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Renewable energy investment: Policy and market impacts

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ABSTRACT

The liberalization of electricity markets in recent years has enhanced competition among power-generating firms facing uncertain decisions of competitors and thus uncertain prices. At the same time, promoting renewable energy has been a key ingredient in energy policy seeking to de-carbonize the energy mix. Public incentives for companies to invest in renewable technologies range from feed-in tariffs, to investment subsidies, tax credits, portfolio requirements and certificate systems.

We use a real options model in discrete time with lumpy multiple investments to analyze the decisions of an electricity producer to invest into new power generating capacity, to select the type of technology and to optimize its operation under price uncertainty and with market effects. We account for both the specific characteristics of renewables and the market effects of investment decisions. The prices are determined endogenously by the supply of electricity in the market and by exogenous electricity price uncertainty.

The framework is used to analyze energy policy, as well as the reaction of producers to uncertainty in the political and regulatory framework. In this way, we are able to compare different policies to foster investment into renewables and analyze their impacts on the market.

1. Introduction

The liberalization of electricity markets in recent years has enhanced competition among power-generating firms facing uncertain decisions of competitors and thus uncertain prices. At the same time, promoting renewable energy has been a key ingredient in energy policy aiming at the de-carbonization of the energy mix. Public incentives for companies to invest in renewable technologies include inter alia feed-in tariffs, investment subsidies, tax credits, portfolio requirements and certificate systems.

A problem connected to these new technologies in contrast to the traditional ones is that they often yield uncertain amounts of electricity depending on the current environment (variable amount of sunny days, high vs. low wind speeds, etc.). Moreover, the political frameworks and regulations differ between the individual countries of the European Union (EU), change over time and are thus often subject to major uncertainties themselves. Although costs for renewable technologies are falling (e.g. [1]), installed and established capacity such as coal-fired plants still benefit from relatively low investment and operations and maintenance (O&M) costs. Renewable technologies (such as wind power), however, have positive external effects, e.g. by emitting less to no CO_2, and creating jobs or energy security, which could trigger support from public administrations. This support has played an important role in encouraging wind power respectively renewable power development and could e.g. take the form of tax and financial incentives, CO_2 costs or feed-in tariffs. With respect to the latter, Blancoa and Rodrigues [2] quote the current German feed-in tariff for wind power to be 90 €/MW h.

We introduce a modeling framework, which captures (a) the specific properties of electricity markets (e.g. high up-front sunk costs and flexibility to time installations differently), where (b) large companies can have an impact on prices in the market. Furthermore, we model (c) the dynamic nature of investment decisions, (d) the associated uncertainties emanating from both markets and environment and analyze, and (e) the impact of policy and the uncertainty surrounding it. For the latter part we pick Germany as a case study, which has a feed-in tariff system since 1991, which has often been cited as a success case and example for other countries. Renewable energy producers receive a fixed tariff from the grid operator, who has the obligation to accept the electricity. The tariff depends on the type of technology – and in the case of wind also location – and is fixed for up to 20 years.[1] Moreover, Germany's renewables share has more than doubled between 2000 and 2009, where wind

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[1] Note that the tariff for new projects decreases each year to accelerate investment, but we abstract from this complication, as the investor in our model opts for immediate investment and including this features would thus not change our results.

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Nomenclature

Symbol Meaning (Unit)

State variables

P_t^{fit} feed-in tariff for the electricity generated by wind (€/MW h) in year t following a Markov process

n_t^c number of coal fired power plants that the investor has built prior to year t

n_t^w number of wind farms that the investor has built prior to year t

Control Variables

u_t^c number of coal fired power plants the investor decides to build in year t

u_t^w number of wind farms the investor decides to build in year t

Random Variables

q_t^w yearly output (MW h) of one wind farm in year t

X_t multiplier representing the electricity price shock in year t

Secondary Variables

Q_t yearly aggregate electricity supply (MW h) in the market in year t

Y_t yearly income proxy (€)

$P_t^e(Q_t, X_t)$ electricity price (€/MW h) in year t

$c(n_t^c, n_t^w)$ yearly costs (€) of the investor as a function of the number of owned coal fired and wind power plants. Account for both the operational and maintenance costs and the annualized capital costs needed for construction

$\pi(n_t^c, n_t^w, X_t)$ yearly profits (€) of the investor as a function of the number of owned coal fired and wind power plants

Parameters

t time (years)

r subjective discount rate

n upper constraint on the number of plants constructed by the investor in the planning period

q^c yearly output (MW h) of one coal fired power plant

T planning period in years

Q^{fixed}, N parameters for the aggregation of supply. Fixed supply in each year (MW h) and the multiplier of new investment respectively

Y_0, y income parameters. Starting value (€) and growth rate respectively

ε_i, ε_p income and electricity price elasticity respectively

FIT, p feed in tariff parameters. Value of the feed in tariff in (€) and probability defining the transition matrix respectively

μ_w, σ_w^2 mean and variance of the yearly output of one wind farm

μ_x, σ_x^2 mean and variance of the shock process

is the most important of the supported renewable energy carriers. For this reason we pick wind power as the subject of our study.

In the discrete time model developed in this paper, we are analyzing the investment decisions of a firm, producing a homogenous and non-storable good, over a fixed planning horizon. The firm decides whether to irreversibly invest in new capacities or not at the end of each time period. When deciding about investing in new capacities, which are lumpy, the firm can choose between different technologies implying different cost structures and production uncertainties. The yields of some technologies depend on the state of the environment, e.g. wind power plants with high or low wind speeds over a specific period. Electricity prices are stochastic. Furthermore, market prices are influenced by changes in the total supply, e.g. supply fluctuations, new capacity investments. Firms in this environment have to consider the effects of their own and competitors' investment decisions (which are modeled indirectly in this study) and their impact on their firm value instead of an isolated investment.

Standard real options models, which are described e.g. by Trigeorgis [3] or Dixit and Pindyck [4], have traditionally been applied to similar timing and investment decision problems. The requirements to apply real options analysis of the flexibility of the producer (to decide whether to invest in new capacities or not), the uncertainties pervading the future paths of price, production and policy, as well as the irreversibility of the investments are given in the markets observed by our model. Examples of lumpy investment real options models are e.g. [5,6]. These models, however, do not capture the effect of an investment on the value of past and future investments. In our model, we do not assume that firms can continuously (infinitely small increments) add capacity without any adjustment costs.

Real option models have been applied to questions in the electricity industry most recently e.g. by Siddiqui and Fleten [7] or Murto and Liski [8]. Also, non-real options models have been used to determine the optimal incentive scheme for renewable energy uptake (e.g. [9]).

In contrast to the existing literature we extend the model introduced by Reuter et al. [10] addressing points (a)–(e), as explained above. Strictly speaking, with respect to point (e), regulatory uncertainty has been addressed in the case of the energy market by previous work in real options modeling (e.g. [11–13]), where the uncertainty emanates from variability in different scenarios of future CO_2 price paths. These studies generally find a negative response of investment to regulatory uncertainty. In this paper we are also interested to examine whether uncertainty about the durability (or re-introduction) of feed-in tariffs has a similar impact when there are feedbacks of decisions to the market.

The paper is organized as follows. Section 2 presents the basic framework and notations, whereas Section 3 offers an overview and explanation of the data and the sources they come from. Section 4 describes the policy experiments and their results, which are then further analyzed and put into the policy context in the conclusion in Section 5.

2. A real options model with endogenous prices

In this paper we seek to analyze the investment decisions of an electricity company under the uncertain climate policy. The investor tries to find the investment strategy that maximizes expected profits during the planning period. He can decide whether and when to construct new electricity generating capacities. There are two possible technologies available, one representing the standard fossil fuel power plants (referred to as coal) and another one representing renewable technologies (e.g. wind). The assumptions underlying the model formulation can be summarized as follows: