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Green Electricity Investment Timing in Practice: Real Options or Net Present Value?

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Abstract

Using data from 214 hydropower projects in Norway we study whether investors in renewable energy projects exert discretion about the timing of investment decisions. We know from interviews with these investors that they do not use the real options model; however, we would like to learn whether they act consistently with this approach. These investments were expected to be supported financially through renewable policy schemes, but were not during the time period we consider. We calculate subsidies implied by investors' decisions using both real options and net present value models and compare these expected subsidies with subsidies observed in a very closely related market (Sweden). Our analysis indicates that our assumed real options model implies expected subsidies that align well with the ones observed. If we assume investors used a net present value model, the corresponding implied subsidies are close to zero. However, we know from interviews with investors that they did expect subsidies. We therefore conclude that the real options model is a meaningful descriptor of the observed investment behavior.

Keywords: renewable energy, investments, real options, subsidies

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1 Introduction

A range of policies has been proposed to promote green investments Carley (2011). In this context it is important to know how investors in green projects make investment decisions. This section provides insights into how such investors exercise discretion about investment timing. Specifically, we examine investment timing and subsidy expectations among investors in 214 small hydropower plants in Norway. By varying assumptions regarding their investment timing decision rules, we are able to infer an implied level of expected subsidy per project. In addition we also interview some of the investors about their expected subsidies. Combining this implied data with observed data and the fact that interviews indicate that subsidies are counted in project assessments we conclude that a real options model is meaningful in explaining actual investment behavior.

Investments in small hydropower plants in Norway are subsidized. There have been political discussions about subsidies since 2001. Small hydropower plants are characterized by a maximum installed power of 10 MW. Subsidies (certificates) were supposed to be given through a common market for Norway and Sweden, but it was not until 2011 that the subsidies were passed by law in Norway. The market in Sweden was up and running from May 2003. The subsidies are a response to the EU directives 2001/77/EC and 2009/28/EC promoting the use of renewable energy sources, where only the latter directive was binding for the Norwegian government. In 2010, Norway and Sweeden agreed to increase the amount of new renewable energy by 26.4 TWh per year by 2020 using a common market for certificates Ministry of Petroleum and Energy (2010). By investigating licenses granted between 2001 and 2008 we precede the introduction of this market in Norway, which did not become active before 1 January 2012. The motivation for a common market, instead of two separate ones, was to achieve a more cost-effective development through higher liquidity, lower price volatility and lower political risk.

All those years of political discussion led to policy uncertainty for green energy investors. Dixit and Pindyck (1994) state that "If governments wish to stimulate investments, perhaps the worst thing they can do is to spend a long time discussing the right way to do so". The Norwegian Minister of Petroleum and Energy promised a transitional agreement in a press release indicating that all who invested after 1 January 2004 would be included in the subsidy scheme once introduced Ministry of Petroleum and Energy (2003). However, a few years later negotiations with Sweden broke down. In December 2007 negotiations were restarted. In 2009, a second transitional agreement was promised by the Minister of Petroleum and Energy whereby only plants built after 7 September 2009 were allowed to receive certificates.

During this period, investors in Norway had varying expectations as to whether they would receive subsidies or not. Some were sitting on the fence waiting for a final confirmation. Others invested knowing that their projects would be profitable regardless of any subsidy scheme. Others again invested believing they would receive subsidies based on the promised transitional arrangement.

To model the investment decision when investors face two sources of uncertainty (the price of electricity and the amount of subsidies), a two-factor model is required. We use a real options model by Boomsma and Linnerud (2015), who in turn rely on Gahungu and Smeers (2009) and Adkins and Paxson (2015). The advantage of this model is that, despite including two-factors, it can be solved quasi-analytically.

Even though investors may not be familiar with real options theory, they might behave in accordance with it. Over time, investors can develop decision rules which can be similar to what is predicted by theory. Kellogg (2014) states that the real options theory is consistent with the existence of a strong incentive for firms to behave optimally. In his study of oil well drilling he finds that the cost of failing to respond to changes in the volatility of the price of oil can be substantial. Thus, there is good motivation for taking a rational approach to exercising one's options.

Real options theory, which is rooted in the financial options pricing theory of Merton (1973) and Black and Scholes (1973), was first introduced by Myers (1977). McDonald and Siegel (1986) discuss the value of waiting to invest in irreversible projects. There are numerous applications of real options to the energy industry. Tourinho (1979) examines the option to wait in valuing natural resources. Brennan and Schwartz (1985) use real options theory to evaluate natural resource investments and stress the importance of treating output prices as stochastic when there is considerable price variation. This feature distinguishes many natural resource industries, including electricity. Fernandes et al. (2011) summarize research involving real options theory applied to renewable energy resources.

Previous work on policy uncertainty includes, amongst others, Rodrik (1991), Mauer and Ott (1995) and Hassett and Metcalf (1999) who examine investor behavior under an uncertain reform or tax law change. Blyth et al. (2007), Yang et al. (2008) and EIA (2007) discuss climate policy uncertainty and its implications for the choice of power generation technology. These studies generally find that uncertainty acts as a hefty tax on investment or as a risk premium for investors. Boomsma et al. (2012) analyze investment timing and capacity choice for renewable energy projects under different support schemes, namely feed-in-tariffs and renewable energy certificate trading. They analyze a three-factor contingent claims (real options) model applied to a wind power case study. Adkins and Paxson (2015) derive the optimal investment timing and real options value for a renewable energy facility with price and quantity uncertainty, in the presence of an uncertain government subsidy proportional to production. Boomsma and Linnerud (2015) analyze the risk of a change in the current support scheme at some random future point in time, using a case study for an onshore wind power project. Fleten et al. (2011) study decisions to shutdown, startup and abandon power plants and find that these decisions are consistent with the real options theory.

We apply our real options model to data obtained from a regulatory database[1] verified or updated through interviews. This data set was originally gathered in 2011 and used by Linnerud et al. (2014). We updated and extended it by contacting the license holders that had not previously responded or had not made an investment decision in 2011. The overall response rate was 99% (211 of 214 plants).

Empirical research on real options began with Paddock et al. (1988). Further work includes Quigg (1993) and Moel and Tufano (2002). They all find empirical support for a model that incorporates the option to wait. Case studies on real options in the Nordic electricity market include Bøckman et al. (2008), Fleten et al. (2007) and Fleten and Ringen (2009), which focus on investment timing and optimal capacity choice for small hydropower projects. Secomandi (2010) provides empirical evidence in support of the use of the real options approach to price natural gas pipeline capacity. The effect of regulatory uncertainy on investment in renewable electricity generation under feed-in tariffs is studied by Ritzenhofen and Spinler (2016), who find that uncertainty regarding future regulatory regimes delays or even reduces investment activity.

We take advantage of recent progress in analytical and quasi-analytical solution methods developed by Gahungu and Smeers (2009), Rohlfs and Madlener (2011), Adkins and Paxson (2011) and Boomsma and Linnerud (2015). However, to the best of our knowledge, there is almost no empirical research based on multi-factor real options models. Our main contribution is therefore the execution of an empirical study. The work closest related to this paper is Linnerud et al. (2014). We apply a simple analytical solution whereas their solution approach relies on least squares Monte Carlo simulation.

This paper is organized as follows. Section 2 explains the types of subsidies for renewable energy production that we study. Section 3 describes the investor's decision problem and the real options framework. Section 4 presents our data set. Section 5 discusses our findings. Section 6 concludes.

2 Tradable green certificates

The governments of Norway and Sweden have agreed to increase their countries overall renewable power production by 26.4 TWh per year by 2020. This amount equals more than half of the current consumption of all Norwegian households (NVE, 2012). Certificates, a particular subsidy mechanism, address this goal by giving a financial incentive for investment. A detailed description of consumer-based tradable green certificate systems can be found in Schaeffer et al. (1999), Morthorst (2000), Amundsen and Mortensen (2001), Jensen and Skytte (2002), Jensen and Skytte (2003) and Fristrup (2003).

The market for certificates was established in Sweden in May 2003. From the beginning (2001), the intention was to have a common market for Norway and Sweden. However, negotiations broke down. Consequently, the market only included Sweden for many years. Subsequently negotiations with Sweden were

[1] http://www.nve.no/no/Konsesjoner/.

restarted. A common market was finally agreed to in 2009, with a planned start-up in 2012. On 1 January 2012 Norwegian power producers and distributors joined in and a common market was formed. Table 1 presents a summary of publicly available information published by the Norwegian government during this period. It is reasonable to assume that investors were familiar with these statements, as they were debated extensively in parliament and in the media.

[Table 1 about here.]

All Norwegian producers of new renewable energy are eligible to receive certificates, as long as they invest in new or upgraded small hydropower plants with initial developement date betwen 1 January 2012 and the end of 2020. These investors receive certificates throughout 15 years.

3 Modeling the investment decision

The most prominent factors affecting the profitability of small hydropower plants are the revenues from selling electricity and certificates. Investing in a power plant requires a large up front construction expenditure. It consists of the plant's operational and maintenance costs. The revenue stream is therefore approximately determined by the selling price of electricity and certificates, and varies with production over time. Because the uncertainty in the electricity and certificate prices dominates the uncertainty in the investment cost, we model both these prices as uncertain and fluctuating over time, whereas we treat the investment cost as constant.

If investors had some leeway in the timing of the investment, they could sometimes gain additional value by waiting for more information. The investment decision can be regarded as an investment real option exercised at any moment in time (an American call option).

Once the investor has obtained a license to build a hydropower plant, he should invest within five years. Otherwise he must apply for prolonging the license for five more years. However, this extention is almost always granted. Thereby we can assume that the license lasts forever and the investors can choose to invest at their own convenience. Thus, we assume the investment option to be perpetual. In the rest of this section we derive the optimal investment policy implied by real options model and calculate this optimal investment policy for a fictitious, yet representative power plant.

3.1 The Real Options Model

Our real options model is based on Gahungu and Smeers (2009), Adkins and Paxson (2011) and Boomsma and Linnerud (2015). For simplicity, we present this model ignoring taxes. Nevertheless, our empirical results were obtained considering taxes.

For comparability between power plants, we evaluate the performance metrics on a per unit of production basis (i.e. €/MWh per year). To obtain the total profit, revenue or cost, one can multiply the respective per unit amount by the expected annual production of the power plant, Q.

Both the price of electricity (P_t) and the price of certificates (S_t) are modeled as Geometric Brownian motions (GBMs)[2]:

$$\mathrm{d}P_t = \alpha_P P_t \mathrm{d}t + \sigma_P P_t \mathrm{d}z_P, \tag{1}$$

$$\mathrm{d}S_t = \alpha_S S_t \mathrm{d}t + \sigma_S S_t \mathrm{d}z_S, \tag{2}$$

where the constants α_P and α_S represent the trend parameters, also called the drift rates of the prices of electricity and certificates, respectively; the constants σ_P and σ_S are the respective volatilities of those prices; and the terms $\mathrm{d}z_P$ and $\mathrm{d}z_S$ are correlated standard Brownian motions (BMs) with correlation $E[\mathrm{d}z_P \mathrm{d}z_S] = \rho_{P,S}$.

When we consider the company as a price taker, the expected present value of the investment, V, is a linear function of two variables following GBM. Using continuous compounding, this function is:

$$V(P, S) = r_P P + r_S S, \tag{3}$$

with

$$r_P = \left(\frac{\mathrm{e}^{-(r-\alpha_P)T_{P_1}} - \mathrm{e}^{-(r-\alpha_P)T_{P_2}}}{r - \alpha_P} \right), \tag{4}$$

$$r_S = \left(\frac{\mathrm{e}^{-(r-\alpha_S)T_{S_1}} - \mathrm{e}^{-(r-\alpha_S)T_{S_2}}}{r - \alpha_S} \right), \tag{5}$$

Where r is the required rate of return of the project, and T_{P_1} and T_{P_2}, and T_{S_1} and T_{S_2}, respectively, are the beginning and end of the revenue stream from the sale of electricity is therefore denoted as T_{P_1} and T_{P_2} and similarly the subsidy revenue stream lasts from T_{S_1} to T_{S_2} (because subsidy is only granted for a given number of years, the length of these revenue streams might be different).

The net expected profit from the investment is $V(P, S) - I$, where I is the investment cost per unit of production capacity, which consists of the initial cost taken of building the plant, I_0, and the present value of maintenance costs, C:

$$I = I_0 + C. \tag{6}$$

We assume that it is never optimal to shut down the plant, which is true for almost all hydropower plants. We stipulate that the yearly maintenance cost per unit of production at the beginning of production, c_0, grows with the annual inflation rate, i, set at a constant rate reflecting the inflation target. Thus, the time 0 present value of the maintenance costs satisfies:

$$C = r_C c_o, \tag{7}$$

[2]For the sake of brevity we later supress the subscript t for both the price of electricity (P_t) and the price of certificates (S_t) whenever suitable.

where

$$r_C = \left(\frac{1 - \mathrm{e}^{-(r-i)T_P}}{r - i} \right). \tag{8}$$

The value of the option to invest is a function $F(P, S)$ of the prevailing price of electricity P and subsidy S. Application of standard dynamic programming or contingent claim analysis, see Dixit and Pindyck (1994), yields the following partial differential equation (PDF):

$$\frac{1}{2}\left(\sigma_P^2 P^2 \frac{\partial^2 F}{\partial P^2} + \sigma_S^2 S^2 \frac{\partial^2 F}{\partial S^2} + 2\sigma_P \sigma_S \rho_{P,S} PS \frac{\partial^2 F}{\partial P \partial S}\right) + \alpha_P P \frac{\partial F}{\partial P} + \alpha_S S \frac{\partial F}{\partial S} - rF = 0. \tag{9}$$

This equation is a second order homogeneous PDE. A first order homogeneous PDE for a two-factor problem has a known solution[3] as shown in McDonald and Siegel (1986). Assuming a solution of a similar functional form, i.e.,

$$F(P, S) = AP^{\beta_P} S^{\beta_S} \tag{10}$$

for some constants A, β_P, β_S we obtain the following fundamental quadratic equation:

$$Q(\beta_P, \beta_S) = \frac{1}{2}\left[\sigma_P^2 \beta_P(\beta_P - 1) + \sigma_S^2 \beta_S(\beta_S - 1) + 2\sigma_P \sigma_S \rho_{P,S} \beta_P \beta_S\right] + \alpha_P \beta_P + \alpha_S \beta_S - r = 0. \tag{11}$$

This is the equation of an ellipse on all four quadrants of the two-dimensional plane. When $\beta_P = 0$ or $\beta_S = 0$, we have the standard quadratic function in option valuation with a positive and a negative root, comprehensively explained in Dixit and Pindyck (1994). The terms β_P and β_S cannot be negative, because an invalid option value would ensue if any of the two prices fell to zero. Therefore, we have the following restrictions:

$$\beta_P, \beta_S \geq 0. \tag{12}$$

The optimal stopping boundary set that specifies the electricity and certificates prices that trigger an investment decision is a set P^*, S^*, where P^* and S^* respectively denote the optimal electricity price and subsidy thresholds. The optimal option value for such a price pair is $F(P^*, S^*)$. It is independent of time, as the PDE (9) is time-homogeneous. The optimal decision rule is to invest the first time pair (P, S) reaches this boundary.

To determine $F(P, S)$ we specify the following value matching and smooth pasting conditions at an optimal investment point:

[3] One can let $F(P, S) = Pv(p), p = \frac{P}{S}$ for some function $v(\cdot)$ and reduce the two-factor problem to a one-factor problem.

$$F(V(0,0)) = 0, \tag{13a}$$

$$A(P^*)^{\beta_P}(S^*)^{\beta_S} = r_P P^* + r_S S^* - I, \tag{13b}$$

$$A\beta_P(P^*)^{\beta_P - 1}(S^*)^{\beta_S} = r_P, \tag{13c}$$

$$A\beta_S(P^*)^{\beta_P}(S^*)^{\beta_S - 1} = r_S. \tag{13d}$$

The option value F falls to and remains at zero thereafter when either P or S go to zero by the properties of GBM (Dixit and Pindyck, 1994). By manipulation of the boundary conditions (13b)–(13d) we obtain the following expressions for the triggers:

$$P^* = \frac{\beta_P}{\beta_P + \beta_S - 1}\frac{I}{r_P}, \tag{14}$$

$$S^* = \frac{\beta_S}{\beta_P + \beta_S - 1}\frac{I}{r_S}. \tag{15}$$

We have five unknowns $(A, P^*, S^*, \beta_P, \beta_S)$, but only four equations, (11) and (13b)–(13d). The solution thereby has one degree of freedom. Hence, in contrast to the standard real options model, the value of the investment cannot be determined before prices actually reach the trigger. To find the required subsidy level for investment to be optimal, we choose to specify the electricity price. For a given price $P_t = P$, we introduce new variable

$$\eta(P) = \frac{I - r_P P}{r_P P}. \tag{16}$$

Using (16) to rearrange (15) expressed with P^* replaced by P yields

$$\beta_S = \beta_P \eta(P) + 1. \tag{17}$$

The terms β_S and β_P depend on each other, making the triggers dependent on each other. Using (17), the optimal time to invest is the first time $S_t \geq S^*(P)$, where

$$S^*(P) = \frac{\beta_P \eta(P) + 1}{\beta_P\left[\eta(P) + 1\right]}\frac{I}{r_S}, \tag{18a}$$

$$Q\left[\beta_P, \beta_P \eta(P) + 1\right] = 0, \tag{18b}$$

$$\beta_P, \beta_P \eta(P) + 1 \geq 0. \tag{18c}$$

The expressions for $\eta(P)$ and r_S can be evaluated when we have chosen P. When we insert (17) in the quadratic equation (11) we obtain the solutions:

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}, \tag{19}$$

where

$$a = \frac{1}{2}\left[\sigma_P^2 + \sigma_S^2\eta^2(P)\right] + \sigma_P\sigma_S\rho_{P,S}\eta(P), \tag{20a}$$

$$b = \frac{1}{2}\left[-\sigma_P^2 + \sigma_S^2\eta(P)\right] + \sigma_P\sigma_S\rho_{P,S} + \alpha_P + \alpha_S\eta(P), \tag{20b}$$

$$c = \alpha_S - r. \tag{20c}$$

conditional on

$$\beta_P, \beta_S \geq 0 \;\Leftrightarrow\; \beta_P, \beta_P\eta(P) + 1 \geq 0. \tag{21}$$

Moreover it holds that[4]

$$\beta_P + \beta_S > 1. \tag{22}$$

We find the following expression for A by manipulating of the boundary conditions (13a)–(13d):

$$A = r_P^{\beta_P} r_S^{(1-\beta_P)} \beta_P^{-\beta_P} \beta_S^{(\beta_P-1)} S^{*(1-\beta_P-\beta_S)}. \tag{23}$$

Substituting (23) in (10) yields the following expression for the project value at a point on the optimal stopping boundary:

$$F(P^*, S^*) = r_P^{\beta_P} r_S^{(1-\beta_P)} \beta_P^{-\beta_P} \beta_S^{(\beta_P-1)} S^{*(1-\beta_P)} P^{*\beta_P}. \tag{24}$$

We cannot calculate the value of the option outside this boundary. We can only evaluate the *expected* option value before reaching the triggers using Monte Carlo simulation, as in Gahungu and Smeers (2009).

Inserting the triggers in the value matching boundary condition (13b) we find the following condition:

$$F(P^*, S^*) = r_P P^* + r_S S^* - I = \left(\frac{\beta_P + \beta_S}{\beta_P + \beta_S - 1}\right) I - I. \tag{25}$$

Because $\beta_P + \beta_S > 1$ when investment is optimal, the present value of income is greater than the investment cost. As usual in real options models, see Dixit and Pindyck (1994), uncertainty and irreversibility drive a wedge between discounted revenues and investment cost.

Our model formulation ignores taxes for the sake of exposition. In this chapter we take taxes into account. However, because tax rules are somewhat complicated in this case, a detailed explanation of relevant taxes is not included in this paper, but is available upon request.

[4]When $\beta_P = 0$, it is well known from the standard real options model, see Dixit and Pindyck (1994), and the positive root of the quadratic equation satisfies $\beta_S > 1$. Similarly, when $\beta_S = 0$ then $\beta_P > 1$. Hence, the ellipse defined by $Q(\beta_P, \beta_S) = 0$ must always be above the line $\beta_P + \beta_S = 1$ in the first quadrant of the plane. For more detailed explanation see Adkins and Paxson (2011).

3.2 Example

We now illustrate our model by an example. The chosen parameters belong to a fictitious, yet representative power plant. These are displayed in Table 2. In particular, the investment cost is representative of the average power plant investment cost in our data set. Subsidies are awarded immediately and have known duration equal to be 15 years. The parameters T_{S_1} and T_{S_2} are thus deteministic. We set their values accordingly.

[Table 2 about here.]

We calculateg the optimal stopping boundary for an electricity price ranging from 0 €/MWh to 50 €/MWh. For each electricity price, we find the minimum required subsidy level S^* for the investment to be optimal. The optimal boundary, displayed in Figure 1, is a nonlinear function of P and S.

[Figure 1 about here.]

This boundary divides the graph into two regions: the continuation region and the investment region. As long as the combination of a given electricity price and a given subsidy price is below this boundary, an investor should not invest. When the electricity price plus the subsidy price lie above the boundary, it is optimal to invest. At the boundary, investors are indifferent between these two choices. A more datailed discussion of the shape of this curve can be found in Boomsma and Linnerud (2015). We can infer from Figure 1 that subsidies are required even when the electricity price is 50 €/MWh.

4 Data

Our data set consists of 214 licenses to build small hydropower plants granted by Norwegian Water Resources and Energy Directorate (NVE) during the period 2001–2008. NVE stores information concerning applications and licenses such as application date, license date, rated power, expected annual production and investment cost. We conducted interviews[5] to gather information about

[5]The survey was conducted as telephone interviews. We did not use a formal questionnaire. But, we had agreed upon questions to ask. The interviews worked as a control on the correctness of the NVE information. 1) We checked if the license ownership information in the NVE database still was correct, and if it had changed, we asked for the date. 2) We checked the timing of the investment decision, if a decision had been made. 3) We checked the expected investment cost, capacity (MW) and production (GWh) at the time the investment decision was made, and if no decision had been made we asked the questions with respect to today. 4) We checked if there had been any no-economic constraints that have prevented the license owner from making the investment decision, and if so what type of constraint and for what period. This information was used to complement and improve the information gathered from the NVE database. We revised the information on timing of the investment decision, expected investment costs, ownership and production. We also used two dummy variables–one for whether we had interviewed the license owner or only relied on NVE data and one for whether investments had been prevented by non-economic constraints.

investors' expectations regarding subsidies and profitability, possible delays and whether the costs and size of the plant deviated from the original application.

We set the common rate for maintanace cost per unit of production capacity for all the power plants at 9 €/MWh in 2012, in line with Linnerud et al. (2014). For years prior to 2012 we deflated this figure to obtain maintenance cost that grows at a rate of 2.5%.

When conducting our survey we strived to obtain the expected investment cost at the time the decision to invest was made. If a decision was not yet made, we tried to obtain the most current cost estimate. In cases where the investor did not remember exactly the relevant cost, either the cost from the license application or the actual incurred investment outlay was used. To obtain the relevant cost in each year for which the investor possessed a license, inflated or deflated the figure we received from the investor according to the NVE Hydropower Index. Due to lack of data, we assumed that the growth rate of investment cost in 2011 and 2012 is equal to the growth rate in 2010.

The revenue from operating a hydropower plant depends on the annual production. Future production depends on snow and rain precipitation, but it is impossible to forecast it years ahead. As a proxy for production we have used the expected annual production.

Electricity price was obtained from Nord Pool spot and cerrtificate price was obtained from Svensk Kraftmäkling. We calculated the correlation between the yearly electricity and green certificate price changes and found it to be very close to zero. Nevertheless, investors might have expectated, as economic intuition suggests, that such price changes were in fact negatively correlated. We have therefore chosen to use a correlation of -0.5 in our calculations.

Our calibrated model uses after-tax cash flows of the project. The required return on investment was calculated using the capital asset pricing model (CAPM) on an after-tax basis. As a proxy for the risk free rate we used the interest rate on 5-year government bonds from Norges Bank, 4.5%. The market risk premium was set to 5%.[6] In calculation of required returns we use beta of 0.7 as recommended by Gjølberg and Johnsen (2009).

5 Results

In this section we calculate the subsidies implied by both the real options model (subsection 5.1), the NPV rule (subsection 5.2) and compare these results (subsection 5.3). We evaluate the investment decision for each power plant in the years in which investors had an active license. The parameters are updated in each year, representing the available information presumably known by the investor at that time. In the year the investor chose to invest we calculate the real options implied subsidy level, S^*, required for the investment to be optimal given the current electricity price. We cannot calculate the required subsidy for an investor who did not invest. However, we can still calculate what would

[6] A survey of Fernandez et al. (2011) finds that a median market risk premium that finance and economics professors, analysts, and managers of companies in Norway use is 5%.

be the implied subsidy for this investor if he had invested, $S^*|ni$. Since the investor did not invest, he required in reality higher subsidy than $S^*|ni$. $S^*|ni$ is therefore just the lower bound of the required subsidies for investor who did not invest. Thus, for each year we divide investors into two groups: those who invested in a given year and those who could, but did not. The cases in which an investor could not invest for external reasons are excluded.

For both investor groups we also calculate the corresponding subsidy levels that make the NPV of the investment equal to zero. Such subsidy values trigger investment assuming NPV rule is used. Table 3 summarizes our results, which we discuss in subsections 5.1–5.3.

[Table 3 about here.]

5.1 Real Options Approach

Figure 2 displays the average real options implied subsidies, $S^*|i$ and $S^*|ni$, and the Swedish certificate price during the considered time period.

[Figure 2 about here.]

If investors invested according to the real options model and the green certificate price in Sweden represented their expected subsidies, then the implied subsidies of an investor who invested should be approximately equal to the price of the green certificates.[7] The required subsidy level when the investor did invest is close to the certificate price in the years 2003–2010, but is higher than the latter in the years 2011 and 2012. Both the magnitude and the evolution of the subsidy, apart from a slight hike in 2005, are similar to the price of certificates.[8] This finding suggest that investors had a long perspective regarding Swedish certificate prices when they invested. The implied required subsidy levels for the investors that did not invest are generally higher than both the implied required subsidies for the investors that did invest and the certificate price.[9] This comparison indicates rational investment behavior in the sense that investors who deferred investing required higher subsidies than investors who did invest. Additionally, as the required subsidy levels for the investors who did not invest are generally higher than the certificate prices, it would not have been optimal to invest if had expectations been in line with the certificate prices. Investor would have consequently waited as postulated by real options theory.

[7]If the expected subsidy was below the required subsidy, the investor would not have invested. If the expected subsidy was above the required subsidy, the investor should have already invested.

[8]We are comparing expected subsidies with current price of green certificates because green certificates are tradable instruments and therefore their expected future price is the current price.

[9]We run a statistical test to compare the mean required subsidies of investors who did not invest with the mean implied required subsidies of investors who invested and with the mean green certificate prices. In both cases the difference in means is statistically significant with a p-value smaller than 0.001%.

5.2 NPV Approach

If a now-or-never investment approach is applied, the corresponding decision rule is the NPV rule. If we consider the NPV excluding subsidies at the time of investment, we can study the investors' expectations about subsidies assuming that they followed the NPV rule. Investment occurred for 122 and 68 plants with positive and negative NPV, respectively, for a total 190 investment decisions.

The investor is indifferent to investing if the investment NPV is zero. Setting the NPV including subsidies to zero, we can find the minimum subsidy level required for investment. Figure 3 displays average implied subsidies and the Swedish certificate prices. The average implied minimum required subsidy level on average for those who invested is negative in most years, 8 out of 10. As the certificate price cannot be negative, we interpret the negative numbers such that the investor would be willing to invest even without subsidies. Interpretation of this conjectured behavior might be that the investors did not expect subsidies at all when they invested. The reasons for this could be that the investors did not rely on the government's promises and only invested if they had a positive NPV, even without subsidies. For example, some investors claimed "We did not dare to believe in revenue from certificates." and "We started production without even considering revenue from certificates. We have the financial resources to manage without". This show that investors could be risk averse (Pratt, 1964) and relying on subsidies before a scheme is implemented imposes a risk. Also, investors might not get the necessary financial support to make an investment decision with negative NPV, as banks do not grant loans based on uncertain expectations.

[Figure 3 about here.]

In 2005 and 2007 the required subsidy level is positive, which implies that someone invested with negative NPV. This can be explained by three possibilities. The first, and the most likely according to us, is that the investors did actually expect subsidy. The second possibility is that the negative NPV could be caused by other factors not captured by the model, while the third is that the investor did not expect subsidies and behaved irrationally.

We believe, based on the results and our interviews with investors, that some of the investors expected subsidies. An investor who decided to invest in 2007 said for example: "We expected to receive certificates given promises that everyone who invested after 2004 would receive support". Another who invested in 2009, just a few months before the new transitional agreement was set, said "It was a big disappointment. We were sure we would receive certificates".

In the cases where the license holder did not choose to invest, the required subsidy is positive on average. Thus, we have negative NPV on average and according to the NPV rule one should not invest if you have negative NPV. Thereby, the results display rational investment behavior given that the investor did not rely on subsidies. Nevertheless, we cannot rule out the plausible explanation that the investors were waiting for more information or better market conditions, in accordance with real options theory. The average required subsidy for the investors that did not invest is in fact negative in 5 out of 10 years, meaning that the NPV was positive half of the time. Thus, according to the NPV rule they should have invested. This negates the validity of the NPV in our case, and we therefore do not regard it as the best descriptor of the investment behavior in our case.

5.3 Comparison

We know from interviews that quite a lot of investors expected subsidies.[10] We therefore assume that investors expected a subsidy and took the current Sweedish certificate price as a proxy for the expected future subsidy. Given this assumption, we can evaluate whether investors' decision to invest or to not invest was in accordance with considered investment rule, be it either NPV or real options theory. This evaluation depends on the comparison between certificate price $P_{certificate}$ and implied subsidy S (S^* in case of real options theory and S^{NPV} in case of the NPV rule). If the subsidy implied (required) by a given investment rule was below the certificate price, then the investor should have invested according to this rule. If investors invested in such a situation, it is an evidence in favour of the considered investment rule. If investor did not invest, it is a piece of evidence against the considered investment rule. This is summarized in Table 4.

[Table 4 about here.]

This way we can easily evaluate whether investment decisions are consistent with the NPV and real options investment rule. The results are summarized in Tables 5 and 6. From Table 5 we can see that there are 16 cases in favor of real options theory and only 3 cases against. From Table 6 we can see that NPV rule is supported only in 10 cases and there is also 10 cases aginst the NPV rule. The results favor an investment behavior predicted by real options theory over the NPV rule. The real options model implies subsidies in line with the level of the Swedish certificate prices.

[Table 5 about here.]

[Table 6 about here.]

6 Conclusion

This study examines the investor behavior in 214 small hydropower projects in Norway. Our primary interest is to evaluate whether investors follow the real options or the net present value approach in making decision whether or not to invest. Our goal is to investigate whether investors act consistently with the

[10]Such a question was not part of our questionnaire. We obtained this information as a by-product of conducting interviews by simply listening to investors. As a result, we are unable to provide an exact fraction of investors that expected subsidies.

real options model, even though we know (from interviews) that they do not use this model directly.

We address this issue indirectly. If we assume a specific investment decision rule used by investors (implicitly or explicitly), we can infer the level of subsidies implied by their decision to invest (or not invest). We consider the real options and net present value decision rule, calculate implied subsidies and compare them to the actual subsidies observed in a very closely related market, Sweden.

Our empirical analysis provides support for investor behavior consistent with the real options decision rule. At the time investment decision was made, the implied subsidy according to a real options rule was comparable in size to the current Swedish certificate price. Furthermore, we find that the evolution in implied subsidies follows the predicted trend based on publicly available information published by the government as well as certificate price in Sweden.

On the contrary, the net present value rule implies that investors on average did not expect any subsidies and we know from the interviews with investors that some of them expected subsidies. Thus, we conclude that the two-factor real options decision rule is consistent with the observed investment behavior.

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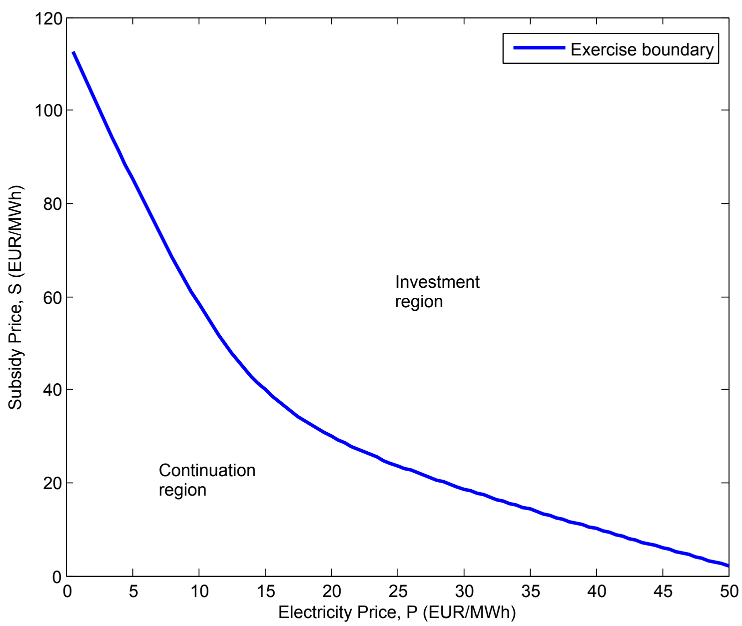

Figure 1: The optimal stopping boundary for a hypothetical power plant.

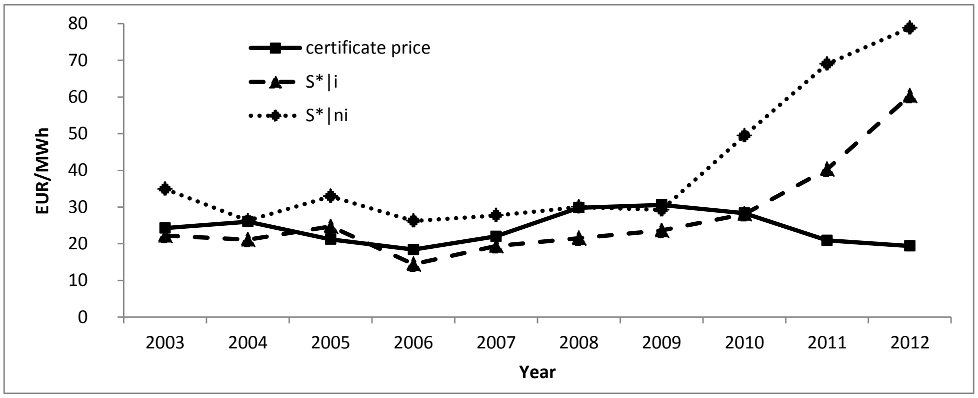

Figure 2: Actual and implied certificate prices using the real options rule.

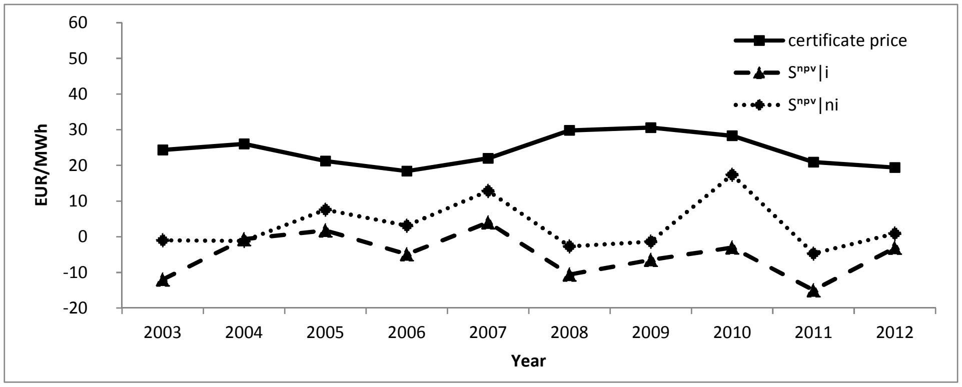

Figure 3: Actual and implied certificate prices using the NPV rule.

Table 1: Information published by the Norwegian Government.

Year	Information published by the Norwegian government	Planned start
2002	The Ministry of Petroleum and Energy expresses a positive view about establishing an international certificate market and believe Norway should participate in it (Ministry of Petroleum and Energy, 2002).	-
2003	Parliament asks the Government to initiate a Norwegian/Swedish certificate market.	-
	The Petroleum and Energy Minister announces that power producers who initiate construction after 1 January 2004 will have the opportunity to participate in the scheme, even though a scheme will only be established afterwards (Ministry of Petroleum and Energy, 2003).	2004
2004	A draft of the Certificate Act is sent to external hearing. A start-up date of 2006 is recommended by the Ministry (Ministry of Petroleum and Energy, 2004).	2006
2005	A common market is delayed by one year (Ministry of Petroleum and Energy, 2005).	2007
2006	At the start of the year the negotiations break down. Already established policy instruments are said to be strengthened (Ministry of Petroleum and Energy, 2006a).	-
2007	A feed-in premium will replace the certificate market. Hydropower producers will receive 5€/MWh for production representing the first 3MW of the installed capacity (Ministry of Petroleum and Energy, 2006b).	2008
2008	The feed-in premium is put on hold and negotiations with the Swedish government are restarted (Ministry of Petroleum and Energy, 2007).	-
2009	The Norwegian and Sweedish governments sign an agreement on the basic principles for the common market with a planned 2012 date (Ministry of Petroleum and Energy, 2009a).	2012
	Transitional arrangements are decided for power plants built after 7 September 2009. For power plants with capacity not exceeding 1 MW the previous date, 1 January 2004, applies. The years prior to 2012 will be withdrawn from the 15 years of certificates (Ministry of Petroleum and Energy, 2009b).	
2010	The Norwegian and Sweedish governments sign a protocol concluding the discussions on a system for renewable energy certificates (Ministry of Petroleum and Energy, 2010).	2012
2011	A draft of the Certificate Act is approved by the Council of State (Ministry of Petroleum and Energy, 2011).	2012

The table contains publicly available information on subsidies for the hydropower sector published by the Norwegian Government in the period 2002–2011.

Table 2: Parameter values for a hypothetical power plant.

Notation	Parameter	Value
I_0	Investment cost	350 €/MWh
c_0	Start value annual maintenance cost	9 €/MWh
α_P	Electricity price drift rate	2.5%
α_S	Subsidy drift rate	2.5%
σ_P	Electricity price volatility	15%
σ_S	Subsidy price volatility	15%
$\rho_{P,S}$	Correlation	-0.5
r	Required return	5%
T_{P_1}	Revenue lag of electricity income	0
T_{P_2}	Lifespan of power plant	40 years
T_{S_2}	Lifespan of subsidies	15 years
T_{S_1}	Revenue lag of subsidies	1 year

Table 3: Actual and implied certificate prices.

Year	Cert. price	$S^*\|i$	$S^*\|ni$	$S^{NPV}\|i$	$S^{NPV}\|ni$
2003	24.3	22.2	34.9	−12.0	−1.0
2004	26.0	21.1	26.3	−5.7	−1.2
2005	21.2	24.7	32.9	1.8	7.6
2006	18.4	14.4	26.2	−4.9	3.1
2007	22.0	19.4	27.7	4.0	12.8
2008	29.8	21.5	30.0	−10.6	−2.7
2009	30.6	23.6	29.2	−6.5	−1.4
2010	28.3	28.1	49.4	−3.0	17.4
2011	20.9	40.3	69.0	−15.0	−4.7
2012	19.4	60.3	78.8	−3.1	0.9

Average expected subsidies implied by the real options model (S^*) and the NPV calculations (S^{NPV}), calculated both for investors who invested in a given year ($|i$) and investors who did not ($|ni$). In case that investor did not invest, calculated implied subsidy is a lower bound of the requred subsidy. All numbers are in €/MWh.

Table 4: Possible outcomes of the empirical test.

	|i	|ni
$S \leq P_{certificate}$	evidence supports the theory	evidence against the theory
$S > P_{certificate}$	evidence against the theory	evidence supports the theory

This table summarizes whether the decision to invest (|i) or not invest (|ni) was or was not in accordance with considered theory depending on whether implied subsidy S was greater than certificate price $P_{certificate}$.

Table 5: Actual outcomes of the empirical test of the real options rule.

	|i	|ni
$S^* \leq P_{certificate}$	7	1
$S^* > P_{certificate}$	3	9

This table presents number of years in which the average real options implied subsidy S^* was smaller (greater) than certificate price $P_{certificate}$ for investors who invested (|i) and investors who did not invest (|ni).

Table 6: Actual outcomes of the empirical test of the NPV rule.

	|i	|ni
$S^{NPV} \leq P_{certificate}$	10	10
$S^{NPV} > P_{certificate}$	0	0

This table presents number of years in which the average NPV implied subsidy S^{NPV} was smaller (greater) than certificate price $P_{certificate}$ for investors who invested (|i) and investors who did not invest (|ni).