Uncertain climate policy decisions and investment timing:
Evidence from small hydropower plants

Abstract

Based on panel data of 214 licenses to construct small hydropower plants, we examine whether uncertainty with respect to the introduction of a market for renewable energy certificates affected the timing of investments in Norway from 2001 to 2010. Using regression analysis, we find that (1) investors owning a portfolio of licenses acted in accordance with a real options investment rule, and uncertain climate policy decisions delayed their investment rate; and (2) investors owning a single license acted in accordance with a traditional net present value investment rule, focusing on the value of the immediate investment and ignoring policy uncertainty.

Keywords: Policy uncertainty; Renewable energy; Investments; Real options; Discrete choice models.

1. Introduction

Political discussion on whether, when, and how to support renewable energy projects can be a powerful deterrent to immediate investments because it creates an incentive to wait until a political decision is made. A potential investor in a small hydropower plant in Norway recently stated, "Our power plant may be profitable now; however, the green certificates will significantly boost profitability, so we are waiting to see what the government has up its sleeve." [1] Similar concerns were raised by Iberdrola Renewable in a U.S. Senate hearing in 2008 on the possible fate and extension of the Production Tax Credit (PTC) and how it pertains to renewable energy development: "The stop-start nature of the PTC has impeded development of a domestic manufacturing base and has raised significantly the capital cost of a wind power project." [2] In their textbook on real options theory, Dixit and Pindyck (1994, p. 20) state, "If governments wish to stimulate investment, perhaps the worst thing they can do is to spend a long time discussing the right way to do so."

Recently, there have been several contributions to the literature using real options theory to predict the relationship between uncertain climate policy decisions and the timing of investments. A general result in these studies is that uncertain changes in policy regimes have a greater impact on how firms time their investments than volatile prices. In the related studies by Blyth et al. (2007), IEA (2007), and Yang et al. (2008), the impact of uncertain shifts in the climate policy regime is represented by a price jump (either up or down) in CO_2 prices at a given date in the future. According to IEA (2007, p. 13), the uncertainty created by such price jumps will dominate the uncertainty created by annual variation in CO_2 prices. Fuss et al. (2008) also consider both market-driven CO_2 price volatility and policy-driven changes in the underlying CO_2 price trend. Similar to the studies mentioned above, they conclude that policy uncertainty induces the producer to wait and see whether the government will further commit to

[1] Steinar Røhme, spokesperson for Jamtåsbekken, which is a small hydropower company in Norway (Adresseavisen, September 26, 2009).

[2] Statement of Donald N. Furman, Senior Vice President of Business Development, Transmission and Policy for Iberdrola Renewables, Committee on Energy and Natural Resources, U.S. Senate, June 17, 2008.

climate policy, and that market uncertainty—up to a reasonable degree—should not be as much of concern. They point out that some market uncertainty may in fact induce the investor to invest earlier in carbon-saving technology than in the case of perfect information.[3] In a forthcoming paper, Boomsma et al. (2011) consider relevant sources of uncertainty under two support schemes for renewable electricity (feed-in tariffs and renewable energy certificates) and uncertainty with respect to change of the support scheme. They conclude that feed-in tariffs encourage earlier investment, whereas renewable energy certificate trading creates incentives for larger projects once investment is undertaken. They also show that without renewable energy subsidies, in some cases, investment may in fact take place earlier and the capacity may be larger than with renewable energy subsidies.

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 climate policy decisions. Moel and Tufano (2002) examine the determinants of the decision to close or re-open a mine using a sample of 285 gold mines. They estimate a reduced-form probit model and find that gold price volatility has a statistically significant negative effect on these decisions, but that factors such as firm-specific managerial decisions also matter. Other studies (Bulan et al., 2009; Cunningham, 2006; Dunne and Mu, 2010; Kellogg, 2010) have also examined the relationship between price volatility and the probability of investment using a similar methodology—the reduced-form hazard model—which captures the idea that the set of available options are reduced over time. Cunningham (2006) investigates property transaction data from the Seattle metro area and shows that a one standard deviation increase in volatility of the property price reduces development by 11.3%. Bulan et al. (2009) examine the extent to which price volatility delays investment using a sample of 1,214 condominium developments in Vancouver, Canada. They split the volatility measure into a systematic and an

[3] In Fuss et al. (2008), the impact of market uncertainty is measured in a different way from existing approaches, in which only the volatility parameter varies. In Fuss et al. (2008) the outcomes of optimization and realization of strategies in the deterministic case are compared with the case where optimization takes place under uncertainty.

unsystematic component to explore the different predictions by traditional discounted cash flow models and real options value models. They find that increases in both unsystematic and systematic risk lead developers to delay new real estate investments, however, the relation between unsystematic risk and development is weakened as competition increases. They argue that the latter finding supports models in which competition erodes option values and provides evidence for the real options framework over simple risk aversion. Dunne and Mu (2010) investigate the effect of uncertainty on the investment decisions of petroleum refineries in the U.S. They construct uncertainty measures from the commodity futures market and use data on actual capacity changes to measure investment episodes. An increase in uncertainty decreases the probability that a refinery might adjust its capacity. Kellogg (2010) estimates firms' responsiveness to changes in uncertainty using detailed data on oil well drilling in Texas. In contrast to earlier studies that rely on historical price records when calculating price volatility, the expectations of future oil price volatility are derived from the NYMEX futures options market. 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 climate policy regimes, (2) empirically tests the predictions on investment timing given by real options investment rules as compared with traditional net present value (NPV) investment rules, and (3) bases these investment rules on detailed and project-based information on the market value of each underlying asset and the objective function of each investor.

We use a case study on investments in Norwegian small hydropower plants.[4] There are three reasons for this. First, by focusing on small hydropower projects we get access to a high number of standardized individual projects which lends themselves more easily to empirical testing compared to

[4] Small hydropower plants are defined as power plants with capacity up to 10 MW.

other real investment projects, including alternatives in the area of renewable energy. Since small hydropower projects have minimal environmental and licensing procedures, and their equipment is usually in serial production, standardized and simplified, small hydropower projects may be developed quite rapidly. Therefore, we can more easily isolate the impact of uncertain policy on the timing decision. Second, we have access to high-quality data. Nord Pool Spot, the electricity market for Norway, Sweden, Finland, Denmark, and Estonia, is Europe's largest and most liquid market for physical power contracts. As of 2007, Nord Pool Spot is owned by NASDAQ OMX Commodities, which provides access to the world's largest power derivatives exchange. Thus, an extensive collection of price data is available. Furthermore, both authorities and license owners have been willing to share information relevant for empirical studies. Last but not least, the Norwegian Government has spent the last 12 years discussing whether, how, and when to introduce a subsidy scheme for renewable energy. Thus, investment data for this period provides a natural experiment on how uncertain policy decisions may affect timing of investments.

Using panel data of 214 licenses to construct small hydropower plants, we examine whether uncertainty with respect to the introduction of a common Norwegian–Swedish market for renewable energy certificates[5] affected the actual timing of investments in small hydropower plants in Norway during the period from 2001 to 2010. The license gives the owner the right, but not the obligation, to construct a power plant within a limited time period. Hence, the owner of the license is holding a real option.

The market value of each power plant was calculated based mainly on two sources of information: a database of the planned costs and production at the time the application for a license

[5] With quantity-driven support schemes, the federal or state level sets a target on the supply of new renewable energy (known in the U.S. as renewable portfolio standards and in the EU as quota obligations), whereas competition between generators determine the prices of the so-called renewable energy certificates (as in the U.S.) or tradable green certificates (as in the EU).

was submitted, and interviews with the majority of the license owners to update and complement the database. In addition, we obtained views on which factors influence the market value of the power plant as well as the objective function of investors from a reference group of stakeholders representing the industry, the regulator, and the public administration in Norway.[6]

Using an approach similar to that of McDonald and Siegel (1986), we investigated whether a real options value investment rule can better explain actual investor behavior as compared to a traditional NPV investment rule. In contrast to the above-mentioned empirical studies, we included two stochastic factors in the options model: uncertain climate policy decisions and stochastic electricity prices. The option value for each license and each point in time was approximated using a simulation method developed by Longstaff and Schwartz (2001).

Finally, the results of the two investment rules were tested using a logistic regression model. Similar to Moel and Tufano (2002), we chose to control for factors affecting the investment decision in addition to the two investment rules. Most importantly, we divided the investors into two groups: investors owning a portfolio of licenses (professional investors) and investors with a single license (nonprofessional investors). Entities controlling more than one license to construct a hydropower plant are typically owned by investors with a portfolio of real and financial assets. Thus, unsystematic risk is reduced by diversification. Nonprofessional investors, on the other hand, may be exposed to both systematic and unsystematic risk. As noted by Bulan et al. (2009), these factors may lead nonprofessional investors to require a higher rate of return on their investment as compared with the professional investor group, a result not driven by the real options theory's emphasis on the value of

[6] As mentioned in Acknowledgements, this paper is funded by a research project called PURELEC. The project has appointed a reference group consisting of two power companies, the regulator of the power sector, and the public administrator of renewable energy subsidy schemes.

waiting but by investor characteristics. This should be taken into consideration when interpreting the results of the regression analysis.[7]

We tested the two investment rules under different assumptions of how uncertain climate policy decisions and electricity prices were perceived by investors. More specifically, we tested which of the following hypotheses was supported by empirical evidence:

> *Hypothesis 1:* Uncertainty with respect to whether, when, and how a common market for renewable energy certificates is introduced provided a risk factor for investors, which delayed the investment decision. Furthermore, they did not believe government statements of a transitional arrangement in which power plants being constructed today would be included in a future support scheme, if implemented.
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> *Hypothesis 2:* Investors' decisions on when to invest were influenced by uncertainty in future electricity prices.
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> *Hypothesis 3:* The real options investment rule, which (1) translates policy and market uncertainty into investment risk and (2) compares the value of immediate investment with the value of postponing investment, provides a better explanation of investors' behavior compared to the NPV investment rule.

We found that uncertainty created by the political debate resulted in delayed investment in small hydropower plants and that this delay was greatest for licenses held by professional investors. Nonprofessional investors seem to consider investments from a "now-or-never" perspective consistent with the traditional NPV investment rule. Thus, they seem to have ignored the possibility of future subsidies altogether. Professional investors, on the other hand, act more in accordance with the real

[7] Other reasons for controlling for investor type in the regression model are discussed in Section 4.1.

options investment rule comparing the value of immediate investment with the value of waiting to invest. Thus, the prospects of possible future subsidies imposed a value of waiting, and this incentive was not reduced by the government promises of a transitional arrangement. Neither professional nor nonprofessional investors' decisions seem to have been influenced by the uncertainty of future electricity prices.

The structure of this paper is as follows. Section 2 gives a description of the investment decision and the dataset. Section 3 describes the real options model and how uncertain climate policy decisions and stochastic electricity prices are translated into investment risk. Section 4 presents the regression models and the results from the regression analysis, and Section 5 discusses the robustness of the results. The results are summarized in Section 6.

2. The investment decision and the dataset

When modeling the investment decision in a small hydropower plant, three challenges must be overcome: (1) the value of the power plant is not observable because it is not traded in a market, (2) we do not completely know the firm's objective function because neither the choice set nor all factors affecting the decisions are observable, and (3) the preferences and other characteristics of the investors will differ.[8] Sections 2.1 and 2.2 deal with these challenges, starting with a thorough description of the factors influencing the timing of an investment decision and then presenting the availability and quality of relevant data. Section 2.3 briefly describes main findings from the data.

2.1 The investment decision

To construct a hydropower plant in Norway, an investor must hold a license issued by the Norwegian Water Resources and Energy Directorate (NVE). A license holder has the permission to start constructing a power plant within five years, at which time the license expires. However, the license can

[8] For a discussion of the challenges confronting a researcher trying to model an empirically testable real options model, see Gamba and Tesser (2009).

normally be extended for another five years without going through the process of resubmitting a new application. Thus, the license to construct a hydropower plant has characteristics similar to an American option, which can be exercised within a period of 10 years.

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 contracts on electromagnetic components, pipes, and building-related work, so that a major part of the total costs is quality assured; (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 in the previous paragraph, 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 the result of economically rational investors balancing the value of immediate investment against the value of putting the project on hold and seeing how the policies and market conditions evolve.

Most often the ownership of the river and the power plant is split into two separate companies, one owning the rights to utilize the river water and one owning the power plant, with the company that owns the power plant renting the right to use the water. Although rivers are most often fully controlled by local landowners, power plants may be owned, fully or partly, by professional investors. In circumstances where the power plant is fully owned by a group of local landowners, the power plant and the water rights may be organized in one company. We consider these differences in organization to have only minor impacts on the net cash flows to the investor and will therefore use the same cash flow setup for all investors irrespective of organizational form.[9] However, professional and nonprofessional investors may differ with respect to preferences and risk attitudes, and we consider such differences in our empirical analysis in Section 4.

Project appraisal is concerned with the assessment of the value of investing capital today in return for an income stream in the future. The after-tax cash flows relevant for total capital considerations consist of investment expenditure (including upfront cost to get access to the electricity transmission grid), the revenues (including subsidies, if relevant), the operational and maintenance costs, rental payments for the right to use the river, the income tax, the resource tax, and the property fee. How we determine these cash flows and other parameters relevant for project appraisal is discussed below.

2.2 The dataset

We created a database of 214 licenses to construct small hydropower plants granted by Norwegian authorities in the period from 2001 to 2008. With a few exceptions, the database includes all licenses to construct power plants with a capacity between one and ten MW (183 plants), and a selection of licenses to construct power plants with installed capacity below one MW (31 plants). There are two main sources to this database; the NVE database and investor interviews.

The NVE database includes information given by the investor to the NVE in the application for a license like the date the application was received, the date the license was granted, the year operation began, estimated investment costs, capacity in MW, and expected annual production in MWh. This

[9] For example, although the last model does not involve rental payments for the right to use the river, these costs should be included because local landowners can choose to not invest in a power plant and instead lease the right to use the river to others.

information has been updated to some extent to reflect revisions in the agreed upon characteristics of the power plant. The NVE database also includes information on whether and when complaints have been filed and settled and, in a few cases, information on other delays, such as problems with access to the electricity transmission grid and changes in the organization of the investor group.

In our analysis we also need to know, for each license and each year, the license holders' expectations with respect to all parameters affecting the value of the investment. Thus, to complement the information we received from NVE, we interviewed the owners of 179 of the 214 licenses (84%) in our dataset to determine the time of the investment decision, the expected investment outlay, capacity, and production level at this point in time as well as check whether investment was delayed for non-economic reasons not included in the NVE database. Through the interviews, we also obtained information and views on which factors influence the investment decision, which cash flows were included in the investment setup, and the value of central parameters used to calculate the investment value.

We consider the quality of the information gathered through the interviews to be high because we were able to explain the purpose of our questions and clear up any misunderstandings. Furthermore, we do not expect that license holders want to purposefully under- or overestimate the cost and capacity measures. In some instances, however, the license holder could only remember the actual investment outlay, which may have deviated from the expected investment outlay at the time when the investment decision was made. Using the deflated actual investment cost as a proxy for the expected investment cost, we may have introduced an upward bias in the investment costs because unexpected costs are included. On the other hand, a major part of the total investment cost is normally secured by enterprise contracts (see Section 2.1), so we do expect the deviations to be limited. In other instances, the license holder could not remember the exact year the investment decision was made, and we had to rely on public announcements of tenders or start of power production to determine the year the investment decision was made.

For the 35 licenses where we did not get in contact with the license holders, we had to rely on the NVE information supplemented with publically available information such as advertisement of tenders and media covering of openings of new power plants. The quality of the data for these power plants may be lower as compared with the rest of the dataset, and to control for this we introduce a dummy variable in the regression analysis in Section 4. Additional details about the panel dataset are listed in the following paragraphs.

Timing of the investment decision. In the few cases where we lack information, we assume that investment decisions were made one year before operation began. According to the NVE and the Norwegian Association of Small Hydropower Plants,[10] the time required to construct a small hydropower plant is approximately 1 to 1.5 years.[11] In our dataset, many power plants were built in the same year the license was granted. *Lifetime of a small hydropower plant.* The NVE (2010) advised using a 40-year lifetime on invested capital for NPV calculations for small hydropower plants.

Cash flows and discount rates.[12] All cash flows and discount rates are given in nominal, after tax terms and are relevant for total capital considerations. We used the capital asset pricing model (CAPM) for estimating the nominal, after tax required rate of return on total capital in hydropower plant investments. Using Gjølberg and Johnsen's (2009) average estimated beta value of 0.7 for total capital expenditure in the renewable power sector in Norway, a market premium of five percent, and a risk free

[10] In Norwegian, *Småkraftforeninga*.
[11] The construction lag was discussed with the director of the Norwegian Association of Small Hydropower Plants, Henrik Glette and Senior engineer Håvard Hamnaberg in the NVE in a meeting on November 16, 2010, and they agree to these assumptions.
[12] See ... (2011) for a more detailed discussion of the cash flows, taxes and discount rate used in this paper.

rate of return equal to the tax adjusted 12 months NIBOR interest rate, 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 costs. Through the interviews with the license holders, we gathered information on the expected investment outlays 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.[13] In the cases were we did not get in contact with the license holder, we had to rely on investment costs given in the NVE database, and inflated 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, and 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, (2) access to the electricity transmission grid, and (3) a fee to compensate a bigger power company for the inconvenience of offering intermittent run-of-river power production onto 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.

[13] Index for road construction costs: http://www.ssb.no/bkianl/tab-2011-01-28-03.html. Source: Statistics Norway (accessed June 1, 2011).

Taxes. Hydropower plants are exposed to taxation through the income tax, resource tax, and property fees. 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. Power plants with an installed capacity below a certain level, are exempt from the resource tax. The tax rates are summarized in Table 1.

Table 1 Tax rates[1)]

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Income tax (%)	28	28	28	28	28	28	28	28	28	28
Resource tax (%)	27	27	27	27	27	27	27	30	30	30
Resource tax is payable for generator size above (MVA)	1.5	1.5	1.5	5.5	5.5	5.5	5.5	1.5	5.5	5.5
Property fee (%)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

[1)] Source: Norwegian fiscal budgets, 2001–2010.

2.3 Descriptive data

Our study contains data on 214 licenses granted from 2001 to 2008 to construct small hydropower plants. The processing time of these applications was 1.5 years on average. The licenses represent power plant investment costs of approximately 1000 million euro measured in 2011 prices, an installed capacity of 670 MW, and a production volume of 2.4 TWh (approximately 2% of Norway's total power production).

Of the 214 power plants that received a license in the period from 2001 to 2008, 65% chose to postpone the investment decision one or more years. Of these 137 licenses, approximately one-third had not reached a decision by 2010, while the remaining two-thirds took an average of 1.6 years from the time the license was granted to make the decision. Some of the delay was caused by factors outside the control of the license holder.

Table 2 Descriptive data

	Professional investors	Nonprofessional Investors	Total
Number of licenses	99	115	214
Investment costs (MEUR)	643	357	1 000
Total capacity (MW)	383	288	671
Annual production (GWh)	1 375	1 071	2 446
Average production per plant (MWh)	3.9	2.5	3.1
Plants with capacity below 1 MW	3	23	26
Plants with capacity between 1 and 5.5 MW	82	90	172
Plants with capacity between 5.5 and 10 MW	14	2	16
Investment cost (EUR/kWh)	0.47	0.33	0.38
Decision made [1)] (%)	82	82	82

[1)] Percentage of total licenses issued.

Professional and non-professional investors have approximately one half of the licenses each. On one hand, the average size of the power plants is bigger for the professional investors as compared to the non-professional investors. On the other hand, the non-professional investors control licenses which are on average less costly to construct. The same percentage of the licenses granted in the period from 2001 to 2008 has been constructed for both investor groups, namely 82%.

3. Real options valuation and stochastic processes

3.1 Real options valuation

According to the traditional NPV investment rule, the owner of a license to construct a small hydropower plant should invest if the discounted value of future net cash flows exceeds the investment cost. In its simplest form, the NPV investment rule takes a now-or-never perspective and focuses on whether it is profitable to invest immediately.

Faced with a risky irreversible decision investors can value the opportunity to gain additional information about likely future conditions affecting the project. The real options value investment rule allows the investor to consider both whether and when to invest. Thus, the value of immediate investment, NPV, must be compared with the expected value of postponing the investment—also called the continuation value. According to the real options value investment rule, the investment should be made once the NPV of the project exceeds the continuation value. The real options value (ROV) can be expressed as follows:

$$ROV = max[X - I, F] \quad , \tag{1}$$

where X is the present value of the project, I is the investment cost, and F is the continuation value.

Longstaff and Schwartz (2001) suggest an approach for approximating option values by using simulations. The key to this approach 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. The approach for finding the continuation value, called least squares Monte Carlo (LSM), is readily applicable to multifactor situations where finite difference techniques are more challenging. The LSM method allows for flexibility in option specifications. Different subsidy regimes featuring jump-processes (as outlined in Section 3.2) and stochastic price processes with time-varying trends (as outlined in Section 3.3) are easily implemented. Furthermore, expiration time and taxes, as well as other variables important to investors, can be included in the valuation framework.

Using power functions as basis functions, the parameters used in calculating the continuation value are estimated by running a least squares regression as follows:

$$Y_\omega = \sum_{m=0}^{M} a_m \cdot X^m + \epsilon \quad , \tag{2}$$

where Y is the discounted value of subsequent cash flows in simulation ω. The parameters a_m are found through the regression, and ϵ is the error term. Using backward iterations, we follow this procedure from the last year of the option lifetime to the first, in each time step estimating the conditional expectation function for the continuation value. These functions are then used to find the predicted continuation value at each point in time conditional on the observed present value. Starting from the beginning, the value of immediate exercise is compared with the predicted value of continuing holding the option until an investment signal is given.

We find the NPV and the continuation value for each power plant in each year the option is alive. The dataset contains licenses granted in the period from 2001 to 2008, and for each year, we update the parameters for the electricity price processes, subsidy regimes, tax rates, eligibility for payment of the resource tax, the size of the tax, and discount rates. The calculations of the NPV and the continuation value in each year are based solely on information available in the given year. The NPV and the continuation value serve as input in the regression analysis presented in Section 4.

Longstaff and Schwartz (2001) note that the LSM provides a lower bound on the option value, and consequently a lower bound on the continuation value. To reduce this bias, we include numerous simulations[14] and use eight basis functions. We also tested the model for four different sets of basis functions (power functions, Laguerre polynomials, Hermite polynomials, and trigonometric functions) and tested how the results are affected by changing the number of simulations.[15] None of these tests significantly changed the timing of investment signal according to the real options value investment rule.

When evaluating hydropower projects, there is uncertainty with regards to many parameters. In this paper we aim to decide whether uncertain climate policy decisions have affected investor behavior; thus, stochastic climate policies should be considered. Furthermore, we include stochastic electricity prices because electricity price is commonly thought to be an important source of uncertainty for a hydropower producer. Other sources of uncertainty which could have been considered are annual production, the required rate of return, legislation regarding taxation, and total investment cost.

[14] We use 15,000 simulations for electricity price and subsidy price for each option price we calculate.
[15] To test whether the number of simulations affected results, we conducted the analysis with 10,000 and 20,000 independent simulations in addition to the 15,000 simulations.

Although such additional stochastic variables could have readably been included using the LSM approach, we have chosen not to do so because it would make the analysis less tractable and make the results more difficult to interpret. A discussion on whether omitting other sources of uncertainty may bias the result of the regression analysis is included in Section 5. In the following two sections, we present the two sources of uncertainty: uncertain climate policy decisions and electricity price.

3.2 Uncertain climate policy decisions

We test to see if uncertainty regarding the introduction of a market for renewable energy certificates has affected the timing of investments in small hydropower plants in Norway. This approach requires probability distributions that reflect the investors' expectations on two aspects: whether a subsidy regime will be implemented and which power plants will be eligible for support.

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

$$\rho_{t,c} = \gamma_{N_t} \cdot \theta_{t,c} \ , \qquad (3)$$

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 support scheme being implemented, a power plant with installed capacity c will be included in the scheme in year N_t. Eq. (3) assumes that there is no transitional arrangement. To investigate whether investors have believed in a transitional arrangement, we also analyze the situation where power plants starting construction before N_t will be entitled to subsidies if the scheme is implemented in year N_t.

The probability of the introduction of a subsidy regime has changed over time, and the political debate can be divided into four phases. (1) In 2001 the idea of a common Norwegian and Swedish renewable energy 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 renewable energy certificates, and the first round of negotiations of a common market for Norway and Sweden took place in winter 2005–06. However, 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 tariff system starting in 2008. The simplicity of the plan made many believe that it was more likely than not that the tariff would be implemented. (4) The second round of negotiations with Sweden started in December 2007, and the feed-in tariffs were abandoned before being implemented. The negotiations gradually changed the sentiments from disbelief to belief 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 renewable energy certificates in December 2010.

The political discussions have favored hydropower plants with installed capacity below one MW, making it almost certain that these power plants would be included if a subsidy scheme were introduced. These attitudes are reflected by the fact that, after the change of government in 2005, only power plants with installed capacity under one MW were included in the government's statement to work for a common Norwegian–Swedish market for renewable energy certificates, and that only hydropower plants with installed capacity up to one MW were included in the draft of a new law for renewable energy certificates presented in December 2010 (see Table A1 in the Appendix for further details). The feed-in tariffs suggested in 2007 included the first three MW installed for all hydropower plants. With this exception, there has been uncertainty with respect to the inclusion of power plants with installed capacity between one and ten MW.

There has also been political debate on whether the scheme, if implemented, should be applied retroactively and be valid for power plants constructed as early as January 1, 2004, reflecting the statement made by the Petroleum and Energy Minister Einar Steensnæs in 2003.[16] It is important to note that *if* investors believed strongly in a transitional arrangement, the policy uncertainty had a smaller impact on their timing decision as compared to if they did not believe in it. We therefore include three alternative real options models in Section 4, one in which the investors believed that they would be entitled to subsidies only for power plants constructed after the scheme was implemented, one in which investors believed the scheme would be applied retroactively for power plants that started construction after January 1, 2004, and one in which the investors believed there would be no subsidies.

Based on the above discussion, we assigned values to the probabilities in Eq. (5), dividing the probabilities into five categories: very unlikely (0%), more unlikely than likely (25%), equally likely (50%), more likely than unlikely (75%), and very likely (100%). The subjectively assigned probabilities were reviewed by the project's reference group. The information used is summarized in Table A1 in the Appendix, and the resulting probabilities are given in Table 3.

Table 3 Overview of subsidy probabilities, level of support, and year of introduction

t	γ_{N_t} (%)	$\theta_{t,M_t,<0MW,1MW]}$ (%)	$\theta_{t,N_t,<1MW,10MW]}$ (%)	N_t	$\bar{s}_t$*(EUR/kWh)*[1)]
2001	25	100	50	2004	0.022
2002	25	100	50	2004	0.022
2003	25	100	50	2004	0.022
2004	25	100	50	2006	0.021
2005	75	100	50	2007	0.024
2006	25	100	50	2008	0.024
2007	75	100	100 up to 3 MW [2)] 0 from 3 to 10 MW	2008	0.005
2008	25	100	50	2012	0.023
2009	50	100	75	2012	0.029
2010	75	100	100	2012	0.034

[1)] The expected certificate price at time t is denoted $\bar{s}_t$. It is assumed to be constant over time The expected certificate prices are equal to average historical Swedish certificate prices. From 2004 and onwards we use a rolling window of two year. For earlier years we use the average price for 2003. In 2007, the feed-in tariff for hydropower approved by the Parliament in 2007 was included. Reflecting the content of draft bills for certificates and feed-in schemes, we assume the payment is made 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.
[2)] Only for the first three MW installed.

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

3.3 Electricity price

Pindyck (1999) analyzes the long-run evolution of energy prices, such as oil, coal and natural gas. He claims that, although long-run energy prices may be mean reverting, the use of geometric Brownian motion (GBM) models is unlikely to lead to large errors in optimal investment rules because the rate of mean reversion is low. This claim is confirmed by Schwartz (1998) who shows how a simple one-factor model has the same implications as a two-factor model when applied to valuing long-term assets. Lucia and Schwartz (2002), on the other hand, claim that electricity prices on the Nordic power exchange NordPool should be modeled as mean reverting. Because our aim is to disclose how investors perceive electricity price processes, we examine both approaches.

The electricity price process is given in Eq. (4):

$$\Delta P_{t,r} = \alpha_{t,r} \cdot P_{t,r} \cdot \Delta r + \lambda \cdot \left(\bar{P}_{t,r} - P_{t,r}\right) \cdot \Delta r + \sigma \cdot P_{t,r} \cdot \Delta W_{t,r} \,,$$
$$t \in 2001,..,2010, \quad r \in 1 + l, \ldots, L + T + l \qquad , \tag{4}$$

where $P_{t,r}$ is the expected electricity price in year r based on information available in year t, $\alpha_{t,r}$ is the trend parameter, $\bar{P}_{t,r}$ is the level to which the process reverts, and σ is the volatility parameter. $\Delta W_{t,r}$ is the increment of a standard Wiener process. When the mean-reverting factor, λ, is zero, the electricity price follows a GBM process and when it is positive, it follows a mean reversion with trend (MRT) process where the volatility grows with price. When the volatility is set to zero, the price process is deterministic. 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. The value of λ is set equal to 0.68, implying that 90% of a price deviation caused by a shock is eliminated after three years in the MRT price process. The impact of setting a different value for λ is discussed in Section 5.

The process for the trend parameter is outlined in Eq. (5).

$$\Delta\alpha_{t,r} = \mu \cdot (\bar{\alpha} - \alpha_{t,r}) \cdot \Delta r, \qquad t \in 2001, \ldots, 2010\,, \;\; r \in 1 + l, \ldots, L + T + l \tag{5}$$

In the short term, the expected trends, $\alpha_{t,r}$, of the electricity price is determined by market information from NASDAQ OMX. More precisely, we derive the expected trend by analyzing the difference between two and three year forward contracts.[17] Contracts with delivery beyond three years are not regularly traded. To deal with this lack of market information, we have assumed 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. The rate at which the process returns to the inflation target is unknown; hence, we analyzed three possible trend adjusting rates. We set $\mu = 0.90$, 0.68, 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. Again, the impact of using different parameters is discussed in Section 5.

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 4. The volatility estimate is 15.8% and is calculated as the annualized standard deviation of the log returns implied by daily prices of three-year forward contracts in the period from 2001 to 2010.

Table 4 The starting points of the trend parameter and the electricity price

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

[1]The starting point of the trend is found as the implied drift from two- and three-years forward contracts using a rolling window.
[2] The starting point of the electricity price is found as the discounted three-years forward contracts from the last half of the previous year and the first half of the present year.

[17] These forward contracts are settled every day from one year prior to maturity until maturity.

4. Regression models and analysis

4.1 Regression models

To conduct a formal examination of whether investments decisions in small hydropower plants are consistent with the predications from our real options valuation framework, we employ a multivariate discrete-choice regression model where the investment decision is the dependent variable. More specifically, we use the maximum-likelihood method to estimate the parameters of the following logistic regression model:

$$\Pr\text{ob}\left(y_{i,t} = 1\right) = e^{\boldsymbol{\beta}'\boldsymbol{x}}/(1 + e^{\boldsymbol{\beta}'\boldsymbol{x}}) \, , \qquad (6)$$

where $y_{i,t}$ is equal to one if an investment decision is made for license i in year t and zero otherwise. The vector $\boldsymbol{x}$ of independent variables includes two variables that reflect when an investor should invest according to the NPV and when an investor should invest according to the real options value investment rule. In addition, we control for non-economic variables that may affect the timing of investment decisions. The independent variables are presented below.

Two investment rules. Each investment rule can be represented by either a dummy variable or by a continuous variable where the latter can be expressed in either absolute or relative terms. We used the NPV and the difference between the continuation value and the NPV as independent variables because this resulted in the best fit.

Investor types. Because nonprofessional investors are typically less diversified than professional investors, they may behave differently when faced with the same investment opportunity. In addition, professional investors may be less risk averse, be less restricted with respect to capital, and have less concern for local conflicts arising because of the power plant as compared to a group of local land owners considering whether to invest in a small hydropower project for the first time. Professional investors may also put different values on aspects such as size as compared with nonprofessional owners. Furthermore, professional investors may be better informed about the various factors (including renewable energy certificates) affecting the investment's profitability. They may also have more knowledge of and be more willing to use sophisticated investment rules. To account for possible systematic impacts of investor types, we use a dummy variable (D_prof in Table 5) which is equal to one for professional investors and zero otherwise. The regression model includes interaction between the dummy for investor types and the independent variables for the two investment rules and size to account for these mechanisms.

Size. It may be that investors attach a separate value to the absolute value or the size of the project. For example, although two investments yield the same rate of return, the bigger project may be preferred because it generates more revenue. Potential conflicts with ones neighbors and the local society must also be weighed against economic gains, and they may render the smallest projects unattractive. Size may also correlate with variables that are omitted or not sufficiently included in our model. For instance, it may be that the managerial competence and capacity and the money and time available to make a detailed prospect on which an investment decision can be made and loan be granted is higher for a big project compared to a small project. To account for possible systematic impacts of size, we analyze regression models including a continuous variable measuring installed capacity (in MW) and a dummy variable for power plants with an installed capacity below one MW. We used only the latter independent variable (D_below1MW in Table 5) because this resulted in the best fit.

Non-economic reasons for delay: We control for non-economic reasons for delays of investments (see Section 2.1 for examples) by using a dummy (Non-economic delays in Table 5) equal to one for licenses and years in which such delays occur.

Interviews: To control for possible systematic differences between the majority of licenses where we have interviewed the license holder and the minority where we have not, we use a dummy variable (License owners interviewed in Table 5) equal to one for those interviewed and zero for the others.

4.2 Regression analysis

Table 5 presents estimations of the logistic regression model presented in Eq. (6). To test hypotheses 1–3 presented in the Introduction, we made different assumptions with respect to investors' expectations of future subsidies and electricity prices. This results in nine different regressions where the only differences are the values stored in the two independent variable vectors: NPV and Continuation value-NPV. Regressions 1–3 represent the case with no subsidies, 4–6 the case where subsidies would be introduced but with no transitional arrangement in place, and 7–9 the case where investors believe subsidies will be introduced with transitional arrangements. All three subsidy alternatives have three alternatives for electricity price process: deterministic, GBM, and MRT.

Informal tests, where we examine the pseudo R^2 and likelihood ratio measures for goodness of fit and the sign, magnitude, and significance of the coefficients as compared with initial beliefs, indicate that the following four regressions perform better than the others: no subsidies, deterministic electricity price (regression 1); no subsidies, MRT electricity price (regression 3); subsidies but no transitional arrangement, deterministic electricity price (regression 4); and subsidies but no transitional arrangement, MRT electricity price (regression 6). Furthermore, for each investor group, one and only one of the coefficients for either NPV or Continuation value-NPV is significant, implying that investors' behavior is consistent with one of the investment rules.[18] The formal MacKinnon J-tests for comparisons of non-nested models further confirm that these four regressions seem to better reflect actual behavior

[18] For all nine regressions the likelihood ratio rejects the null hypothesis that all coefficients are zero. And, as expected, non-economic reasons for delay have a significant and negative impact on investment decisions. Furthermore, nonprofessional investors seem to require a higher rate of return to be willing to invest in the smallest hydropower plants. Finally, there is a significant difference between the licenses with interviews and those without.

Table 5 Estimated regressions [1)]

Subsidy scheme	No subsidies			Subsidies, no transitional arrangement			Subsidies, transitional arrangement		
Electricity price processes	Deterministic	GBM	MRT	Deterministic	GBM	MRT	Deterministic	GBM	MRT
Regression number	1	2	3	4	5	6	7	8	9
NPV									
D_proff=0	+0.06	+0.04	+0.06	+0.06	+0.04	+0.06	+0.03	+0.00	+0.03
	(0.01)**	(0.44)	(0.01)**	(0.00)**	(0.43)	(0.00)**	(0.07)	(0.92)	(0.08)
D_proff=1	-0.01	-0.00	-0.01	0.02	-0.01	+0.02	-0.00	0.02	-0.00
	(0.68)	(0.93)	(0.66)	(0.11)	(0.90)	(0.11)	(0.60)	(0.62)	(0.58)
Continuation value-NPV									
D_proff=0	+0.05	-0.03	+0.04	-0.06	-0.03	-0.06	-0.11	-0.04	-0.12
	(0.74)	(0.67)	(0.79)	(0.13)	(0.64)	(0.13)	(0.51)	(0.45)	(0.47)
D_proff=1	-0.06	-0.02	-0.06	-0.03	-0.02	-0.03	-0.07	-0.01	-0.07
	(0.04)*	(0.60)	(0.04)*	(0.05)*	(0.57)	(0.05)*	(0.03)*	(0.79)	(0.02)*
Size below 1MW									
D_proff=0 and D_below1MW=1	-0.86	-0.97	-0.87	-0.93	-0.97	-0.93	-1.04	-1.12	-1.05
	(0.03)*	(0.02)*	(0.03)*	(0.02)*	(0.02)*	(0.01)**	(0.01)**	(0.01)**	(0.01)**
D_proff=1 and D_below1MW=0	+0.14	-0.17	+0.14	-0.11	-0.17	-0.11	-0.06	-0.57	-0.06
	(0.68)	(0.74)	(0.68)	(0.73)	(0.75)	(0.73)	(0.86)	(0.26)	(0.85)
D_proff=1 and D_below1MW=1	+0.73	0.56	+0.73	+0.57	+0.55	+0.57	+0.52	+0.35	+0.51
	(0.56)	(0.66)	(0.56)	(0.64)	(0.66)	(0.65)	(0.67)	(0.78)	(0.68)
Non-economic delays (D=1)	-5.15	-5.18	-5.14	-5.05	-5.18	-5.05	-5.07	-5.09	-5.06
	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**
License owner interviewed (D=1)	+1.19	+1.19	+1.19	+1.22	+1.19	+1.22	+1.13	+1.13	+1.13
	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**
Constant	-1.22	-1.05	-1.21	-1.09	-1.04	-1.09	-0.97	-0.83	-0.96
	(0.00)**	(0.02)*	(0.00)**	(0.00)**	(0.03)*	(0.00)**	(0.01)**	(0.06)	(0.01)**
Pseudo R2	0.255	0.247	0.255	0.257	0.247	0.257	0.249	0.237	0.249
LR	167	162	167	168	162	168	163	155	163
	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**

[1)]Number of observations is 508. Number of groups is 214. The *P*-value is given in parenthesis and * and ** indicate that the coefficient is significantly different from zero at the 5% and 1% significance levels, respectively.

than the others (see Table A2 in the Appendix). Bearing these insights in mind, we examine hypotheses 1–3.

Hypothesis 1: We find mixed support for the first hypothesis, saying that uncertainty with respect to whether, when and how a common market for renewable energy certificates is introduced did provide an additional risk factor for investors which further delayed the investment decision; and, that investors did not believe in the government statements that investors could invest today and still be included in a future subsidy scheme, if implemented. On one hand, both informal tests and the MacKinnon J-test show that regressions 7 and 9, indicating that investors believed that subsidies would be introduced and a transitional arrangement would be implemented, perform worse than regressions based on other subsidy assumptions (*ceteris paribus*). On the other hand, neither the informal nor the formal tests are able to identify which of the two remaining assumptions with respect to investors' expectations on future subsidies is best.

The results suggest that political statements did not succeed in mitigating the deterrent effect on immediate investments caused by the policy debate of a future subsidy scheme. Either the investor chose not to consider subsidies at all or, if they did, they did not believe government statements that power plants constructed today would be entitled to future subsidies. In both cases, investments would be delayed compared to a situation where investors expected that a power plant constructed today would be entitled to future subsidies. In the first case, the expected profitability would be lower because subsidies would not be included. In the second, the required profitability of immediate investment would be higher to compensate for potentially foregone subsidies. Most likely, the investors decided that the current government could not commit future governments or that the ongoing negotiations between Norway and Sweden could result in outcomes that made it less desirable to keep these promises.

Hypothesis 2: We find no support for the second hypothesis, saying that models which are based on uncertain electricity prices provide a better explanation of investors' behavior than models which include deterministic electricity prices. In fact, the informal tests indicate that regressions based on stochastic GBM price processes perform worse than regressions based on the other price processes. MacKinnon J-tests, comparing regressions with different price processes (*ceteris paribus*), confirm these results; regressions based on the stochastic MRT and the deterministic price process perform significantly better than regressions based on the stochastic GBM price process. Neither the informal nor the formal test is able to identify whether the deterministic price process or the MRT better explain investor behavior.

The investors we studied do not seem to think that electricity price follows a stochastic GBM price process when making their decisions on whether and when to invest. Thus, market uncertainty has to a small extent contributed to slow down their investment rate. This is interesting because many real options papers on investment in the power sector assume GBM price processes to make predictions on the speed of investment, the required rate of return, and the impact on electricity prices.

Hypothesis 3: For professional investors, we find some support for the third hypothesis saying that the real options investment rule which 1) translate market and policy uncertainty into investment risk and 2) compares the value of immediate investment with the continuation value, provides a better explanation of investors' behavior than the net present investment rule. That is, the variable Continuation value-NPV has a negative and significant impact on the probability to invest whereas the variable NPV does not; so as the value of continuation increases relative to the value of immediate investment, professional investors' propensity to invest decreases (*ceteris paribus*). However, because we are not able to say that regression 1 (no stochastic processes) performs worse than regressions 3, 4, or 6 (stochastic prices and/or subsidies), we cannot firmly conclude that market and policy uncertainty are translated into investment risk. Consequently, it may be that professional investors' behavior reflects a dynamic NPV investment rule with no stochastic factors (regression 1) or a real options value investment rule with stochastic factors (regressions 3, 4, or 6).

For nonprofessional investors, the third hypothesis is rejected. The coefficients for the NPV variable are significant, whereas the coefficients for the Continuation value-NPV variable are not. Thus, we find support for investors applying the traditional NPV rule, possibly ignoring the additional information given in the difference in value between an immediate and a postponed investment. One important implication is that nonprofessional investors did not consider the possibility of future subsidies when making their investment decisions in small hydropower plants.

Consequently, nonprofessional investors seem to consider the investment opportunity from a now-or-never perspective, whereas professional investors seem to consider not only whether to invest but also when. A possible explanation for this finding is that professional investors, who by definition, have already invested in at least one hydropower plant, have a better knowledge of the factors influencing investment decisions compared to nonprofessional investors. This knowledge may be gained through a more specialized education or job position in finance or by experience from similar investment projects.[19] Furthermore, our interviews with the license holders revealed that many nonprofessional investors had to document profitability without including revenues from the sale of renewable energy certificates to obtain external funding. A speculative hypothesis is that this requirement may have led the investors to ignore the question of a possible introduction of tradable renewable energy certificates altogether, and therefore not value the opportunity to wait until this uncertainty was revealed.

[19] We cannot rule out, however, that we have omitted factors that covary with investors' propensity to invest and the two investment rules and where these relations are different between the professional to the nonprofessional investor groups. We return to this issue in the Conclusion.

Figure 1 illustrates the difference in investment rules for the two investor groups. Both are based on regression 6 in which we assume the investors expect electricity prices to follow a MRT process and believe that there will be no transitional arrangement if subsidies are introduced. Figure 1a shows how the probability of investing is affected for professional investors when the difference between the NPV of immediate investment versus the continuation value varies between the lowest and highest values in the dataset. When the NPV of immediate investment is equal to or greater than the continuation value, it is more likely that the professional investor will invest rather than postpone the decision.[20] This result is in accordance with the real options value investment rule.

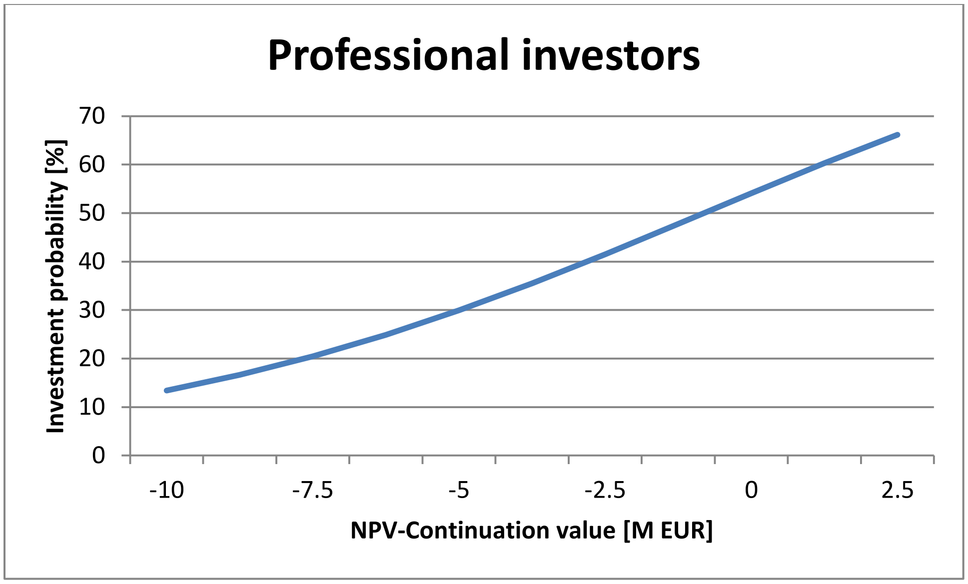
Figure 1b illustrates how the propensity to invest is affected for nonprofessional investors when the NPV of immediate investment varies from the lowest to highest values in the dataset. We find that when the NPV of immediate investment is equal to zero, the probability of investing in a power plant with an installed capacity above one MW is 46%. Thus, when the NPV of immediate investment is smaller than zero, the empirical data shows that investors are more likely to postpone investment and vice versa when the NPV is slightly greater than zero. This is in accordance with traditional NPV investment theory.

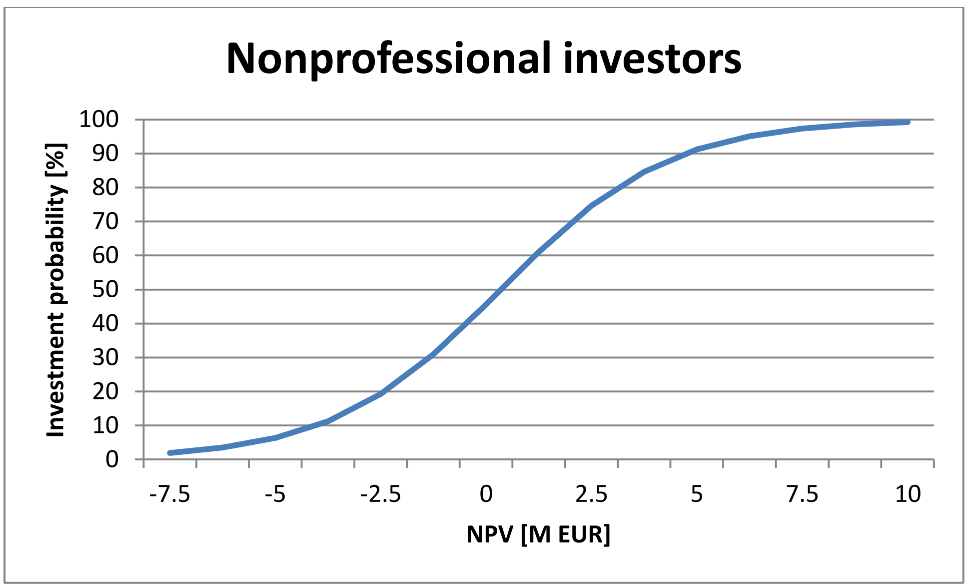
5. Robustness of the results

The results presented above could be biased as a result of problems encountered at various stages of our research process. We made serious efforts to keep these sources of bias to a minimum by (1) conducting interviews with a majority of license holders to calculate the expected value of the power plant; (2) discussing the setup of investors' objective functions, including their choice sets and all factors affecting the investment value, with the reference group; (3) extending the analysis to include different assumptions with respect to each of the two stochastic factors (uncertain policy decisions and electricity

[20] The probability of investment is 54% when the NPV of immediate investment is equal to the value of continuation.

Figure 1 The probability of investing for (a) professional and (b) nonprofessional investors. [1)]





[1)] Both figures are based on the estimated regression coefficients in regression 6 (Table 5). The dummies for delay and installed capacity below 1 MW are set equal to zero. The dummy for interview is set equal to one. For professional investors, the variable NPV is set equal to the average value for the entire set of plants, which is 1.2 million euro; the NPV-Continuation value is allowed to vary between the lowest and highest observed values in our dataset. For nonprofessional investors, the NPV-Continuation value is set equal to the average value for the entire set of plants, which is 0.6 million euro; the variable NPV is allowed to vary between the lowest and highest observed NPVs in our dataset.

price); (4) using a high number of simulations and basis functions in the LSM approach as well as different basis functions to make the simulated option values as close as possible to the analytically correct option values; and (5) controlling for variables in the regression analysis that may have affected the timing of investments and that may be correlated with the two investment rules.

In light of the results from the regression analysis, here we focus on four aspects of our research where making different assumptions may have led to different results and where more research is required to understand how investors perceive different sources of uncertainty and translate these into investment risk.

First, would a wider set of stochastic factors alter our conclusions? The general answer to this question is that as long as the omitted independent variables are not correlated with the independent variables included in our regression model, the estimated coefficients of our model will be unbiased. For example, it may be argued that modeling the investment costs stochastically instead of deterministically would make our model more realistic and increase its explanatory power. However, we do not think that the stochastic movements of the investment costs are correlated with the introduction of a subsidy scheme, the electricity price, or any other factor included in the calculations of the variables NPV and Continuation value-NPV. Thus, if our main concern is to explore the impact of uncertain climate policy decisions and uncertain electricity prices, excluding the stochastic process of investment costs does not bias the coefficients of our model.

It may also be argued that stochastic movements in the price of renewable energy certificates should be included. Investors may perceive the long-term movements of electricity price and certificate price to be negatively correlated because the sum of these two prices should be equal to the long-term marginal cost of new power production to satisfy the quantitative objects for renewable energy set by the Government. Thus, it may be that the lack of empirical support for electricity prices following a GBM stems from a belief that the sum of electricity prices and certificate prices follow a more predictable pattern. Further research with respect to how investors perceive the development of the sum of these two prices is required.

Second, would a different set of parameter values in the price process in Eq. (3) alter our conclusions? We analyzed the impact of using different trend adjustment rates (μ=0.9, 0.68, and 0.44), reflecting that 90% of the trend implicit in the forward contracts with two and three years to maturity would be eliminated after one, three, and five years, respectively. The different trend adjustment rates had only a marginal impact on the investment signals provided by the two investment rules. Although μ=0.44 resulted in marginal better goodness of fit measures in the regression analysis as compared to μ=0.68 and 0.9, there were no changes in the coefficients' signs or significance.

For the MRT price process, the mean-reverting factor, λ, is set equal to 0.68, implying that 90% of a price deviation caused by a stochastic shock is eliminated after three years. Letting λ approach one, the MRT would approach the deterministic price process, which would most likely not alter our conclusions with respect to hypothesis 2. Letting λ approach zero, the MRT would approach the GBM price process, which would at some point result in a rejection of hypothesis 2 altogether because both stochastic processes would perform worse than deterministic prices.

The volatility parameter, σ, is set equal to 15.8% 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. This is similar to Benth and Koekebakker (2008), who find the volatility of yearly contracts on NordPool to be 18.2%. Ideally we would have preferred to 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 15.8% represents an upper limit to the expected volatility. Using a lower volatility measure could have altered our conclusion when testing hypothesis 2.

Third, could the uncertain climate policy decisions have been modeled in an equally convincing way, giving clearer support for hypothesis 2? Based on formal decisions made by the Norwegian Government or Parliament, we assigned probabilities using a rather rough classification of how likely investors perceived future subsidies to be. We chose the planned year for introducing the subsidy as a milestone where uncertainty would be revealed. This approach has resulted in a rather low probability for receiving subsidies and a rather short time horizon until uncertainty is revealed (see Table 3). With the benefit of hindsight, we know that the power plants will be entitled to subsidies from January 2012 and it took 12 years to settle this issue. Thus, it could be argued, that perhaps the investors foresaw this development and assigned a rather high probability to their power plants being entitled to future subsidies if they waited but that the waiting period would be long. Changing our assumptions in this direction would not necessarily alter our conclusions, however, because a higher probability implies a higher value of waiting whereas a longer period until uncertainty is revealed implies a lower value of waiting.

Fourth, could the objective function of the nonprofessional investors have been modeled differently, leading to a conclusion in which they do also consider the value of waiting? As mentioned in the Introduction, nonprofessional investors may be exposed to both systematic and unsystematic risk. Thus, they may require a higher rate of return on their investments than the rate of return used in this paper (see Section 2.2), which only reflects the systematic risk of hydropower plant investments. With a higher required rate of return, the value of waiting is reduced relative to the value of immediate investment, and our conclusion that the nonprofessional investor act in accordance with a NPV investment rule is weakened or rejected. The same line of reasoning is not valid for professional investors because they will typically own a diversified portfolio of real and financial assets.

6. Conclusion

The Norwegian Government spent 12 years discussing whether, how, and when to introduce a subsidy scheme for renewable energy. In an attempt to persuade investors not to postpone their investments until this issue was settled, the Government stated that power plants being constructed in the interim period would be entitled to future subsidies, if a scheme was introduced. In our interviews with license holders, some investors claimed that they were misled by this statement and invested in power plants that were not profitable without such subsidies.

However, our empirical evidence suggests otherwise. Investors seem to have either (1) ignored the political debate and not considered the possibility of future subsidies at all or (2) considered the possibility of future subsidies, thinking that they would only be for power plants where construction started after the subsidy scheme was implemented. In both cases investment decisions were delayed compared to the situation in which investors considered the possibility of future subsidies and believed the political statements of transitional arrangements for power plants being constructed. In the first case, investments were delayed because the expected profitability of immediate investment is lower relative to the value of continuation when investors ignore subsidies as compared to a situation in which they considered the possibility of future subsidies with a transitional arrangement. In the latter case, an immediate investment would be entitled to subsidies starting at the time of the implementation of the scheme whereas a postponed investment would receive subsidies starting from a later point of time. In the second case, investments are delayed because the investor will require a higher level of profitability of immediate investments when they risk not receiving subsidies possibly implemented in the near future.

The uncertainty created by the political debate resulted in a greater delay of investments among professional investors as compared to nonprofessional investors. We found strong evidence for professional investors basing their investment decisions on a comparison of the value of immediate investment with the value of continuation. The nonprofessional investors, on the other hand, behaved with a now-or-never perspective. Thus, although they could have invested more if the Government had introduced subsidies earlier, they did not delay investments in projects that were profitable without subsidies.

These results confirm the quote by Dixit and Pindyck (1994, p. 20) saying: “If government wish to stimulate investment, perhaps the worst thing they can do is to spend a long time discussing the right way to do so.” To achieve a given policy target, two related questions must be answered: (1) What policies are effective? (2) What is required to gain enough support for these policies? There may be a tradeoff between these two issues. If pursuing the best policies means spending a long time discussing and negotiating the policy design with all stakeholders involved, it may be socially desirable to pursue more popular second-best policies that can be quickly implemented. The social cost of less effective policy instruments must be weighed against the social cost of uncertain policies. In some situations this tradeoff may imply that no policies are better than uncertain policies.

Appendix

Table A1 The political process on renewable energy certificates in Norway, 2001–2010. [1)]

Year	The political status of renewable energy certificates in Norway	Phase/prob.[2)]
2001	01.12.2000: The Parliamentary Energy and Environment Committee asks the Government to explore the consequences of a system with renewable energy certificates adapted to suit the Norwegian and Nordic situation (Budsjett-innst. S.nr. 9 (2000-2001)). 21.09.2001: The Government says it has started its work on examining the consequences of a renewable energy certificate market in Norway/ Nordic countries similar to those under consideration in EU countries (St.prp. nr. 1 (2001–2002)).	Idea launched (25%)
2002	08.04.2002: The Government refers to six research reports examining the impact of a Norwegian/Nordic market for renewable energy certificates (OED Report). 13.09.2002: The Government presentedwill present an evaluation of renewable energy certificates compared with other support schemes for renewable electricity for the Parliament. (St.prp. nr. 1 (2002–2003)). 01.11.2002: The OED recommends the introduction of a mandatory certificate market for renewable electricity. The Ministry is positive about the creation of an international market and believes that Norway should be part of such a market (St.meld. nr. 9 (2002–2003)).	
2003	01.05.2003: Sweden starts up a national market for renewable energy certificates (*Energimyndigheten*, Sweden). 19.12.2003: In a strategy document issued by the OED, the minister says that all power plants constructed after January 1, 2004 will be eligible for renewable energy certificates (Source: Strategy document named *Strategi for økt etablering av små vannkraftverk*). 19.12.2003: The Government argues for the introduction of renewable energy certificates. This is supported by Parliament, which asks the Government to take initiative to establish a common Swedish–Norwegian market for renewable energy certificates. This should result in a proposal no later than spring 2004 (OED press release, ref 138/03 and cf. St.meld. nr. 9 (2002–2003)).	
2004	14.05.2004: Based upon St.meld nr. 18 (2003–2004), the Energy and Environment Committee recommends that a common market for renewable energy certificates be implemented by January 1, 2006. The committee supports the transitional arrangement promise made by OED Minister Steensnæs in 2003. 06.08.2004: The OED works to establish a common certificate market with Sweden, and draws up the framework for further work (St.meld. nr. 47 (2003–2004)). 10.09.2004: The OED says it has started exploring the possibilities of a common market on renewable energy certificates with Swedish authorities (St.prp. nr. 1 (2004–2005)). 24.11.2004: A draft law on renewable energy certificates is distributed to consultative bodies for comments. All plants that have started construction after January 1, 2004 are included. There are no limits on installed capacity. Plants eligible for support will receive subsidies for 10 years. The bill provides that the certificate scheme will be operating as of January 1, 2006. It is planned that the law will be submitted to Parliament in spring 2005 and that the law will only take effect when the necessary clarifications with Sweden are made (Press release from OED, ref. 133/04).	
2005	14.02.2005: The start of a common market, if an agreement is made, is delayed until January 1, 2007 (Press release from OED, ref 20/05). 13.10.2005: A new Government is elected, which confirms its commitment to introduce renewable energy certificates in January 1, 2007. In a public declaration (*Soria Moria I*, p. 58), it says: "[The] Government will introduce a mandatory renewable energy certificate market for renewable energy and mini and micro power plants." Negotiations with Swedish authorities start.	First round of negotiations (75%, 25%)

2006	27.02.2006: The negotiations between Norway and Sweden are terminated. Prime Minister Stoltenberg says the system the costs of the system are too high for Norwegian consumers and industries. The Government would instead strengthen the focus on already established instruments (OED press release, ref. 26/06). 05.10.2006: The OED says that a new support system for electricity production from renewable energy sources will be introduced beginning January 1, 2008. Hydropower producers will receive 0.04 NOK/kWh as a feed-in tariff for production representing the first three MW of the installed capacity. Support will be paid for 15 years. The transitional arrangement established when preparing for a Norwegian–Swedish renewable energy certificates' system will be continued (OED press release, ref. 117/06). 24.11.2006: The Government proposes the new Feed-in tariffs (St.meld. nr. 11 (2006–2007)).	
2007	19.03.2007: The Parliament approves the Government's proposal for feed-in tariffs (St.meld nr 11 (2006-2007), Innst. S. nr. 147 (2006–2007)). 04.10.2007: A draft Directive on feed-in tariffs is distributed to consultative bodies for comments (OED press release, no reference). 07.12.2007: The Government announces it will start a new dialogue with Sweden on a Norwegian–Swedish market for renewable energy certificates. The initiative is supported by the political opposition in Norway. If the negotiations do not succeed, the Government will seek to implement a national subsidy scheme. The transitional arrangement for plants constructed after January 1, 2004 will be continued (OED press release, ref. 173/07).	Feed-in tariffs (75%)
2008	23.05.2008: Sweden signals that it needs time to explore the implications of the EU's Renewable Directive. The OED says that if this results in a delay of the common market for renewable energy certificates, other support schemes must be considered (OED press release, no reference). 27.06.2008: The Norwegian Petroleum and Energy Minister Riis-Johansen and the Swedish Industry Minister Olofsson signs an "Understanding" on cooperating for a common Swedish–Norwegian market for renewable energy certificates (OED press release, ref. 89/08).	Second round of negotiations (25%, 50%, 75%)
2009	07.09.2009: A Swedish–Norwegian Agreement is signed outlining the main principles of the common market including ambition level, start-up date (January 1, 2012), and the technology neutrality principle (OED press release , ref. 102/09). 26.11.2009: The Government proposes a transitional arrangement, stating that all plants under construction after September 7, 2009 and hydropower plants with a capacity than of less than one MW under construction by January 1, 2004, should receive subsidies. The transitional arrangement gives a right to take part in the common renewable energy certificate market when and if it starts up. The number of years between when the plant started production and when the renewable energy certificate market was implemented should be deducted from the number of years plants normally receives subsidies (15 years) (OED press release, ref. 143/09).	
2010	11.03.2010: The political opposition puts forth Document No. 8: 91 S (2009-2010), stating "Parliament requests the Government to ensure that all facilities with construction starting from January 1, 2004, and who are eligible for renewable energy certificates from 2012, are included in the transitional arrangement." 03.06.2010: Document No. 8 is voted down in Parliament (Document No 8: 91 S (2009/2010), Innst. 281 S (2009/2010)). 08.12.2010: The Norwegian OED Minister, Riis-Johansen, and Swedish Industry Minister, Olofsson, sign a Protocol concluding the discussions on a system for renewable energy certificates that started September 2009. The new system is expected to generate 26.4 TWh by 2020, with each country financing 13.2 TWh (OED press release, ref. 117/10). 08.12.2010: The Government presents a draft Norwegian law on renewable energy certificates (news from OED).	
2011	11.04.2011: It remains to be seen if and how the law is implemented. Both the Norwegian and the Swedish Parliaments must enact a new law on renewable energy certificates during 2011. And, the whole agreement is dependent on the ratification of	

	the EU Renewable Directive in Norway.	

[1)] Sources: Press releases and public documents from the Ministry of Petroleum and Energy (OED), the Parliament and the Government in Norway. Public document from Energimyndigheten (energy authorities) in Sweden.

[2)] Probability for subsidy scheme to be introduced

Table A2 MacKinnon J-test results [1)]

Subsidy scheme			**No subsidies**			**Subsidies, no transitional arrangement**			**Subsidies, transitional arrangement**		
	Electricity price process		Deterministic	**GBM**	**MRT**	Deterministic	**GBM**	**MRT**	Deterministic	**GBM**	**MRT**
		Reg. no.	1	2	3	4	5	6	7	8	9
No subsidies	Deterministic	1		0.67	0.67	0.11			0.21		
	GBM	2	0.04		0.04		0.64			0.06	
	MRT	3	0.63	0.67				0.24			0.19
Subsidies, no transitional arrangement	Deterministic	4	0.16				0.29	0.46	0.50		
	GBM	5		0.70		0.01		0.12		0.06	
	MRT	6			0.01	0.02	0.16				0.04
Subsidies, transitional arrangement	Deterministic	7	0.01			0.02				0.29	0.03
	GBM	8		0.00			0.00		0.02		0.00
	MRT	9			0.08			0.31	0.34	0.06	

[1)] **The model in the row is the reference. First we estimate Y_hat, representing the model in the column, with NPV and added value as explanatory variables. Next, we store the predicted values and include these in the model in the row. When the Y_hat estimated from the model in the column contributes significantly to improve the model in the row, we cannot say that the model in the row is significantly better than the model in the column.**

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