Fleten [1] investigate investment timing and capacity sizing under different support schemes for renewable energy.

In this paper, we examine a market equilibrium under uncertainty in RPS by means of real options analysis. More concretely, we analyze an investment timing for renewable producer. After that, we derive optimal RPS target.

2 Problem Formulation

We consider two types of power producers in the electricity industry. One is a non-renewable producer: NRE, and the other is a renewable producer: RE. We assume there is only NRE in the market at initial time, and RE enters into the market by incurring investment cost I. Market states are represented by 0 and 1 before/after the entry.

In state i, q_{ni} denotes generation by a NRE, and q_r denotes generation by a RE. Then, electricity price in state i, p_i, is given by

$$p_0 = X_t - \eta q_{n0}, \tag{1}$$
$$p_1 = X_t - \eta(q_{n1} + q_r), \tag{2}$$

where X_t is the following GBM:

$$\mathrm{d}X_t = \mu X_t \mathrm{d}t + \sigma X_t \mathrm{d}W_t, \qquad X_0 = x. \tag{3}$$

We set linear operating cost functions of NRE in state i and RE as

$$c_{ni}(q_{ni}) = C_n q_{ni}, \qquad c_r(q_r) = C_r q_r, \tag{4}$$

respectively. Moreover, we set the quadratic function of output only for NRE as

$$d(q_{n,i}) = \frac{1}{2} K q_{n,i}^2. \tag{5}$$

We assume the parameter $\alpha \in (0, 1)$ defines the RPS requirement, and the risk adjusted discount rate is given by ρ.

3 The Model

Profit functions in state 1 are given by

$$\pi_{n1} = p_1(x, q) q_{n1} - C_n q_{n1} - \alpha p_r q_{n1}, \tag{6}$$
$$\pi_r = p_1(x, q) q_r - C_r q_r + (1 - \alpha) p_r q_r, \tag{7}$$

and maximized under Cournot equilibrium:

$$\max_{q_{n1}} \ \pi_{n1}, \quad \max_{q_r} \ \pi_r, \tag{8}$$
$$\text{s.t.} \quad 0 \le p_r \perp q_r - \alpha(q_{n1} + q_r). \tag{9}$$

As a result, we have

$$q_{n1}^* = \frac{(1 - \alpha)(x - C(\alpha))}{B(\alpha)}, \tag{10}$$
$$q_r^* = \frac{\alpha(x - C(\alpha))}{B(\alpha)}, \tag{11}$$

where

$$B(\alpha) = 2\eta(\alpha^2 - \alpha + 1), \tag{12}$$
$$C(\alpha) = (1 - \alpha) C_n + \alpha C_r. \tag{13}$$

Then, we have the market equilibrium in state 1:

$$q_1^*(x) = q_{n1}^* + q_r^* = \frac{x - C(\alpha)}{B(\alpha)}, \tag{14}$$

$$p_1^*(x) = p(x, q_1^*) = \frac{\eta\{(2\alpha^2 - 2\alpha + 1)x + C(\alpha)\}}{B(\alpha)}. \tag{15}$$

Next, we derive value functions. Expected value of RE after investment is given by

$$
\begin{aligned}
G_r(x) &= \mathbb{E}\left[\int_0^\infty e^{-\rho t}\pi_r^* dt\right] \\
&= \frac{\eta\alpha^2}{B^2(\alpha)}\left(\frac{x^2}{\delta} - \frac{2C(\alpha)x}{\rho-\mu} + \frac{C^2(\alpha)}{\rho}\right),
\end{aligned} \tag{16}
$$

where $\delta = \rho - 2\mu - \sigma^2 > 0$. Then we have value function of RE

$$
V_r(x) = \begin{cases} A_r(\alpha)x^{\beta_1}, & \text{for } x < X_r^*, \\ G_r(x) - I, & \text{for } x \geq X_r^*, \end{cases} \tag{17}
$$

and investment threshold X_r^* has a complicated analytical form. On the other hand, value function of NRE is given by

$$
V_n(x) = \begin{cases} G_{n0}(x) + A_n(\alpha)x^{\beta_1}, & \text{for } x < X_r^*, \\ G_{n1}(x), & \text{for } x \geq X_r^*. \end{cases} \tag{18}
$$

Finally, we define social welfare in state i

$$
\begin{aligned}
G_{si}(x) = \mathbb{E}\Bigg[\int_0^\infty e^{-\rho t}\Bigg(X_t q_i^* - \frac{1}{2}\eta q_i^{*2} \\
- C_i q_{ni}^* - C_r q_{ri}^*\Bigg)\mathrm{d}t\Bigg],
\end{aligned} \tag{19}
$$

and the global social welfare function

$$
SW(x) = \begin{cases} G_{s0}(x) + A_s(\alpha)x^{\beta_1}, & \text{for } x < X_r^*, \\ G_{s1}(x) - I, & \text{for } x \geq X_r^*. \end{cases} \tag{20}
$$

Optimal RPS target is solved by

$$
\alpha^*(x) = \operatorname*{argmax}_{\alpha} G_{s1}(x;\alpha). \tag{21}
$$

4 Numerical Analyses

We use base case parameters: $\mu = 0$, $\rho = 0.1$, $C_n = 0.2$, $C_r = 0.8$, $\eta = 0.01$, $I = 10$. Additionally, we compute comparative statistics with respect to $\sigma \in [0.16, 0.24]$ and $K \in [0.0075, 0.01, 0.0125]$.

Figure 1 shows optimal RPS target, and Figure 2 shows investment threshold with optimal α.

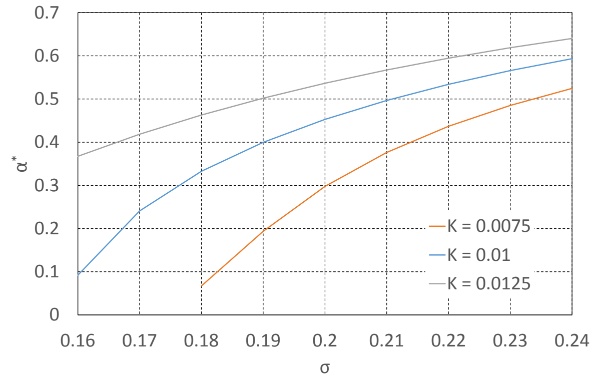

Figure 1: Optimal RPS target.

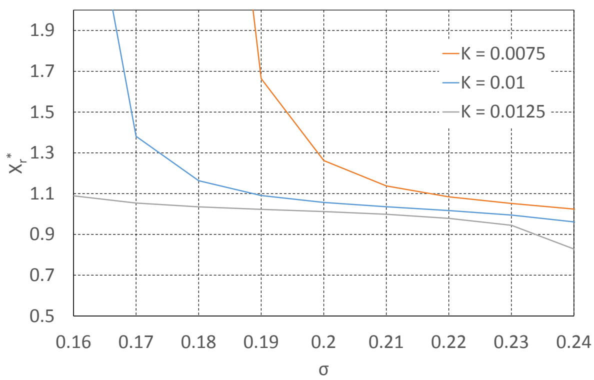

Figure 2: Investment threshold with optimal α.

5 Conclusion

We have found results about the effect of uncertainty on market equilibrium and optimal RPS target. For fixed RPS target, investment opportunity increases (decreases) with RPS target (uncertainty). For the optimal RPS target, investment opportunity increases with uncertainty. This is a new finding in this area.

References

[1] Boomsma, T. K., Meade, N. and Fleten, S.-E. (2012): Renewable energy investments under different support schemes: A real options approach, *European Journal of Operational Research*, **220**, 225–237.

[2] Sidiqui, A., Tanaka, M. and Chen, Y. (2016): Are targets for renewable portfolio standards too low? The impact of market structure on energy policy, *European Journal of Operational Research*, **250**, 328–341.