A two stage stochastic equilibrium model for electricity markets with two way contracts

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Abstract This paper investigates generators’ strategic behaviors in contract signing in the forward market and power transaction in the electricity spot market. A stochastic equilibrium program with equilibrium constraints (SEPEC) model is proposed to characterize the interaction of generators’ competition in the two markets. The model is an extension of a similar model proposed by Gans et al. (Aust J Manage 23:83–96, 1998) for a duopoly market to an oligopoly market. The main results of the paper concern the structure of a Nash–Cournot equilibrium in the forward-spot market: first, we develop a result on the existence and uniqueness of the equilibrium in the spot market for every demand scenario. Then, we show the monotonicity and convexity of each generator’s dispatch quantity in the spot equilibrium by taking it as a function of the forward contracts. Finally, we establish some sufficient conditions for the existence of a local and global Nash equilibrium in the forward-spot markets. Numerical experiments are carried out to illustrate how the proposed SEPEC model can be used to analyze interactions of the markets.

Keywords Electricity market · Nash equilibrium · Stochastic equilibrium programs with equilibrium constraints

1 Introduction

Over the past two decades, the electricity industry in many countries has been deregulated. One of the main consequences of deregulation is that the governments under-
take their efforts to develop fully competitive electricity spot markets. In most of the wholesale spot markets (pool-type systems), generators make daily (or hourly) bids of generation at different prices, and then an independent system operator (ISO) decides how actual demand is to be met by dispatching cheaper power first. In these pool-type electricity markets (found in Australia, New Zealand, Norway, at one time in UK, and some parts of US), a single market clearing price is determined by a sealed-bid auction and paid to each generator for all the power they dispatch.

Along with the spot market emerges the forward market where generators and retailers may enter into hedge contracts before bidding in the spot market. For example, in the early 1990s, during the restructuring of the electricity market in UK, some long term, “take-or-pay” contracts (or agreements) are stipulated by three main Scottish electricity generators, see Onofri (2005). Moreover, various contract markets have also been established in Europe, Australia, New Zealand and North America. By participating in the forward markets, generators and retailers may share their risks associated with a fluctuating pool price for the real power dispatching. The most common type of contract is known as a (two-way) contract-for-difference (or hedge contract), which operates between a retailer and a generator for a given amount of power at a given strike price. The signing of this type of contracts is separate from the market dispatching mechanism and can be taken as financial instruments without an actual transfer of power.

In this paper, we formulate generators’ competition in the forward-spot market mathematically as a two stage stochastic equilibrium problem where each generator first aims at maximizing its expected profit by signing a certain mount of long term contracts and then bids for dispatches in the spot market on a daily or hourly basis. Differing from the two stage competition model, a volume of previous research has been performed to study the effect on the competition in the spot market from the contract quantities, in which the competition of signing contracts in the forward market is not considered. von der Fehr and Harbord (1992) investigate the spot market by modeling it as a multi-unit auction and demonstrate that contracts give generators a strategic advantage in the spot market by allowing them to commit to dispatch greater quantities during peak demand periods. Powell (1993) explores the interaction between the forward market and the spot market by characterizing the competition in the spot market within a framework of Nash–Cournot equilibrium, and shows that risk-neutral generators can raise their profits by selling contracts for more than the expected spot price. Moreover, Green and Newbery (1992) appropriately look at the endogenous formation of both pool and contract prices in a supply function model, and apply their analysis to the British electricity market.

By modeling the mechanism of the competition in the forward market as a Nash–Cournot game, previous contributions, such as (Allaz and Vila 1993; Willems 2005; Gans et al. 1998), focus on the impact of the forward market on the spot price and show that generators have incentives to trade in the forward market whereas forward contracting reduces spot prices and increases consumption levels. The exploration of the bilevel deterministic Nash–Cournot model for a duopoly forward-spot market is first carried out by Allaz and Vila (1993), which identifies two critical assumptions: One is the so-called Cournot behavior where producers (generators) act as though the quantity offered by the other competitors is fixed; the other is the connection to the