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An analysis of a forward capacity market with long-term contracts

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ABSTRACT

We analyze the effectiveness of a forward capacity market (FCM) with long-term contracts in an electricity market in the presence of a growing share of renewable energy. An agent-based model is used for this analysis. Capacity markets can compensate for the deteriorating incentive to invest in controllable power plants when the share of variable renewable energy sources grows, but may create volatile prices themselves. Capacity markets with long-term contracts have been developed, e.g. in the UK, to stabilize capacity prices. In our analysis, a FCM is effective in providing the required adequacy level and leads to lower cost to consumers and more stable capacity prices, as compared to a yearly capacity market. In case of a demand shock, a FCM may develop an investment cycle, but it still maintains security of supply. Its main effect on the power plant portfolio is more investment in peak plant.

1. Introduction

We analyze the effectiveness of a forward capacity market (FCM) in the presence of a growing share of intermittent renewable energy sources in the generation mix. We implement a representation of a FCM based on the United Kingdom's capacity market design in the “EMLab-Generation” agent-based model for this analysis.

Adequacy concerns arising from the growing share of intermittent renewable energy (cf. Nicolosi and Fürsch, 2009; Steggals et al., 2011), along with concerns about market failure due to imperfections (Cramton et al., 2013; Joskow, 2008a, 2006), have led to the implementation of a capacity market in the United Kingdom (UK) (UK Parliament, 2013). After much deliberation, the design for the capacity market was finalized in 2014. The UK chose a forward capacity market (FCM), characterized by long-term contracts for new generation capacity. The design of the capacity market is defined by the Electricity Capacity Regulations 2014 (DECC, 2014a) and the Capacity Market Rules (DECC, 2014b). The first capacity auction took place in December 2014. The expectation was that it would improve generation adequacy by providing a more stable investment signal, thus lowering investment risk.

Market participants' decisions regarding investment in new power generation assets and with respect to decommissioning existing assets are characterized by bounded rationality, as they are limited by their current information and therefore their forecasts are inevitably imperfect (Simon, 1986). The market participants' imperfect knowledge of the future can be expected to lead to suboptimal results in terms of generation investments and decommissioning. This may affect the effectiveness of capacity markets in reaching public policy goals such as generation adequacy. Our analysis considers the impact of uncertainty, imperfect (myopic) investment behavior and path dependence on the performance of a forward capacity market (FCM). We analyze the effectiveness of the forward capacity market under different demand growth scenarios and design considerations.

In order to understand the impact of a FCM, we compare a FCM's performance with that of a yearly capacity market design (YCM), extending our earlier work in this field (Bhagwat et al., 2017b, 2017a). We base the YCM design in our analysis on the NYISO-ICAP[1] market because this is an example of a successful yearly capacity market and has a relatively simple design.

Several types of computer models have been used to study generation investment in the electricity market. A classification of different electricity market modeling approaches is provided by Ventosa et al. (2005). Boomsma et al. (2012) and Fuss et al. (2012) use a real option approach in to study investment in renewable generation capacity under uncertainty. Hobbs (1995) uses a mixed integer linear

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[1] NYISO-ICAP: New York Independent System Operator – Installed Capacity market.

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programming approach to study generation investment under perfect conditions. Eager et al. (2012) use a system dynamics approach to study investment in thermal generation capacity in markets with high wind penetration. In this model, the investment decision are based on net present value and a value at risk criterion to account for uncertainty. Bunn and Oliveira (2008) use an agent-based computational model that is based on game theory to study the impact of market interventions on the strategic evolution of electricity markets. Powell et al. (2012) present an approximate dynamic programming model to study long-term generation investment under uncertainty. Botterud et al. (2002) use a dynamic simulation model to analyze investment under uncertainty over the long-term. None of these studies, however, considered the impact of a capacity mechanism on generation investment.

Hach et al. (2014) utilize a system dynamics approach to study the effect of capacity markets on investment in generation capacity in the UK. Similarly, Cepeda and Finon (2013) use a system dynamics approach to analyze impact of a forward capacity market on investment decisions in presence of a large-scale wind power development. As system dynamics is a top-down approach, Mastropietro et al. (2016) use an optimization model to analyze the impact of explicit penalties on the reliability option contracts auction. Meyer and Gore (2015) use a game-theoretical approach to study the cross-border effects of capacity mechanisms on consumer and producer surplus. Gore et al. (2016) use an optimization model to study the short-term cross border effects of capacity markets on the Finnish and the Russian markets. An optimization approach is used by Doorman et al. (2007) to study the impact of different capacity mechanisms on generation adequacy. Elberg (2014) uses an equilibrium model for the analysis of cross-border effects of two capacity mechanisms, a strategic reserve and a capacity payment, on the investment incentive. Dahlan and Kirschen (2014) and Botterud et al. (2003) study generation investment in electricity market using an optimization approach. Ehrenmann and Smeers (2011) study impact of risk on capacity expansion using a stochastic equilibrium model. In this model investment decisions are made based on the level of risk aversion of the investor. The risk aversion is modeled using a conditional value at risk (CVaR) approach.

None of the reviewed studies considered the combined impact of uncertainty, myopic investment (boundedly rational investment behavior) and path dependence on the development over time of an electricity market with a capacity mechanism. We do include these aspects of imperfect investor behavior in our study, as the point of a capacity mechanism is to compensate for them. We do this by implementing capacity markets as an extension of the EMLab-Generation agent-based model (De Vries et al., 2013; Richstein et al., 2015a, 2015b, 2014).[2] Agent based modeling (ABM) is a bottom up approach in which actors are modeled as autonomous decision making software agents (Chappin, 2011; Van Dam et al., 2013; Farmer and Foley, 2009). The behavior of the agents – in our model: the generation companies – is based on programmed decision rules. They decide about investments in new generation capacity, dismantling of old power plants and dispatch of their generation units (De Vries et al., 2013). The simulation results emerge from the agents' decisions.

The advantages of using ABM in modeling complex socio-technical systems are discussed (Chappin, 2011; Van Dam et al., 2013; Helbing, 2012; Weidlich and Veit, 2008). In the context of electricity markets, ABM captures the complex interactions between energy producers and a dynamic environment. No assumptions regarding the aggregate response of the system to changes in policy are needed, as the output is the consequence of the actions of the agents. Furthermore, the behavior of the agents is based on the principle of bounded rationality (as described by Simon (1986)), i.e., the decisions of the agents are limited by their current knowledge and their (imperfect) prediction of the future. The agents base their decisions on their understanding of their environment, including other agents' actions. The results from the model are an emergent property of the agents' interactions with each other and their environment, thus the results typically do not follow an optimal path. This allows us to study the possible evolution of the electricity market under conditions of uncertainty, imperfect information and non-equilibrium.

Aside from the advantages of using an ABM for this analysis, the implementation of a detailed representation of capacity markets in EMLab-Generation model provides several advantages. The first is that the ability to vary different design parameters (such as the installed reserve margin (IRM) requirement) of the FCM forward capacity market allows us to study the sensitivity of the design to changes in the design parameters. Secondly, it allows us to compare two different capacity market designs. Furthermore, EMLab-Generation allows us to study the effectiveness of the FCM under varying demand growth conditions, especially a situation in which the system undergoes a demand shock. A disadvantage of ABM is that it is time- intensive, both with respect to developing the model (in Java) and running it (it requires a high-performance computer cluster to conduct Monte Carlo runs that are required for this analysis). Due to the long runtime, the scope is limited. A key limitation for this purpose is the abstraction of demand into a load-duration curve, which does not allow for the representation of demand elasticity or storage. This may cause more volatile prices and therefore exaggerate the need for a capacity mechanism. Another drawback of this modeling approach is that traditional validation processes cannot be applied, making validation of agent-based models challenging (Louie and Carley, 2008).

We will proceed by describing the EMLab-Generation agent-based in the next section. In Section 3, the implementation of a capacity market in EMLab-Generation is presented. This is followed by the description of the scenarios and performance indicators that are used in this study in Section 4. The results are discussed in Section 5 and the conclusions are summarized in Section 6.

2. The EMLab-Generation model

2.1. EMLab-Generation

The EMLab-Generation agent-based model (ABM) was developed in order to model questions that arise from the heterogeneity of the European electricity sector and the interactions between different policy instruments (De Vries et al., 2013; Richstein et al., 2015a, 2015b, 2014). The model provides insight in the simultaneous long-term impacts of different renewable energy, carbon emissions reduction and resource adequacy policies, and their interactions, on the electricity market.

Power generation companies are the central agents in this model. The behavior of the agents is based on the principle of bounded rationality (as described by Simon (1986)), i.e., the decisions made by the agents are limited by their current knowledge and their limited understanding of the future. The agents interact with each other and other agents via the electricity market and thereby change the state of the system. Consequently, the results from the model do not adhere to an optimal pathway and the model is typically not in a long-term equilibrium. Therefore, the model allows us to study the evolution of the electricity market under conditions of uncertainty, imperfect information and non-equilibrium.

In the short term, the power generation companies make decisions about bidding in the power market. Their long-term decisions concern investments in new capacity and decommissioning of power plants. The model resembles a cost-minimizing model in which investments are based on expected costs, as we did not program differences in the agents' behavioral algorithms. The only difference between the agents develops in the state of their finances during the simulation: agents that made bad investment decisions have less money to invest in later years. By having multiple agents with different bank balances, the effects of

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[2] http://emlab.tudelft.nl/.