Deploying a Renewable Energy Project: An Equilibrium Analysis

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Abstract

Deploying a renewable energy project is an important decision that can facilitate sustainability. In addition, these projects can mitigate many environmental and health issues that arise with the excessive generation from depletable resources, such as gas and coal. This paper analyzes the impact of increasing the probability of deploying a renewable energy project in a Cournot oligopoly energy market, where two generation firms are in equilibrium. The results show that supply rises and prices fall, when the probability of deploying an energy project increases.

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1. INTRODUCTION

The consumption of depletable resources, such as gas or coal, for generating energy is a problem from a sustainability perspective, since supplies used now are not available for future generations. These carbon-based energy sources are also directly related to many environmental and health issues; due to this fact, there are many policies in place to mitigate theses energy generation problems (Grubb 2004), thus reducing environmental pollution, global warming and public health issues.

As the number of people living in cities increases, the demand for energy in urban areas also increases. Madlener and Sunak (2011) state that the process of urbanization is increasing energy consumption, especially in less developed countries; hence, energy planning in urbanization management is a key issue that has to be addressed. In addition, energy generation from depletable resources is not a sustainable solution for this issue and this is why renewable energy technologies are an important part of the portfolio mix of generation companies. Policies for promoting renewable energy, such as the Renewable Portfolio Standards (Wiser, Namovicz, Gielecki, and Smith 2007) in the US and the RES Directive (Klessmann, Lamers, Ragwitz, and Resch 2010) in the EU, are playing an increasingly important role in the decision-making process of generation companies. Hence, planning the allocation of depletable and renewable sources over time is an issue that has to be addressed.

One might think that it is a reasonable strategy to extract less depletable resources today in order to save the reserves for future generations. However, restricting the supply makes the price increase above the competitive level. Renewable resources are becoming an important alternative for generation companies; in addition, price-based systems (e.g., feed-in tariffs) are becoming an effective policy for incentivizing the deployment of renewable energy (Burer and Wustenhagen (2009); Couture and Gagnon

(2010)). Hence, it is important to analyze how the probability of deploying a renewable energy project might change the energy prices and profits of generation companies.

This paper aims to analyze energy prices, allocation of depletable and renewable resources, and profits of generation companies in a two stage Cournot oligopoly, where generation companies have the option to deploy a renewable energy project in the future. The key contributions of this paper are twofold. First, we analyze the impact of these decisions on important economic variables. Second, we calculate the value added by the option of deploying a renewable energy project.

In literature, many papers have utilized the Cournot oligopoly to predict interesting properties of energy markets and propose policies to resolve some of the economic and sustainability issues. For instance, Wolfram (1999) analyzes the market power of generation companies in the British electricity market, and show that prices are lower than estimates due to many reasons, such as entry deterrence and actions from the regulator. Chuang, Wu, and Varaiya (2001) formulate a Cournot oligopoly market for generation expansion planning, and present numerical results to analyze industry expansion, generation investment and trends. Murphy and Smeers (2005) present an open-loop and closed-loop Cournot model, in which investment and power dispatch decisions occur simultaneously in the former model and in two stages in the latter model; in addition, this work compares both models with a perfect competition. Nanduri, Das, and Rocha (2009) utilize a similar single stage Cournot model as (Murphy and Smeers 2005) taking into consideration the network transmission constraints. Twomey and Neuhoff (2010) examine the case of intermittent generation return under perfect competition, monopoly and oligopoly; the results show that, when different technologies are used, the market participants benefit differently from the increased price. Moreover, intermittent technologies benefit less from the market power effect than conventional technologies. Despite the numerous papers with Cournot oligopoly models for energy markets, none of these works have analyzed the economic aspects of the energy market, when generation companies have the option to deploy a renewable energy project in the future; in addition, we also analyze these aspects when the probability of deploying the project increases and calculate the value added by the option.

This paper is organized as follows. Section 2 introduces the model and some economic implications of important variables, such as the price and the probability of deploying a renewable energy project. Section 3 presents a numerical example and an analysis from an economic and social welfare perspective. Conclusion and future research close the paper in Section 4.

2. THE MODEL

Twomey and Neuhoff (2010) state that electricity markets are neither a monopoly nor a perfect competition; in fact, modeling the market as an oligopoly is the most appropriate assumption. Hence, we assume that our market has two established generation companies, which have to choose simultaneously on how much energy to produce from a depletable resource, such as gas and coal, or a renewable resource.

Our model is a Cournot oligopoly with 2 periods, where the amount of energy produced from a depletable resource at time 0 depends on the total amount each generation company has of this resource; hence, the more they use this resource at time 0, the less it will be available in the future. The amount of energy produced at time 0 also depends on the probability of the generation companies deciding to deploy a renewable energy project at time *t*.

2.1 Assumptions of the Model

The generation companies (or simply firms) must decide simultaneously a quantity to be produced at time 0 and at time t in the future. At time 0, the firms can only produce energy from a depletable resource, and at time t, the firms can produce energy from both depletable and renewable resources (if it decides to deploy a renewable energy project). In order to create an incentive for deploying a renewable energy project, we use a price-based system (i.e. feed-in-tariff) based on a market-dependent model (Couture and Gagnon 2010).

The following table summarizes all the symbols that will be used in our model:

Q_i	energy produced from a depletable resource owned by firm i, with $i \in \{1,2\}$
q_i^0	quantity of energy generated by firm i at time 0
q_i^t	quantity of energy generated by firm i at time t
λ_i	probability of firm i deploying a renewable energy project
β	expected rate of increase in energy production, as a percentage of Q_i, from the deployment of a renewable energy project from firm i, where $\beta \in [0,\infty)$
ε	deviation from expected energy generated from a renewable resource, where $\varepsilon \sim (0, \sigma^2)$
r	discount rate (opportunity cost)
Q_i^*	expected quantity of energy generated from firm i after deploying a renewable energy project
c_D	marginal cost for generating energy from depletable resources
c_R	marginal cost for generating energy from renewable resources
x	percentage of energy generated from renewable resources in the firm's portfolio, with $x \in [0,1]$
ω	constant premium or bonus over the price (due to a feed-in-tariff)
Π_i	expected profit from firm i
I	investment cost of deploying renewable energy project

We consider a market where the price is a linear function of the total quantity of energy generated. Hence, the inverse demand function of firm i for each period is described as:

$$p^0 = a - \theta(q_1^0 + q_2^0) \tag{1}$$

$$p^t = a - \theta(q_1^t + q_2^t) \tag{2}$$

where θ is the demand slope, a is a constant, and $\theta(q_1^0 + q_2^0) \leq a$. If firm i decides to not deploy the renewable energy project, then the total energy generated is Q_i; otherwise, we assume that the energy generated with the addition of a renewable resource has a fixed and a stochastic component $Q_i + (\beta Q_i + \varepsilon_i)$; the stochastic component has been utilized in previous models of renewable energy generators, such as the model proposed by Twomey and Neuhoff (2010). Hence, the following equation is the expected quantity of energy generated by firm i after deploying a renewable energy project:

$$Q_i^* = Q_i(1-\lambda_i) + ((1+\beta)Q_i + \varepsilon)\lambda_i \quad (3)$$

$$Q_i^* = (1+\beta\lambda_i)Q_i + \varepsilon\lambda_i \quad (4)$$

We also assume that q_i^0 and q_i^t must be equal to the expected quantity of energy generated (Q^*_i), hence:

$$Q_i^* = q_i^0 + q_i^t \quad (5)$$

We utilize a market-dependent model (Couture and Gagnon 2010), also known as feed-in-tariff, for the price of the energy generated from a renewable resource, i.e. $p^t + \omega$. Hence, the expected profit function of firm i for producing energy with depletable and renewable resources is:

$$\Pi_i = \left(p^0 - c_D\right) q_i^0 + (p^t - c_D)(Q_i^* - q_i^0)(1-x)e^{-rt} + (p^t + \omega - c_R)(Q_i^* - q_i^0)x.e^{-rt} - I\lambda_i e^{-rt} \quad (6)$$

Substituting Equations 1, 2 and 4 into Equation 6 will yield:

$$\begin{aligned}\Pi_i = {} & \left(a - \theta(q_i^0 + q_{3-i}^0) - c_D\right) q_i^0 + \\ & (a-\theta((1+\beta\lambda_i)Q_i+\varepsilon\lambda_i-q_i^0+(1+\beta\lambda_{3-i})Q_{3-i}+\varepsilon\lambda_{3-i}-q_{3-i}^0)-c_D)((1+\beta\lambda_i)Q_i+\varepsilon\lambda_i-q_i^0)e^{-rt}(1-x)+ \\ & (a-\theta((1+\beta\lambda_i)Q_i+\varepsilon\lambda_i-q_i^0+(1+\beta\lambda_{3-i})Q_{3-i}+\varepsilon\lambda_{3-i}-q_{3-i}^0)+\omega-c_R)((1+\beta\lambda_i)Q_i+\varepsilon\lambda_i-q_i^0)e^{-rt}x-I\lambda_i e^{-rt}\end{aligned} \quad (7)$$

2.2 First Order Conditions, Reaction Functions and Equilibrium

At time 0, the profit maximization assumption states that firm i generates energy q_i^0 in order to maximize the firm's profit. Thus, the first order maximization conditions for q_i^0 are:

$$\begin{aligned}\frac{\partial \Pi_i}{\partial q_i^0} = {} & a-2\theta q_i^0-\theta q_{3-i}^0-c_D-ae^{-rt}(1-x)+2\theta((1+\beta\lambda_i)Q_i+\varepsilon\lambda_i)e^{-rt}(1-x)-2\theta q_i^0 e^{-rt}(1-x)+ \\ & \theta((1+\beta\lambda_{3-i})Q_{3-i}+\varepsilon\lambda_{3-i})e^{-rt}(1-x)-\theta q_{3-1}^0 e^{-rt}(1-x)+c_D e^{-rt}(1-x)-ae^{-rt}x+2\theta((1+\beta\lambda_i)Q_i+\varepsilon\lambda_i)e^{-rt}x- \\ & 2\theta q_i^0 e^{-rt}x + \theta((1+\beta\lambda_{3-i})Q_{3-i} + \varepsilon\lambda_{3-i})e^{-rt}x - \theta q_{3-1}^0 e^{-rt}x - \omega e^{-rt}x + c_R e^{-rt}x = 0\end{aligned} \quad (8)$$

Solving Equation 8, we find the reaction functions:

$$\begin{aligned}q_1^0 = {} & -\frac{q_2^0}{2} + \frac{a(1-e^{-rt})}{2\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{2\theta(1+e^{-rt})} + \frac{(c_R-c_D)xe^{-rt}}{2\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} + \\ & \frac{((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{2(1+e^{-rt})} - \frac{\omega xe^{-rt}}{2\theta(1+e^{-rt})}\end{aligned} \quad (9)$$

$$\begin{aligned}q_2^0 = {} & -\frac{q_1^0}{2} + \frac{a(1-e^{-rt})}{2\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{2\theta(1+e^{-rt})} + \frac{(c_R-c_D)xe^{-rt}}{2\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} + \\ & \frac{((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{2(1+e^{-rt})} - \frac{\omega xe^{-rt}}{2\theta(1+e^{-rt})}\end{aligned} \quad (10)$$

Substituting Equation 10 into Equation 9 yields Equation 11; in addition, substituting Equation 9 into Equation 10 yields Equation 12. Hence, we have the following equilibrium:

$$q_1^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \quad (11)$$

$$q_2^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \quad (12)$$

Substituting Equations 11 and 12 into Equation 1 yields the price in equilibrium at time 0:

$$p^0 = a - \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} + \frac{2\omega x e^{-rt}}{3(1+e^{-rt})} \quad (13)$$

In addition, substituting Equations 11 and 12 into Equation 5 yields the equilibrium at time t:

$$q_1^t = (1+\beta\lambda_1)Q_1+\varepsilon\lambda_1 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} + \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \quad (14)$$

$$q_2^t = (1+\beta\lambda_2)Q_2+\varepsilon\lambda_2 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} + \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \quad (15)$$

And substituting Equations 14 and 15 into Equation 2 yields the price in equilibrium at time t:

$$p^t = a - \theta(1+\beta\lambda_1)Q_1 - \theta\varepsilon\lambda_1 - \theta(1+\beta\lambda_2)Q_2 - \theta\varepsilon\lambda_2 + \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} - \frac{2\omega x e^{-rt}}{3(1+e^{-rt})} \quad (16)$$

The expected price and quantity in equilibrium, where $E[\varepsilon] = 0$, are:

$$q_1^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \quad (17)$$

$$q_2^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \quad (18)$$

$$p^0 = a - \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} + \frac{2\omega xe^{-rt}}{3(1+e^{-rt})} \quad (19)$$

$$q_1^t = (1+\beta\lambda_1)Q_1 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} + \frac{\omega xe^{-rt}}{3\theta(1+e^{-rt})} \quad (20)$$

$$q_2^t = (1+\beta\lambda_2)Q_2 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} + \frac{\omega xe^{-rt}}{3\theta(1+e^{-rt})} \quad (21)$$

$$p^t = a - \theta(1+\beta\lambda_1)Q_1 - \theta(1+\beta\lambda_2)Q_2 + \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} - \frac{2\omega xe^{-rt}}{3(1+e^{-rt})} \quad (22)$$

The term ε affects both quantities and prices. Therefore, the expected profit contains the term ε^2, which is not zero in expectation but $E[\varepsilon^2] = \sigma^2$. The difference between the expected profit with ε and without the stochastic component is:

$$-\frac{\theta\varepsilon^2\lambda_i(\lambda_i+\lambda_{3-i})e^{-rt}}{(1+e^{-rt})} = -\frac{\theta\sigma^2\lambda_i(\lambda_i+\lambda_{3-i})e^{-rt}}{(1+e^{-rt})} \quad (23)$$

Hence, the stochastic component of the renewable energy generator reduces the expected profit.

2.3 Implications

This section presents some propositions of the model described above; in other words, the economic implications of important variables, such as the price and the probability of deploying a renewable energy project. Thus, we will analyze the impact that these variables can have on the energy market and how they can facilitate social welfare.

Proposition I: As the probability of firm *i* deploying a renewable energy project (λ_i) increases, the quantity generated at time 0 also increases and the price decreases. However, the probability of the other firm deploying a renewable energy project, λ_{3-i}, does not affect the decision of the firm.

Proof:

$$\frac{\partial q_i^0}{\partial\lambda_i} = \frac{(\beta Q_i+\varepsilon)e^{-rt}}{(1+e^{-rt})} > 0; \frac{\partial p^0}{\partial\lambda_i} = -\frac{\theta(\beta Q_i+\varepsilon)e^{-rt}}{(1+e^{-rt})} < 0; \frac{\partial q_i^0}{\partial\lambda_{3-i}} = 0 \quad (24)$$

Proposition II: As the probability of firm *i* deploying a renewable energy project (λ_i) increases, the energy generated at time *t* increases and the price decreases. However, the probability of the other firm deploying a renewable energy project, λ_{3-i}, does not affect the decision of the firm.

Proof:

$$\frac{\partial q_i^t}{\partial \lambda_i} = \frac{\beta Q_i + \varepsilon}{(1+e^{-rt})} > 0; \frac{\partial p^t}{\partial \lambda_i} = -\frac{\theta(\beta Q_i + \varepsilon)}{(1+e^{-rt})} < 0; \frac{\partial q_i^t}{\partial \lambda_{3-i}} = 0 \tag{25}$$

The intuition behind Preposition I and II is clear. As the probability λ_i increases, the expected energy generated also increases, and consequently the price will decrease, since the supply will be greater. Hence, Propositions I and II show that increasing the probability of deploying a renewable energy project will decrease the price in any period, regardless of the competing firm's decision, which in turn may help increase the social welfare.

Proposition III: As the expected rate of increase in renewable energy production (β) rises, the quantity produced at time 0 and t also increases and the prices decrease.

Proof:

$$\frac{\partial q_i^0}{\partial \beta} = \frac{\lambda_i Q_i e^{-rt}}{(1+e^{-rt})} > 0; \frac{\partial q_i^t}{\partial \beta} = \lambda_i Q_i \left(1 - \frac{e^{-rt}}{(1+e^{-rt})}\right) > 0$$
$$\frac{\partial p^0}{\partial \beta} = -\frac{(\lambda_i Q_i + \lambda_{3-i} Q_{3-i})\theta e^{-rt}}{(1+e^{-rt})} < 0; \frac{\partial p^t}{\partial \beta} = -\theta(\lambda_i Q_i + \lambda_{3-i} Q_{3-i}) \left(1 - \frac{e^{-rt}}{(1+e^{-rt})}\right) < 0 \tag{26}$$

Hence, the prepositions above show that energy prices decrease when the expected production of energy from renewable resource increases. Lower energy prices may help reduce costs in many sectors of the economy, such as industry, transportation, services, and agriculture. For instance, low energy prices reduce production costs, which in turn may facilitate economic growth and social welfare.

Proposition IV: As the bonus of the feed-in-tariff (ω) increases, the quantity produced at time 0 decreases and the quantity produced at t increases. In addition, as the bonus increases, the price increases at time 0 and decreases at time t.

Proof:

$$\frac{\partial q_i^0}{\partial \omega} = -\frac{xe^{-rt}}{3\theta(1+e^{-rt})} < 0; \frac{\partial q_i^t}{\partial \omega} = \frac{xe^{-rt}}{3\theta(1+e^{-rt})} > 0; \frac{\partial p^0}{\partial \omega} = \frac{2xe^{-rt}}{3(1+e^{-rt})} > 0;$$
$$\frac{\partial p^t}{\partial \omega} = -\frac{2xe^{-rt}}{3(1+e^{-rt})} < 0 \tag{27}$$

This may suggest that the incentive from the feed-in-tariff has an impact on the decision-making process of the firms; hence, they might wait to produce energy from a renewable energy generator at time t instead of depletable resource at time 0. Additionally, this proposition suggests that the consumers are better off with the introduction of feed-in-tariffs, because the prices decrease at time t.

3. NUMERICAL EXAMPLES

In order to examine important variables of the model, namely the probability of deploying a renewable energy project (λ_i), the expected rate of increase in renewable energy production (β), and the bonus of the feed-in-tariff (ω), we present some numerical examples using plausible parameter values.

We assume an inverse demand function at time 0 of $p^0 = 350 - 3.(q_1^0 + q_2^0)$ and at time t of $p^t = 350 - 3.(q_1^t + q_2^t)$. The marginal costs are $c_D = 27.5$ and $c_R = 0$; these values correspond to variable operations and maintenance costs for generating energy from conventional coal and wind respectively (EIA 2012). The remaining variables are of little concern as we are interested in the effect of λ_i and β on the profit of the firms and the value added by the option to deploy a renewable energy project; hence, in our examples, we used the following value for each parameter: $Q_1 = 40$, $Q_2 = 40$, $r = 10\%$, $x = 20\%$, and $I = 50$.

β	10%	30%	50%	70%	90%
π_1	7,642	7,870	8,011	8,066	8,034
π_2	7,642	7,870	8,011	8,066	8,034
Option 1	254	396	490	537	536
Option 2	254	396	490	537	536

Table 1: Expected profit and value added by the option as the expected rate of increase in renewable energy production (β) rises

λ_1	10%	30%	50%	70%	90%
π_1	7,204	7,629	8,011	8,349	8,644
π_2	8,551	8,281	8,011	7,741	7,471
Option 1	54	284	490	672	831
Option 2	754	622	490	358	226

Table 2: Expected profit and value added by the option as the probability of deploying a renewable energy project (λ_1) increases

Tables 1 and 2 present the expected profit and value added by the option to deploy a renewable energy project as β and λ_1 increase, respectively. The value added by the option is calculated by subtracting the expected profit at time t of firm i with the option to deploy a renewable energy project by the expected profit at time t of the same firm without the option to deploy the renewable energy project.

In Table1, the expected profits of both firms increase as β increases up to a point between 70% and 90%; this is due to the fact that after this point the marginal cost is greater than the marginal revenue. Hence, although the prices decrease and the quantities increase as β increases (Proposition III), there is a β that maximizes the profit and the firm will probably not increase β above this point. In addition, the value of the option increases up to a point between 70% and 90% (the same point as the profit); this is consistent with the Real Option theory, where the European call option value increases as the asset value increases, and the asset value in this case is the additional profit due to the renewable energy generation.

Table 2 shows that the expected profit of firm 1 increases as the probability of deploying a renewable energy project (λ_1) increases; however, the expected profit of firm 2 decreases. The explanations for these results are twofold. First, a higher probability of deploying a project will yield a higher quantity of energy generated for the market; hence, decreasing the price of energy. Second, as prices fall the profit of firm 2 also decreases. The value of the option also follows the same pattern; in other words, as λ_1 increases the value of the option for firm 1 increases and for firm 2 decreases. From firm 2's perspective, this might suggest that a competitor with a high probability of deploying a project will influence the market, by gaining more market share and reducing the price; hence, this will impact the expected profit and the value of the option. This is consistent with the Real Option theory where competition erodes the value of the option.

ω	10	20	50
π_1	7,969	8,011	8,136
π_2	7,969	8,011	8,136
Option 1	447	490	620
Option 2	447	490	620

Table 3: Expected profit and value added by the option as the constant premium or bonus over the price (due to a feed-in-tariff) increases

In Table 3, the profits and the values added by the option to deploy a renewable increase as the bonus for renewable production increases, due to a feed-in-tariff policy. This may suggest that a feed-in-tariff, which uses a market-dependent model, has a positive impact on the decision-making process; hence, firms will have a higher incentive to invest in renewable energy projects. This is consistent with previous works on feed-in-tariffs, such as the paper from Couture and Gagnon (2010).

4. CONCLUSION AND FUTURE RESEARCH

This paper analyzes important economic variables (e.g., energy prices, allocation of depletable and renewable resources, and profits) in a two stage Cournot oligopoly, where generation companies have the option to deploy a renewable energy project. The option to deploy a renewable energy project is very important to decision makers, because it may increase the profit of the firm. In addition, policy makers might also be interested in this analysis in order to create the right incentives for the firms, while contributing to economic growth, social welfare and sustainability.

The key contributions of this paper are twofold. First, we analyze the impact of the option to deploy the renewable energy project on the profits, economic growth, and social welfare. Second, we calculate the value added by the option of deploying a renewable energy project. The results show that as the probability of deploying the project increases, the prices fall and supply increases, which might facilitate economic growth and social welfare.

As future work, we would like to test other remuneration types of feed-in-tariffs (e.g., the remuneration structures in Couture and Gagnon (2010)), and analyze the impact of these incentives on the same economic variables. This analysis might shed some light on how to facilitate economic growth and sustainability, and improve the decision making process of policy makers.

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