Investment Timing under Uncertain Renewable Energy Policy: An Empirical Study

Abstract

Investors in renewable energy projects follow the policy debate closely as part of forming their expectations regarding project viability. Based on panel data of 214 licenses to construct small run-of-the-river hydropower plants, we examine whether the prospects of a common Swedish-Norwegian market for green certificates (i.e., a renewable portfolio standard scheme) affected the timing of investments. Our results show that utilities and other professional investors in the energy market acted in accordance with a real option investment rule, and the prospects of possible future subsidies delayed their investment decision. On the other hand, our results do not show that farmers and other non-professional investors incorporated timing considerations in their investment decisions. Rather, our results indicate that these investors behaved as if their investment opportunity is now-or-never, investing if the project is profitable according to a net present value investment rule, ignoring the opportunity to create additional value by waiting. The observed difference in behavior between professional and non-professional investors is policy relevant given the distributed nature of many renewable energy technologies.

Keywords: Policy uncertainty; Renewable energy; Distributed generation; Investment; Real options; Regression analysis.

JEL: C25; G31; Q48

1 Introduction

Political discussion on whether, when, and how to support technology projects can be a powerful deterrent to immediate investments because it creates an incentive to wait until a policy decision is made. Based on panel data of 214 licenses to construct small hydropower plants, we examine whether the prospects of a common Swedish-Norwegian market for green certificates affected the timing of investments in Norway from 2001 to 2010. Special attention is paid to whether behavioral responses varied systematically across investor groups. We use real options theory to compare the value of immediate investment with the value of postponing the decision and possibly being entitled to sell certificates. The theory's main prediction is that firms will delay investments in long-lived irreversible assets when there is sufficient uncertainty that resolves over time and/or the project value increases over time (Dixit and Pindyck (1994)).

The first theoretical real options studies to address the impact of uncertain policy decisions on the timing of investment focused on tax incentives to invest (e.g. Rodrik (1991); Mauer and Ott (1995); Hassett and Metcalf (1999)). Recently, the focus has been on climate policy measures such as taxes to mitigate greenhouse gas emissions (e.g. Blyth et al. (2007), Yang et al. (2008), Boomsma et al. (2012) and Fuss et al. (2012)). A general result is that sudden changes in the policy target and the instruments chosen to accommodate this target have a greater impact on how firms time their investments than market driven volatility of the prices of these instruments.

Few empirical studies have used project level data to test whether firms time their investments as predicted by real options models, and none of these consider the impact of uncertain policy decisions. The predictions by real options models are seldom tested directly; rather, binary discrete choice models test whether or not investment decisions are negatively related to measures of uncertainty (e.g. Moel and Tufano (2002); Schatzki (2003); Cunningham (2006); Dunne and Mu (2010)). Kellogg (2010) tests the predictions by real options models directly by estimating a structural model. He finds that oil companies respond to changes in expected price volatility by adjusting their drilling activity by a magnitude consistent with the optimal response prescribed by theory.

Our paper contributes to this growing body of literature because it (1) focuses on the uncertainty created by shifts in policy regimes, (2) empirically tests the predictions for investment timing given by real options investment rules as compared with net present value investment rules, (3) bases these investment rules on detailed and project-based information on the market value of each underlying asset, and (4) examines whether investment behavior varies systematically across two investor groups.

Our choice of case gives us three advantages. First, the Norwegian government has spent the last 12 years discussing whether, how, and when to introduce a subsidy scheme for renewable energy, which provided us with a good case on how uncertain policy decisions may affect the timing of investments. Second, by focusing on small hydropower projects, we obtain access to a high number of standardized individual projects that lend themselves more easily to empirical testing as compared with other real investment projects. Finally, we have access to high-quality data, including the regulator's database on all license applications, interviews with the majority of license holders in our sample, discussions with an expert group representing the stakeholders and the extensive collection of price data available through Nord Pool Spot and NASDAQ OMX Commodities.

Using a similar approach to that of McDonald and Siegel (1986), we investigate whether a real options investment rule can better explain actual investor behavior compared with a net present value investment rule. The investigation is carried out by a combination of a numerical simulation to estimate the expected timing of investment decisions followed by empirical testing using a logistic regression model. As in Moel and Tufano (2002), we control for other factors affecting the investment decision.

The remainder of the paper is structured as follows. In Sections 2 and 3, we present the real options and the net present value investment rules and examine whether the assumptions of real options theory are realistic for our study. Based on this evaluation we suggest a division into two investor groups to empirically investigate systematic differences in behavior. In Sections 4–6, we present the data we use to model the projects' cash flows, the simulation approach used to estimate the two investment rules, and the regression analysis with which these rules are tested. We offer concluding remarks in Section 7.

2 Theory

According to a naive version of the net present value investment rule, an investor should invest now if the discounted value of future net cash flows, V, is greater than or equal to the investment cost, I:

$$V - I \geq 0. \tag{1}$$

However, assuming investment expenditures are at least partly irreversible and that investments can be delayed, the investor may value the opportunity to wait. Hence, according to the real options investment rule, the investor should invest now if the net present value of immediate investment, $V - I$, is greater than or equal to the expected value of postponing the investment decision, which is also called the continuation value, C:

$$V - I \geq C \Leftrightarrow V \geqslant I + C = V^*. \tag{2}$$

Consequently, the value of the opportunity to invest, the option value, can be expressed as:

$$F = \max[V - I, C]. \tag{3}$$

Real options theory allows us to explicitly model different sources of uncertainty affecting the project's cash flows. When cash flows are uncertain, investors can value the opportunity to gain additional information about likely future conditions affecting the project. Thus, the threshold V^* that the project value V must exceed in order for the condition in Eq. (2) to hold will increase as volatility in project value increases and as time decreases before an information event where future conditions affecting the project may be revealed. Even ignoring uncertainty, there may be value in waiting if the project value increases over time as a result of price development or the introduction of green certificates. Finally, a lower discount rate (ceteris paribus) increases the threshold V^* because it increases the value of continuation C relative to the value of immediate investment $V - I$ (Dixit and Pindyck (1994)).

The real options investment rule is based upon the neoclassical theory of the firm; that is, firms maximize economic value, their choices are based on rational preferences, and they act independently on the basis of full information or the same probability distributions describing outcomes. This requires that firms have the cognitive ability and time to value every choice against every other choice.

The net present value investment rule rules out the choice of delaying investments. Furthermore, it treats risk in a simplified manner because it bases project appraisal on expected cash flows and lets project risks be represented by a single risk-adjusted discount rate. According to the bounded rationality theory, people may use such simplified rules because they lack the cognitive ability or time to arrive at the optimal solution. Thus, they may instead be rational only after having greatly simplified the choices available. The bounded rationality theory was first proposed by Simon (1957) and is today widely acknowledged through the seminal work of Amos Tversky and Daniel Kahneman (see e.g. Kahneman (2011)).

3 Empirical context

To construct a hydropower plant in Norway, an investor must have regulatory approval. The license gives the owner the right, but not the obligation, to construct a power plant within 10 years. An investor in hydropower may value the opportunity to wait because the investment in turbines, generators, penstock, and construction is to a great extent irreversible. Hence, the owner of the license is holding a real option with characteristics similar to an American option.

After a license is granted, the licensee (1) updates the cost estimate to reflect any changes in license conditions and results of any new water flow measurements; (2) obtains tender offers for turbines, generators, penstock, and construction, so that a major part of the total costs is identified; (3) secures project funding and make sales agreements for delivering the power to the electricity transmission grid and revises the investment budget accordingly; (4) acquires the regulatory authority's approval for the detailed plans for plant development, and (5) decides whether to invest or to postpone the investment decision. Some of these tasks may have been undertaken before the license was granted, and if there are few modifications to the original license application, the investment decision can be made almost immediately. In other cases, non-economic factors may delay the time of the decision. These may be related to the process explained above, including complaints filed by the license owners or other stakeholders, problems with access to the electricity transmission grid, and problems with securing adequate funding. In our regression analysis, we control for these factors to ensure that delays for non-economic reasons are not misinterpreted as a result of economically rational investors balancing the value of immediate investment against the value of putting the project on hold.

For most small hydropower projects, the river is fully controlled by a group of local landowners (i.e., farmers). They can choose between two principally different ways of organizing the ownership and operation of the power plant (NVE (2010) pages 114–115): (1) form a privately owned company, sole trader or partnership, which applies for a license, makes the decisions whether and when to invest, gains access to funding, takes the investment risk, and operates the plant; or (2) ask a professional firm to take these responsibilities and operate the power plant for a fixed number of years, after which the plant is sold back to the landowners at an agreed upon price.We categorize the projects we study according to which of these two organizational models the license owner represents using the labels 'non-professional investor' (model 1) and 'professional investor' (model 2), respectively. The choice of organizational model may depend on characteristics of the project (e.g., profitability, risk and size) and/or of the group of local landowners (e.g., risk preference and access to funding).

This categorization is empirically relevant because Norwegian farmers represent a new type of investor emerging in the renewable power production market. In many areas in europe, private individuals, farmers and community groups with no previous experience in electricity generation have invested in decentralized power production based on renewable energy. In Germany, more than half of all renewable energy capacity installed in the electricity sector in 2010 was owned by private individuals and farmers (AEE (2010)). In an empirical study Bergek et al. (2013) find that investors with no traditional background in electricity production have made the majority of renewable electricity investments in Sweden.

Furthermore, we suspect that the assumptions underlying real options theory are less realistic for local farmers (i.e., non-professional investors) as compared with traditional utilities or professional energy companies (i.e., professional investors). We find it plausible that farmers will most often have less general knowledge on investment theory, no previous experience from the energy sector and/or less time to devote to these issues as compared with a professional energy investor. Also, utility maximization may include aspects other than pure economic considerations for a local farmer. Thus, as long as the project value is satisfactory, other non-economic aspects may determine when to invest.

4 Data

For each of the 214 licenses we examined, we gathered information on the license holder, when the license was granted, when an investment decision was made (if any), and for each year, the factors influencing the calculation of the two investment rules in Eqs. (1) and (2).

4.1 Dataset

We use cash flows and discount rates in nominal, total asset, after-tax terms. The cash flows for project assessment are investment expenditure (including upfront cost to get access to the electricity transmission grid), revenues from the sale of electricity, revenues from the sale of green certificates (if relevant), operation and maintenance costs, rental payments for the right to use the river, income tax, resource tax, and a property fee. The annual discount rates are derived using the capital asset pricing model. Discretionary assessments of project life, construction time, operation and maintenance costs, and rental payments are set based on advice from our expert group. Details on these cash flows and other parameters relevant for project appraisal are given in Table 1.

Our main source of information is the regulator's database, which includes information given by the investor in the license application. The database includes the date the application was received, the date the license was granted, the year operation began, investment costs, capacity in MW, and annual production in MWh. It also includes information on whether and when complaints have been filed and if they were settled and occasionally information about other delays, such as problems with access to the electricity transmission grid and changes in the organization of the investor group. The information has been updated by the regulator, for example, to reflect revisions to the approved plan, but only to a limited extent.

Table 1: Information used for project appraisal

Investment decision	In the few cases where we lack information, we assume that the investment decisions was made one year before operation began. According to our expert group, the time required to construct a small hydropower plant is approximately 1 to 1.5 years. In our dataset, many power plants started production in the same year the license was granted.
Project life	Our expert group advises using a 40-year lifetime for small hydropower plants.
Cash flows and discount rates	All cash flows and discount rates are given in nominal, after tax terms and relate to the total assets. We use the capital asset pricing model for estimating the nominal, after tax required rate of return on total capital in hydropower plant investments. Using an estimated beta value of 0.7 for total capital expenditure in the renewable power sector in Norway (Gjølberg and Johnsen, 2009), a market premium of 5 %, and a risk free rate of return equal to the tax adjusted yield on government bonds with 5 years to maturity, the required rates of return are: 2001, 8 %; 2002, 8 %; 2003, 7 %; 2004, 6 %; 2005, 6 %; 2006, 6 %; 2007, 7 %; 2008, 7 %; 2009, 6 %; 2010, 6 %.
Investment cost	Through the interviews with the license holders, we gathered information on the expected investment outlay at the time when the investment decision was made. If the investment decision had not yet been made, we obtained their updated expectations as of 2010 on investment cost. To estimate the expected immediate investment costs in earlier years, we deflated these values using an index for road construction costs. In the few cases were we did not get in contact with the license holder, we rely on investment costs given in the regulator's database, and inflate these from the year of the application using the road construction cost index mentioned above. However, these inflated investment costs may still include measurement errors as (1) the upfront cost of access to the electricity transmission grid may or may not be included; (2) license modifications may have resulted in new and more expensive power plant layouts; and, (3) the expected investment outlays in the applications are based on a rather weak foundation; before making an investment decision, the license holder normally has conducted a more thorough calculation as well as gathered information regarding investment costs from a public tender.
Annual costs	A small hydropower plant has annual costs consisting of (1) operation and maintenance costs, (2) payment for access to the electricity transmission grid, and (3) a fee to compensate a larger power company for the inconvenience of offering intermittent run-of-river power production into the electricity transmission grid. To account for these three cost elements, we used an annual cost of 9 EUR/MWh, which is the value suggested for the year 2010 by the Norwegian Association of Small Hydropower Plants. In addition, the power producer must compensate the owner of the river for renting the water; this fee is set at 10 % of gross income.
Taxes	Hydropower plants are exposed to taxation through the income tax, resource tax, and property fees. The income tax and the property fee have remained fixed at 28 % and 0.7 % from 2001 to 2010. The resource tax was increased from 27 % to 30 % from 2008. Resource tax was until 2003 only payable for plants with an installed generator size above 1.5 MVA. From 2004 this threshold has been increased to 5.5 MVA with the exception of 2008 when the threshold was temporarily lowered to 1.5 MVA. The annual payment for the right to use the river for power production has been deductible when calculating the resource tax in the period from 2001 to 2010. The source of information has been the Norwegian fiscal budgets, 2001–2010.

To update and complement the data in the regulator's database, we interviewed the owners of 179 of the 214 licenses (84 %) in our dataset to determine the year of the investment decision, the expected investment outlay, capacity, and production level at this point in time as well as to check whether the investment was delayed for non-economic reasons not included in the regulator's database.

When we were unable to interview the license holder, the regulatory information was supplemented with publically available information such as advertisement of tenders and media coverage of new power plants. The quality of the data for these 35 licenses will be lower as compared with the rest of the dataset. To control for possible systematic biases, we introduce a dummy variable for interviews in the regression analysis in Section 6.

4.2 Data description

We gathered data on 214 licenses granted from 2001 to 2008, and the corresponding investment decisions, if any, from 2001 to 2010 (Figure 1). The licenses represent power plant investment costs of approximately 1,000 million euro measured in 2010 prices, an installed capacity of 670 MW, and a production volume of 2.4 TWh (2 % of Norway's total annual electricity generation).

Local farmers own 115 of the licenses, and the remaining 99 are owned by traditional utilities and energy companies specializing in small hydropower. The average size of the power plants, including both planned and realized projects, is smaller for the non-professional investors (2.5 MW) than for the professional investors (3.9 MW). Power plants being constructed under licenses owned by non-professional investors are on average expected to be less costly than those owned by professional investors as well, at 333 and 468 euro per annual MWh production, respectively (see Figure 2).

Professional investors delayed the investment decision by one year or more in 73 % of the cases, as compared with 59 % of the cases for non-professional investors. And, the average delay in investment decision was 1.1 years for professional and 0.8 years for non-professional investors. These numbers are calculated based on licenses where a decision to invest was made in the period 2001–2010.

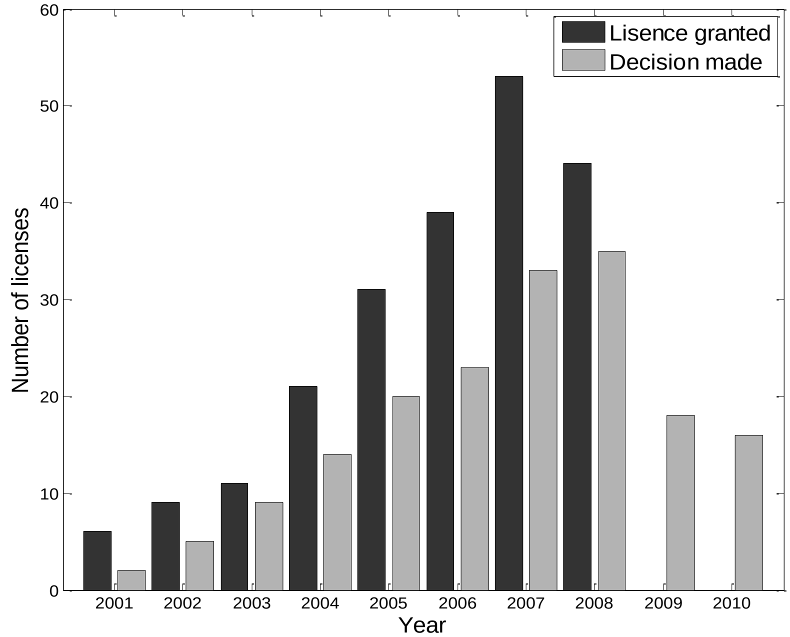


Figure 1: Number of licenses granted each year in the period 2001–2008 and the number of corresponding decisions to invest, if any, for each year in the period 2001–2010.

5 Simulation

For each license and each year, we simulate the expected net present value of immediate investment $(V - I)$ and the continuation value (C), which together with Eqs. (1) and (2), can be used to assess the proper investment timing according to the net present value and real options investment rules, respectively. We simulate the $V - I$ and C variables for three policy and three price process assumptions, and this dataset is used as input to nine regressions in Section 6.

Among the many uncertainties faced by the investor, we choose to model the possible introduction of green certificates (Section 5.1) and the development in electricity prices (Section 5.2) because interviews with investors suggest that these have been the most important uncertainties during the past decade. The simulation approach used to estimate the two investment rules is presented in Section 5.3. Finally we examine the simulated investment rules at the time the investment decisions were made and draw some preliminary conclusions.

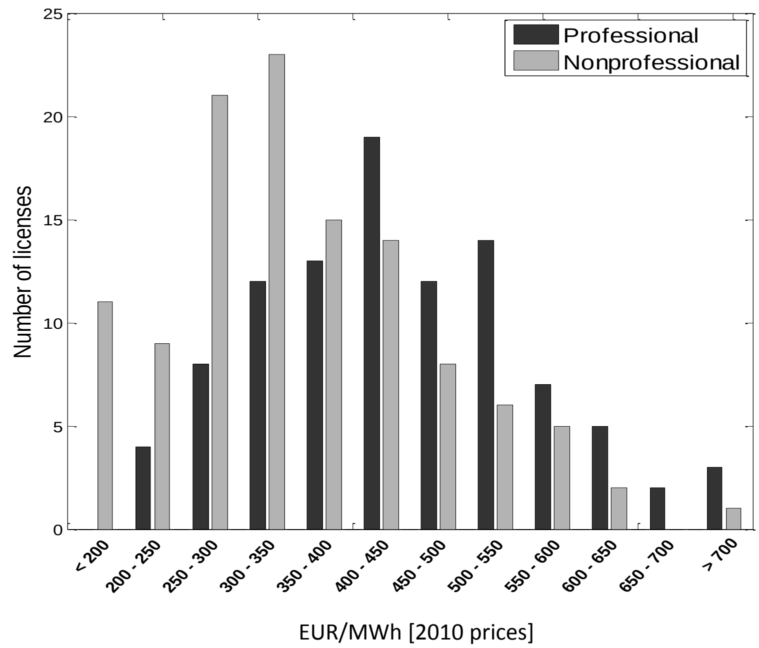


Figure 2: Expected investment costs at the time the investment decision was made or, if no decision has been made, the expected values in 2010.

5.1 Uncertain policy decisions

During the period 2001–2011, the Norwegian government discussed whether, when and how to introduce green certificates, and in January 2012, Norway became a part of the Swedish-Norwegian market for green certificates. In a green certificate scheme, the government sets a target for the supply of new renewable electricity production. The price of the green certificate is determined by a market in which distributors of electricity buy and producers of new renewable electricity sell certificates according to predefined rules. Since the market for green certificates was introduced in Sweden in 2003, the average annual price for these certificates has varied between 20 and 33 euro per MWh, equivalent to roughly 2/3 of the wholesale electricity prices. Thus, if the scheme was introduced in Norway, it would represent a major lift in total revenues for plants entitled to support.

During these years of policy uncertainty, Norwegian investors were at each point in time well informed of the planned date for implementation of the subsidy scheme. Thus, we argue the uncertainty was mainly related to whether this subsidy scheme would be implemented at all and, if so, for which power plants. This uncertainty can be modeled as follows. Consider an investor in year t that has a license to construct a power plant with capacity c. The investor believes that he or she will be entitled to subsidies from year N_t with a probability $\rho_{t,c}$ given by:

$$\rho_{t,c} = \gamma_{N_t} \cdot \theta_{t,c} \tag{4}$$

where γ_{N_t} is the probability that a subsidy scheme will be implemented in a future year N_t and $\theta_{t,c}$ is the probability that, conditional on the subsidy scheme being implemented, a power plant with installed capacity c will be entitled to support.

A major challenge is how to model investors' expectations with respect to the introduction of green certificates. We choose to subjectively assign values to the probabilities in Eq. (4) based on a thorough investigation of political statements and decisions (see Table 2). Our approach is simple, explicit and based on information that was publically available at the time the decisions were made. However, it is possible that other analysts could examine the same information and assign different probabilities. To reduce this ambiguity, we divide the probabilities into five broad categories: very unlikely (0 %), more unlikely than likely (25 %), equally likely (50 %), more likely than unlikely (75 %), and very likely (100 %). Furthermore, the assigned probabilities were evaluated by our expert group consisting of stakeholders from the industry and governmental agencies.

Table 2: Subsidy probabilities, level of support, and year of introduction.[a]

t	$\bar{s}_t(€/MWh)^b$	γ_{N_t} (%)	$\theta_{t,N_t,\langle 0MW,1MW]}$ (%)	$\theta_{t,N_t,\langle 1MW,10MW]}$ (%)	N_t
2001	22	25	100	50	2004
2002	22	25	100	50	2004
2003	22	25	100	50	2004
2004	21	25	100	50	2006
2005	24	75	100	50	2007
2006	24	25	100	50	2008
2007	5	75	100	100 up to 3 MW, 0 from 3 to 10 MW[c]	2008
2008	23	25	100	50	2012
2009	29	50	100	75	2012
2010	34	75	100	100	2012

[a] The subsidy payment is given for the first 10 years after production started in the period from 2001 to 2006, and for the first 15 years after the production started in the period from 2007 to 2010. These assumptions reflect the content of draft bills for green certificates and feed-in schemes in the relevant period.

[b] The expected green certificate price at time t, $\bar{s}_t$, is assumed to be constant over time, and is set equal to average historical Swedish green certificate prices. Since green certificates were introduced in Sweden in 2003, we use the 2003 average price for 2001 to 2003. From 2004 and onwards we use a rolling window of two years. In 2007, $\bar{s}_t$ is set equal to the feed-in premium for hydropower approved by the Norwegian Parliament in 2007.

[c] The feed-in premium is given for the first 3 MW of installed capacity.

The probability of the introduction of a subsidy scheme γ_{N_t} has changed over time, and the political debate can be divided into four phases.[1] (1) In 2001 the idea of a common Swedish and Norwegian green certificate market was launched and debated. Although the scheme was introduced in Sweden in 2003, it lacked necessary political support in Norway. (2) In 2005, the Norwegian government declared its commitment to green certificates, and the first round of negotiations of a common market for Sweden and Norway took place in the winter of 2005–06. However, the optimism in 2005 was replaced by pessimism in the beginning of 2006 when the negotiations failed. (3) In 2007, the Norwegian parliament voted for the introduction of a detailed, national feed-in premium system starting in 2008. The simplicity of the plan made many believe that it was more likely than not that the premium would be implemented. (4) The second round of negotiations with Sweden started in December 2007, and the feed-in premiums were abandoned before being implemented. Investor sentiments were gradually changed from skepticism to optimism as an understanding between the two countries was signed in June 2008, followed by an agreement in September 2009 and finally a draft for a Norwegian law on green certificates in December 2010.

The political discussions have favored hydropower plants with installed capacity below 1 MW, making it almost certain that these power plants would be included if a subsidy scheme was introduced; thus, we have set $\theta_{t,N_t,\langle 0MW,1MW]} = 100\%$. There has been uncertainty with respect to the inclusion of power plants with installed capacity between 1 and 10 MW.

We model and test versions on how the publically available information was perceived and interpreted by investors. In an attempt to persuade investors not to postpone their investments until the issue of renewable electricity subsidies was settled, the Petroleum and Energy Minister stated in December 2003 that power plants being constructed from January 2004 would be entitled to future subsidies, regardless of when the scheme was introduced.[2] We therefore include three policy processes in the regression analysis in Section 6, one in which investors did not consider the possibility of future subsidies (denoted *No subsidies*), one in which the investors believed that they would be entitled to subsidies only for power plants constructed after the scheme was implemented (denoted *Subsidies, no retroactive arrangement*) and one in which investors believed the scheme would be applied retroactively (denoted *Subsidies, retroactive arrangement*).

5.2 Stochastic electricity price

The electricity price process is given in Eq. (5):

$$\Delta P_{t,r} = \alpha_{t,r} \cdot P_{t,r} \cdot \Delta r + \lambda \cdot (\bar{P}_{t,r} - P_{t,r}) \cdot \Delta r + \sigma \cdot P_{t,r} \cdot \Delta W_{t,r},$$
$$t \in 2001, ...2010, \quad r \in 1+l, ..., L+T+l \tag{5}$$

where $P_{t,r}$ is the expected electricity price in year r based on information available in year t. Furthermore, $\alpha_{t,r}$ is the trend parameter, λ is the mean-reverting factor, $\bar{P}_{t,r}$ is the level to which the price reverts, σ is the volatility parameter, and $\Delta W_{t,r}$ is the increment of a standard Wiener process.

We can use Eq. (5) to examine three processes for the electricity price. When the volatility parameter σ is zero and/or the mean-reverting factor λ is one, the price follows follows a deterministic process (denoted

DET). When λ is zero, the price follows a geometric Brownian motion (denoted *GBM*). When λ is between zero and one, the price follows a mean reversion process with trend (denoted *MRT*) where the volatility grows with price. In the last case, we set λ equal to 0.68, implying that 90 % of a price shock is eliminated after three years.

The trend parameter process is given in Eq. (6).

$$\Delta\alpha_{t,r} = \mu \cdot (\bar{\alpha} - \alpha_{t,r}) \cdot \Delta r, \quad t \in 2001, ..., 2010, \quad r \in 1 + l, ..., L + T + l \tag{6}$$

In the short term, the expected trend, $\alpha_{t,r}$, is derived from forward contracts traded at NASDAQ OMX. Because contracts with delivery beyond three years are not regularly traded, we assume that the trend gradually converges to the inflation target set by the Norwegian government (represented by $\bar{\alpha}$), which implies that electricity prices remain fixed in real terms. We set $\mu = 0.90, 0.68, \text{and } 0.44$, which ensures that 90 % of the difference between the inflation target and the starting point of the trend fades out within one, three and five years, respectively.

The volatility parameter, σ, is set equal to 16 % and is calculated as the annual standard deviation of the log returns implied by daily prices of three-year forward contracts in the period from 2001 to 2010. Thus, we assume the investors, when considering long-term investments, did not change their expectations with respect to price volatility during this period.[3]

The electricity price is simulated for $L + T + l$ years where L is the project lifetime, T is the option lifetime, and l is the construction lag. For each year, the investor will gain more information and have new estimates for the starting points of the trend parameter and the electricity price, as outlined in Table 3.

Table 3: The starting points of the trend parameter and electricity price.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
$\alpha_{t,1}$ (%)[a]	7	7	7	4	3	1	-1	0	1	2
$P_{t,1}$ (€/MWh)[b]	16.9	19.5	20.4	24.2	27.3	35.5	44.6	52.8	51.5	43.8

[a]The starting point of the trend is the implied drift from simultaneously observed two- and three-year forward contracts using a rolling window.

[b]The starting point of the electricity price is the discounted three-year forward contracts from the last half of the previous year and the first half of the present year.

5.3 Real options valuation

Longstaff and Schwartz (2001) suggest an approach for approximating option values by using simulations known as the least squares Monte Carlo method. The key to the method is the use of least squares to estimate the continuation value of the option, that is, the conditional expected payoff to the option holder from delaying investment.

We start with simulations of the stochastic processes. For each year we make 15,000 simulations where each simulation ω contains a path for future subsidy premiums (if any) and a path for future electricity prices. The stochastic nature of these prices is described by the jump-process in Eq. (4) and the diffusion process in Eq. (5).

Next, we use least squares to estimate the conditional expectation functions for the continuation value for each of the 214 licenses by using the following procedure. For each simulation ω, we derive the discounted value of the future payoff to the license owner from delaying investment if he or she had perfect foresight (Y_ω) as well as the present value of immediate investment (X_ω). We then regress vector Y on vector X using power functions as basis functions.[4] We follow this procedure from the last year of the option to the first, in each year estimating the conditional expectation function for the continuation value, $E\left[Y|\,X\right]$.

Finally, we calculate the net present value, $V-I$, and the expected continuation value, C, for each license and each year. The present values V are set equal to the average simulated value X for a specific license and year, and we calculate the expected continuation values using the relevant conditional expectation function $E\left[Y|\,X\right]$. The estimated net present values, $V-I$, and continuation values, C, can then be used to derive the first investment signal (if any) for each license according to the two investment rules in Eqs. (1) and (2), and will serve as input to the regression analysis presented in Section 6.[5]

5.4 Main findings

Figure 3 shows the average ratio of *(net present value-continuation value)/net present value* in the year in which the decision to invest was made for different policy and price process assumptions. If the ratio is positive, behavior is on average consistent with the real options value investment rule in Eq. (2). Under these

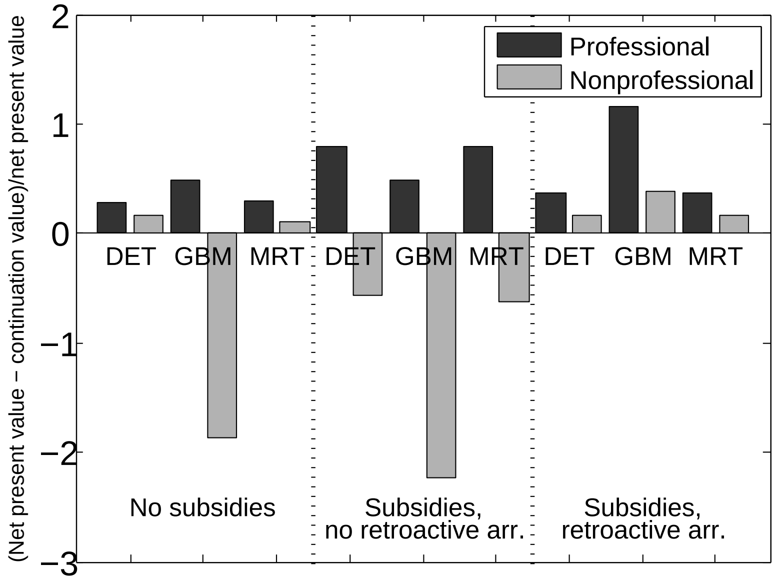


Figure 3: The average ratio of *(net present value-continuation value)/net present value* in the year in which the investment decision was made.

conditions, the net present value investment rule in Eq. (1) will also always be satisfied. Figure 3 illustrates that professional investors only invest when the average ratio was positive, whereas non-professional investors invest even when the average ratio is negative in four out of nine policy and price scenarios which is in conflict with the real options investment rule.

6 Regression analysis

6.1 Regression model

To formally examine whether the timing of investment decisions are consistent with one of the two investment rules simulated in Section 5, we employ a multivariate discrete-choice regression model. We use the maximum-likelihood method to estimate the parameters of the following binary logit regression model:

$$\mathrm{P}(y_{i,t} = 1) = \frac{e^{\boldsymbol{\beta}^\top \boldsymbol{x}}}{1 + e^{\boldsymbol{\beta}^\top \boldsymbol{x}}} \tag{7}$$

where P denotes probability, $y_{i,t}$ is equal to one if an investment decision is made for license i in year t and zero otherwise, $\mathbf{x}$ is the row vector of independent variables augmented by one, and β^T is the corresponding column vector of estimated parameters.

The net present value investment rule is represented by the independent variable *Net present value* $(V-I)$, and the real options investment rule is represented by the independent variable *Continuation value-net present value* $(C-V+I)$. These two variables are simulated in Section 5. The measurement unit is the euro. By including both investment rules in the regression, we can test the partial impact of each one, which is important because the independent variables representing the rules are highly correlated, and omitting one would bias the estimate of the other. If the estimate for the variable *Continuation value-net present value* is statistically significant while the estimate for the variable *Net present value* is not, this indicates that investors behave according to the real options investment rule and that the net present value investment rule does not provide any additional explanation of investor behavior. Similarly, the reverse is true if the opposite situation exists. If the estimates of both variables are significant, no conclusions can be drawn.

To test whether professional and non-professional investors follow different investment rules, we include a dummy variable (denoted *D_prof* in Table 4), which is equal to one for professional investors. The regression model includes interaction between the dummy variable and other independent variables.

To ensure unbiased estimates, we control for other variables that may affect investment behavior. Because the quality of the data is higher for the projects where we were able to interview the license holder, we introduce a dummy variable (denoted *License owner interviewed* in Table 4) equal to one for projects with affiliated interviews. Furthermore, license holders were asked whether non-economic barriers had affected their investment decision in any year, and we include a dummy variable (denoted *Non-economic barriers* in Table 4) equal to one for the project/year combination for which barriers were reported. Finally, project size may serve as a proxy for unobservable costs, for example, the distress caused by conflicts with neighbors and others affected by the project and the time and effort used to make a detailed prospectus with which an investment decision can be made and any relevant loans be obtained. As indicated by some of the interviewed license holders, these costs may be relatively higher for the smallest projects. To control for such effects, we include a dummy variable (denoted *D_below1MW* in Table 4) equal to one for power plants with an installed capacity of less than 1 MW.

6.2 Regression analysis

We estimate Eq. (7) using the nine simulated datasets in Section 5 for the two independent variables: *Net present value* and *Continuation value-net present value* (see Table 4). Each dataset represents a combination of a policy assumption (*No subsidies*; *Subsidies, no retroactive arrangement*; and *Subsidies, retroactive arrangement*) and a price process assumption (*DET*, *MRT*, *GBM*)), described in Sections 5.1 and 5.2.

The estimates are displayed as odds ratios and the ratio corresponding to the jth coefficient is $\psi_j = e^{\beta_j}$; thus, $\psi_j > 1$ means that an increase in the independent variable j increases the probability of investment, and vice versa. The standard errors are estimated allowing for intragroup correlation; that is, although observations are assumed to be independent across projects, they are not necessarily independent across time for one project. More precisely, we have used the clustered sandwich estimator for the variance-covariance matrix where the individual project is the clustering variable.

Most of the regressions in Table 4 indicate that professional investors act in accordance with the real options investment rule, whereas the non-professional investors act in accordance with the net present value investment rule. For non-professional investors the *Net present value* estimate is significantly greater than one in four of the nine regressions, reflecting that the propensity to invest increases as the net present value of immediate investment increases. Conversely, the *Continuation value-net present value* estimate is not significant in any of the regressions; thus, no additional explanation is provided by this variable in this situation. For professional investors, the *Continuation value–net present value* estimate is significantly less than one in five of the nine regressions, reflecting that the propensity to invest declines as the continuation value increases relative to the value of immediate investment. The *Net present value* estimate is not significant in any of the regressions; thus, no additional explanation is provided by this variable. The estimates for the three dummy variables controlling for non-economic barriers, whether our information is based on interviews or not and the size of the project are all statistically significant; thus, including them in the model contributes to unbiased estimates of the investment variables.

Table 4: Estimated regressions.[a]

Subsidy scheme	No subsidies			Subsidies, no retroactive arrangement			Subsidies, retroactive arrangement		
Electricity price process	DET	GBM	MRT	DET	GBM	MRT	DET	GBM	MRT
Regression number	1	2	3	4	5	6	7	8	9
NPV									
D_prof = 0	1.63	1.34	1.62	1.67	1.34	1.65	1.26	1.04	1.25
	(0.01)**	(0.41)	(0.01)**	(0.00)**	(0.41)	(0.00)**	(0.09)	(0.92)	(0.10)
D_prof = 1	0.96	0.97	0.96	1.13	0.96	1.13	0.97	1.13	0.97
	(0.68)	(0.93)	(0.66)	(0.12)	(0.90)	(0.12)	(0.59)	(0.57)	(0.57)
Continuation value–NPV									
D_prof = 0	1.47	0.81	1.37	0.62	0.81	0.62	0.43	0.70	0.39
	(0.72)	(0.65)	(0.77)	(0.09)	(0.62)	(0.09)	(0.46)	(0.42)	(0.47)
D_prof = 1	0.61	0.85	0.61	0.82	0.84	0.82	0.57	1.08	0.57
	(0.04)*	(0.58)	(0.03)*	(0.06)	(0.55)	(0.05)*	(0.02)*	(0.76)	(0.02)*
Size below 1 MW									
D_prof = 0 & D_below1MW = 1	0.42	0.38	0.42	0.40	0.38	0.40	0.35	0.33	0.35
	(0.09)	(0.05)*	(0.09)	(0.06)	(0.05)*	(0.06)	(0.03)*	(0.02)*	(0.03)*
D_prof = 1 & D_below1MW = 0	1.16	0.84	1.16	0.90	0.85	0.90	0.94	0.56	0.94
	(0.72)	(0.74)	(0.72)	(0.75)	(0.75)	(0.75)	(0.88)	(0.26)	(0.87)
D_prof = 1 & D_below1MW = 1	2.08	1.75	2.07	1.77	1.74	1.76	1.69	1.42	1.67
	(0.35)	(0.48)	(0.35)	(0.45)	(0.49)	(0.46)	(0.49)	(0.65)	(0.50)
Non-economic barriers (D = 1)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**
License owner interviewed (D = 1)	3.28	3.29	3.28	3.40	3.29	3.40	3.10	3.11	3.13
	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**
Pseudo R^{2b}	0.255**	0.247**	0.255**	0.257**	0.247**	0.257**	0.249**	0.237**	0.249**
Wald $\chi^2(9)^c$	47**	41**	47**	55**	40**	55**	46**	41**	47**
HL $\chi^2(10)^d$	13.17	18.16	10.22	12.12	20.33	12.13	10.74	13.13	10.94

[a]The estimates are displayed as odds ratios. The P-value is given in parenthesis and * and ** indicate that the estimate is significantly different from one at the 5 % and 1 % significance levels, respectively. The number of observations is 508, and the number of groups is 214.

[b]McFadden's R^2 compares a model with just the intercept to a model with all parameters.

[c]Test the null hypothesis that all coefficients except the intercept are zero.

[d]Test the null hypothesis that the HL statistics follow a χ^2 distribution.

The results reported in Table 4 are robust to the removal of outliers and observations where the dummy for non-economic barriers is equal to one, as well as including various measures of size; that is, although the explanatory power decreases and some relevant estimates are no longer significant in these alternative regressions, the magnitude of the *Net present value* and the *Continuation value–net present value* estimates remain largely unaltered. Furthermore, using different trend adjustment rates in the price process simulations (as suggested in Subsection 5.2) had only a marginal impact on the investment signals provided by the two investment rules and resulted in no significant changes in the regression estimates.[6]

An examination of goodness-of-fit measures and the magnitude and significance of the estimates as compared with initial beliefs indicate that regressions 2, 5 and 8, in which investors expect prices to follow a geometric Brownian motion process, perform less well than the others (Table 4). The Wald χ^2 statistic is clearly lower in these regressions, and the *Net present value* and *Continuation value–net present value* estimates are never significant. Hosmer-Lemeshow (HL) statistics can be used to compare the predicted probabilities with the observations in the sample. We divide our data into 12 groups, and the HL statistics suggest that all regressions fit well (Table 4). Again, regressions 2, 5 and 8 perform less well than the others.[7]

We analyze the residuals by comparing the predicted probabilities to a moving average of the proportion of cases in which $y_{i,t} = 1$. The Lowess graphs presented in Figure 4 reflects reality well if there is a good fit between the diagonal line and the observed fractions. Figure 4 reveals that several regressions fail in predicting the higher probabilities of investment; that is, for high probabilities, the fractions of observed cases are consistently less than the predicted probabilities. This is the case for regressions based on the price assumption of geometric Brownian motion (second column) and the policy assumption of *No subsidies* (first row) or *Subsidies, retroactive arrangement* (third row). When a geometric Brownian motion price process is assumed, the continuation value, and subsequently the value of the variable *Continuation value-net present value*, varies a great deal. It seems that investors did not believe or act on these variations, especially not when they resulted in continuation values close to zero (which result in high predicted probabilities of immediate investment). The policy assumption of *No subsidies* or *Subsidies, retroactive arrangement* both make immediate investment more attractive relative to the policy assumption of *Subsidies, no retroactive arrangement*. However, the Lowess diagrams show that many investors did consider the risk of not being entitled to future subsidies if investing today because they chose to postpone projects beyond what is indicated by these scenarios. Consequently, we conclude that the only regressions that reflect reality well are those that assume that prices follow a deterministic or a mean reversion with trend model and policies that follow *Subsidies, no retroactive arrangement* assumption. This conclusion is further confirmed by the informal tests mentioned above and the Wald χ^2 goodness-of-fit statistic, which reaches its highest values in regressions 4 and 6.

6.3 Results

Our results show that utilities and other professional investors in the energy market acted in accordance with a real option investment rule, and the prospects of possible future subsidies delayed their investment decision. Furthermore, the government statement of a retroactive arrangement did not succeed in preventing such delays. First, Figure 3 documents that these investors, on average, behaved in accordance with real options theory investing only if the value of immediate investment exceeded the value of postponing the investment decision. This conclusion is the same under all the nine price and policy process assumptions. Second, in Table 4 we can reject the null hypothesis that the difference between continuation value and net present value did not affect the investment timing at a 5 % significance level for five of the nine regressions. Finally, our analysis above shows that regressions 4 and 6, based on the policy assumption of *Subsidies, no retroactive arrangement* and no or moderate price uncertainty, perform better than the other regressions.

On the other hand, our results do not show that farmers and other non-professional investors incorporated timing considerations in their investment decisions. First, in Table 4 we cannot reject the null hypothesis that the difference between continuation value and net present value did not affect the investment timing at a 5 % significance level for any of the nine regressions. Furthermore, Figure 3 documents that in four of the nine price and policy process scenarios, the actual investment timing is in conflict with the real options rule, on average. Rather, our analysis above suggests that farmers behaved as if their investment opportunity is now-or-never, investing if the project is profitable according to a net present value investment rule, ignoring the opportunity to create additional value by waiting.

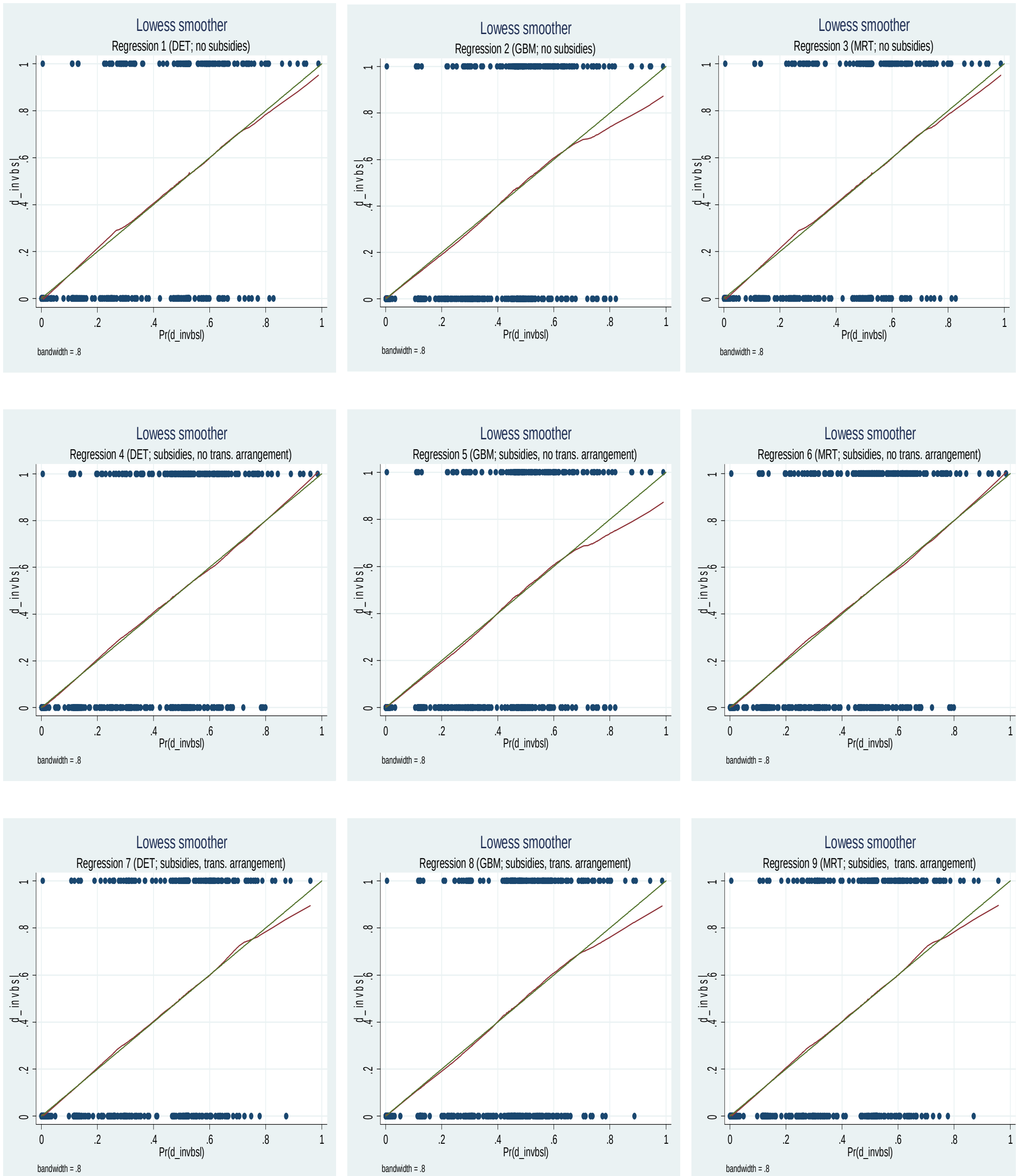


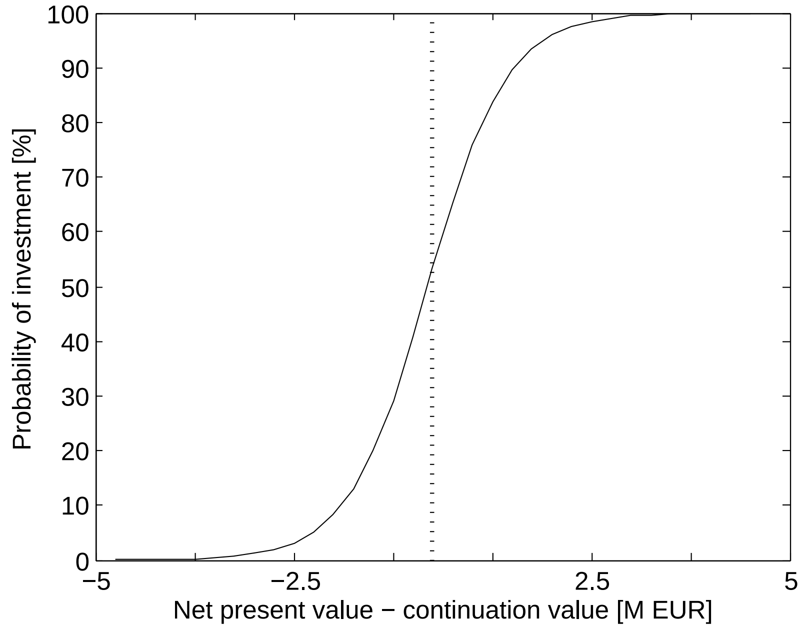
Figure 4: Lowess graphs. The fraction of observed cases that equal one at each level of the model's predicted probability of observing a one. The model reflects reality well if there is a good fit between the diagonal line and the observed fractions.

We end this Section by examining the economic significance of the estimated investment rules based on regression 6 in Table 4. The *Net present value* estimate for non-professional investors is 1.65. This means that if the net present value of a project increases by one million euro, all else equal, the odds ratio for a decision to invest increases by 65 %. Thus, if the probability of investing was originally 50 %, it would increase to 62.3 %, while if it was 80 % it would increase to 86.8 %. The *Continuation value–net present value* estimate for professional investors is 0.82, meaning that if the difference between the continuation value and the net present value of immediate investment increases by one million euro, all else equal, the odds ratio for an investment decision decreases by 18 %. Thus, if the original probability to invest was 50 %, it would decrease to 45.1 %, and if it was 80 % it would decrease to 76.6 %.

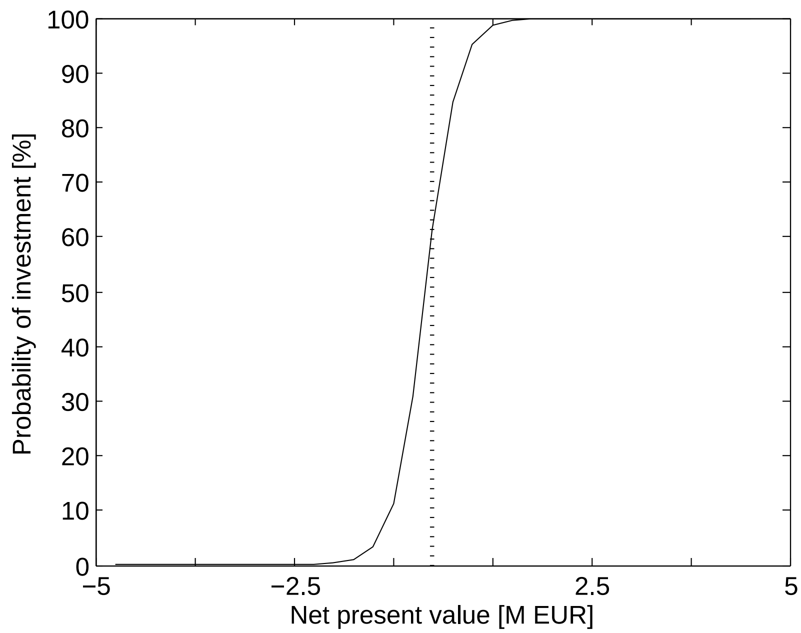
These nonlinear relations between the two investment rule variables and the propensity to invest are further illustrated in Figure 5. The probability of observing an investment decision by professional investors is significantly affected by an increase in the value of immediate investment relative to the value of continuation.They are more likely to invest when the net present value of immediate investment is equal to or greater than the continuation value and vice versa (Figure 5a), whereas the probability of observing an investment decision by non-professional investors is significantly affected by an increase in *Net present value*. They are more likely to invest when *Net present value* is slightly higher than zero and more likely to postpone their decision when *Net present value* is slightly lower than zero (Figure 5b).

7 Conclusion

The Norwegian government spent 12 years discussing whether, how, and when to introduce a subsidy scheme for renewable energy. According to the real options theory, this uncertainty should have delayed investment decisions. Our results show that utilities and other professional investors incorporated timing considerations in their investment decisions, lending partial support to real options theory. Furthermore, the government statement of a retroactive arrangement did not succeed in preventing such delays. On the other hand, our results do not show that farmers and other non-professional investors incorporated timing considerations in their investment decisions. Rather, our results indicate that these investors behaved as if their investment



(a) Professional investors and the real options investment rule.



(b) Non-professional investors and the net present value investment rule.

Figure 5: The probability of investment. Panel (a): Professional investors and the real options investment rule. Panel (b): Non-professional investors and the net present value investment rule. The probabilities are calculated based on Eq. (7) and on the estimates from regression 6 in Table 4. The dummies for non-economic barriers and installed capacity below 1 MW are set equal to zero. The dummy for interview is set equal to one. In panel (a), the variable *Net present value* is set equal to the average value for the dataset (0.9 M EUR). In panel (b), the variable *Net present value–continuation value* is set equal to the average value for the dataset (-0.7 M EUR).

opportunity is now-or-never, investing if the project is profitable according to a net present value investment rule, ignoring the opportunity to create additional value by waiting. This result is interesting from a theoretical perspective because it suggests that the assumptions made by real option theory with respect to investors preferences, characteristics and behavior are less realistic for this group of investors. It is also interesting from an empirical perspective given the distributed nature of many renewable energy technologies. Solar and wind power, for example, can be installed by small land and home owners as well as large corporations. Thus, our findings have important implications beyond the narrow case of small hydropower investments in Norway.

Acknowledgment

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Notes

[1]A detailed overview of the political process is electronically available.

[2]Press release 138/03 from the Ministry of Petroleum and Energy on December 19, 2003.

[3]Ideally we would base the volatility calculation on forward contracts with longer maturity because we assume investors take a long-term view on the profitability and risk of the investment. Because the short end of the forward market tends to be more volatile than the long end (Samuelson, 1965), we argue that 16 % represents an upper limit to the expected volatility.

[4]The regression is given by:

$$Y = \sum_{m=0}^{M} a_m \cdot X^m + \varepsilon \tag{8}$$

where a_m are the regression coefficients, M is the number of subsets of basis functions, and ε is the error term.

[5]Longstaff and Schwartz (2001) emphasize that the least squares Monte Carlo method provides a lower bound on the option value, and present a formal proof of the theoretical convergence of the algorithm towards the true value as the number of simulations and the number of subsets of basis functions increase. We therefore used 15,000 simulations of the stochastic processes for each year and eight subsets of the chosen type of basis function. We also investigate whether our results are affected by the choice of basis function (power function, Laguerre polynomials, Hermite polynomials, and trigonometric functions) or by changing the number of simulations (10,000 and 20,000). None of these choices or changes significantly alters the timing of the investment signal according to the real options investment rule.

[6]These results are available from the authors.

[7]However, as mentioned by Hosmer and Lemeshow (2000): ”The great disadvantage is that in the process of grouping we may miss an important deviation from fit due to the small number of individual data points. Hence, we advocate that, before finally accepting that a model fits, an analysis of the individual residuals and relevant diagnostic statistic be performed.”

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