FORWARD TRADING AND THE VALUE OF FLEXIBILITY IN SEQUENTIAL ELECTRICITY MARKETS WITH INCREASING INTERMITTENT SUPPLY

Derck Koolen, Rotterdam School of Management, Erasmus University, 0031 10 408 9972, koolen@rsm.nl

Overview

The influence of energy on our society is undeniably widespread, being very closely related to challenging problems on national security, economic and sustainable development, and environmental awareness. The vertical disintegration of utilities and the liberalization of sequential wholesale power markets have enabled greater market competition and reduction of electricity prices. Increased competition, lower prices and more price volatility in addition to new production technologies are changing operations in sequential electricity markets and are at odds with the traditional top-down approach in electricity supply chains. The integration of wind and solar power introduces more low marginal costs suppliers to the market, as no fuels are needed to produce electricity, and power prices drop as a result. However, the integration of renewable energy sources, which operate at a variable intermittent production rate, increases the need for flexibility in order to maintain the necessary pre-requisite of balancing load and generation. Intermittent supply from wind turbines and solar panels in combination with limited storability of electricity and relatively price inelastic demand, have caused prices to fluctuate heavily. Key in the transition process is to understand relationships of market behavior by producers operating under heterogeneous constraints, in order to ensure that markets provide adequate price signals for all assets and investments next to ensuring longterm security of supply in a market efficient manner.

With adequate pricing essential for establishing a sustainable electricity supply chain, we focus on the price dynamics of electricity forward and spot contracts. Sequential commodity markets allow for risk sharing with uncertainty over the good's delivery price or quantity and hence participants engage in hedging activities to avoid risks on spot markets from both volatile demand and supply conditions. In the context of electricity markets, hedging is however not fully efficient and systematic price differences, the forward risk premium, and strategic bevaior are observed. In such a setting, our study investigates how changing operational and technological production characteristics with increasing renewable energy supply, affects producers' ability to trade and price formation in sequential electricity markets. We find evidence for a tipping point in the forward premium with increasing volatile supply, modeling competitive wholesale sequential electricity markets via a two-stage equilibrium approach. The tipping point indicates a varying systematic price difference in sequential markets with increasing intermittent capacity. We illustrate the implications of the model with a set of simulations, as empirical testing of the postulate is constrained since the integration of renewable energy is a recent phenomenon and data is scarce. We follow up by including the notion of strategic flexible assets, and find evidence for a systematic arbitrage value of flexibility. Investigating the effects of integrating intermittent renewable energy sources on hedging and strategic flexibility, the model indicates a first-mover advantage for integrating flexible assets in the production portfolio. As such, the work ultimately contributes to one of the key goals of energy economics; to engage policy makers, in order to not only facilitate a high integration of renewable energy sources, but also achieve it in a sustainable manner.

Methods

In order to assess optimal forward and spot positions of power producers, we model the electricity market in a two-stage equilibrium approach. As electricity is a non-storable commodity, traditional cost-of-storage models for pricing forwards cannot be used. We extend the approach of [1] who consider all producers to be homogeneous, by modeling N power producers that use different technologies to produce homogenous, non-storable electricity in a competitive electricity wholesale market. There are M power retailers j that purchase power in the wholesale market and sell it to end consumers at a fixed unit price. The end consumers' total demand for electricity is a random variable D and each producer and retailer take forward positions, Fi and Fj, and spot positions, Qi and Qj respectively. We consider in our model two types of power producers, operating under different constraints, referred to as zero-cost producers and high-cost producers. The former only have fixed costs and do not bear any marginal costs for producing electricity. Most renewable power plants function in this way and are dependent on weather conditions like solar radiation or wind speed. The production capacity of each zero-cost producers is represented by a random variable Ki, and can be interpreted as a production constraint by nature, enforcing prediction accuracy in the forward market. High-cost producers bear a marginal producing cost increasing with output. This type of producers reflects the more traditional set of power producers, and reflects the fact there is a various set of fuel producers in industry who use different types of technologies, like natural gas, coal or nuclear. We solve the equilibrium model of wholesale spot and forward electricity markets, using backward induction. Assuming that the forward market position is given, we begin by analyzing the wholesale spot market equilibrium. Once the optimal positions in the spot market are known, we work back to find optimal positions in the forward market. We assume that producers and retailers are risk averse and use a mean-variance utility function. By solving the first order conditions of optimization problem, we obtain the optimal forward positions. Inserting optimal forward positions in the market clearing condition, the equilibrium forward price is found.

We next expand the analytic model, including the notion of operational flexibility and evaluate in terms of the forward risk premium and profitability with increasing intermittent capacity. We first consider a cooperation of intermittent and flexible assets. Combining the ownership of these two assets in the same portfolio allows to investigate the value of the product flexibility on the supply side in future power systems. Flexibility in essence allows for quick ramping, or updating positions near real-time, when the system (im)balance requires it to assure a stable grid. Second, we assess strategic incentives for financial traders with a degree of flexibility in the portfolio. This substantial value of flexibility benefits from arbitrage between sequential markets, and represents only a lower bound in addition to the short-term value of flexibility. We evaluate viable conditions in the electricity market design for benefiting from arbitrage flexibility and identify policy implications for the sustainable integration of flexibility with an increase of intermittent market capacity.

Results

We analyze the behavior of the forward premium under increasing intermittent capacity via a set of simulations and define the tipping point as the optimal share of renewable capacity in terms of the weak form efficient market hypothesis. Results indicate the existence of a tipping point along the market share of intermittent capacity. The relative behavior of the tipping point can be related back to the interplay of risk related hedging pressures between different types of producers and retailers. The exact location is determined by market characteristics as the composition of producers, risk-aversity and uncertainty of demand and supply. We conduct a robustness check for these variables, given in our simulation by exogenous parameters, and analyse how they define the degree of convexity and dominance of the risk related hedging terms. Interestingly, we find that the contour curve is non-linear along increasing the intermittent capacity share, implying that when the share of intermittent capacity in a given market structure is increased, market efficiency may reach an optima resulting in more than one tipping point. Thus, although moving away from a tipping point by increasing renewable may first be disadvantageous, increasing the share to the next tipping point is desirable for facilitating a high penetration of renewables in the long term.

Analzying the effects of including flexible assets with intermittent production sources, we find a reduction of hedging pressure related to supply uncertainty. As such, the forward risk premium decreases monotonically with increasing intermittent supply. The intuition is that a large market share of low-cost producers in the form of cooperations, implies an increased likelihood of price spikes. This induces pure strategic behavior of flexible assets, capturing both demand and supply uncertainty. Therefore, we next analyze the effects of including flexibility as separate trading entity, to isolate the impact of technology and flexibility. We observe that the systematic value of flexibility reaches a tipping point. Such flexible trading could in essence be done by any speculative trading entity, however is only allowed in electricity markets by the market operator when the flexible capacity can be assured. The analysis thus indicates a first mover advantage for integrating flexible assets in the trading portfolio.

Conclusions

In our study, we combine analytical modeling and numerical simulations to demonstrate the effects of a large-scale integration of renewable intermittent energy on forward price formation and market participants' hedging and strategic behavior. Whereas renewable resources indeed provide sustainability benefits, and help to achieve political targets, their recent sharp increase has pronounced challenges for integration in the electricity system. In the current work, we simulate the relative performance of forward and spot markets under uncertainty of increasing renewable sources in the market to give insights on how market conditions define hedging and strategic behavior of heterogeneous market participants. We find that the risk premium varies and reaches a tipping point along increasing shares of intermittent market capacity depending on the systematic risk and the net hedging pressure of all market participants. This technology varying risk-premium has strong implications for existing market structures integrating renewable energy in an efficient way. Influenced by market conditions as flexibility, market power and risk aversion, relative performance of spot and forward markets is bound by the markets’ operational constraints.

We investigate the implications on existing market structures and their participants’ strategic space and discuss how our results impact a well-functioning electricity market, its design and governing policies. The study, making a clear distinction between strategic and hedging behavior of market participants, shows an incentive for investing in flexibility. The study shows a first mover advantage for producers integrating flexible assets in their portfolio. As such, it calls for an adequate validation of the product flexibility in wholesale electricity markets facilitating the market integration of renewable production sources in a sustainable manner.

References

[1] Bessembinder, H., & Lemmon, M. L. (2002). Equilibrium pricing and optimal hedging in electricity forward markets. *the Journal of Finance*, 57(3), 1347-1382.