Electric Power Systems Research 84 (2012) 1–9

Contents lists available at SciVerse ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Equilibria in futures and spot electricity markets

Carlos Ruiz, S. Jalal Kazempour, Antonio J. Conejo*

Department of Electrical Engineering, Univ. of Castilla-La Mancha, Campus Universitario, 13071 Ciudad Real, Spain

ARTICLE INFO

Article history:
Received 5 April 2011
Received in revised form 4 July 2011
Accepted 21 September 2011
Available online 28 October 2011

Keywords:
Conjectural variation
Electricity market
Futures market
MLCP
Spot market

ABSTRACT

We describe a model to analyze the equilibrium encompassing an electricity futures market and a number of electricity spot markets sequentially arranged along the time horizon spanned by the futures market. Profit-maximizing strategic electricity producers react to both prices and rival production changes, in both the spot and the futures markets. At each time period, the total demand is considered to depend linearly on the spot price of the considered time period, and the futures market price is assumed to equal the average spot price over the time horizon. Equilibrium conditions at each spot market are described as a function of the futures market decision variables, which in turn allows describing the equilibrium in the futures market implicitly enforcing equilibrium in each spot market. The proposed model allows deriving analytical expressions that characterize such multi-market equilibrium and that can be recast as a mixed linear complementarity problem. This model is useful to gain insight on the outcomes and characteristics of the considered multi-market equilibrium. Such insight may allow the regulator to better design the futures and spot trading floors, their rules and sequential timing. It may also allow producers to increase the effectiveness of their respective offering strategies.

1. Introduction

1.1. Motivation and aim

As electricity markets mature throughout the world, futures markets become more and more liquid and relevant for electricity trading. This is the case, for instance, of EEX [1] in Central Europe or NYMEX [2] in the East Coast of the US.

Futures markets allow trading products (mainly forward contracts and options) spanning a large time horizon, e.g., 1 month, while spot markets are typically cleared on an hourly basis throughout the time periods spanned by the futures market products. Thus, futures and spot markets interact and such interaction results in multi-market equilibria. It is important to note that a futures market equilibrium generally encompasses a large number of spot market equilibria.

As an example, consider different peak and base forward contacts (futures market products) spanning, for instance, the month of May. An electricity producer may sell its production using such contracts or, alternatively, through the 31×24 hourly spots markets spanning May. The producer may also sell part of its energy production through forward contracts and the remaining energy in the successive spot markets. The profit-seeking interaction of all producers (strategic or otherwise) within the futures market and the spot markets being cleared during the time horizon defined by the forward contracts does characterize the market equilibria.

Following the practice in some real-world markets, we consider a single futures market that is cleared prior to the subsequent spot markets. Therefore, the quantities sold by each producer in the futures market are delivered in the spot markets without any possibility of continuous renegotiation.

Within the above market framework, we consider strategic electricity producers that react through conjectural variation (CV) models to both the spot prices and the productions of rival producers in both the futures and the spot markets. This characterization of strategic producers is flexible enough to analyzed different types of market competition, including Cournot competition, the formation of cartels by groups of producers, monopoly and perfect competition.

At each time period, the total demand (supplied through futures market products and the spot) is considered to depend linearly on the spot price of the considered time period. Moreover, the average spot price (computed as the arithmetic mean over time of the spot prices) is assumed to be equal to the futures market price, i.e., the risk premium is assumed to be nil. This is an assumption consistent with empirical observation in different energy markets.

Equilibrium conditions at each spot market are described as a function of the futures market decision variables (futures market price and the energy sold in the futures market by each producer), which in turn allows describing the equilibrium in the futures

* Corresponding author. Tel.: +34 926 295433; fax: +34 926 295361.
E-mail addresses: carlos.rmora@uclm.es (C. Ruiz), SeyyedJalal.Kazempour@alu.uclm.es (S.J. Kazempour), Antonio.Conejo@uclm.es (A.J. Conejo).

0378-7796/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2011.09.019

market implicitly enforcing equilibrium in each spot market. The result is a so-called multi-market equilibrium, and involves the futures market price, hourly spot prices, and the energy sold in the futures and each spot market by each producer.

The proposed model allows deriving analytical expressions, equalities and inequalities, that characterize the multi-market equilibrium and that can be recast as a mixed linear complementarity problem, MLCP, easily solved using available software, e.g., PATH [3] under GAMS [4].

Observe that the model described in the paper does not represent the network since representing it makes intractable the proposed analytical approach. If the network needs to be represented, a numerical instead of an analytical approach needs to be used, as for instance in [39]. However, note that an analytical approach provides insights that computational approaches cannot provide.

It is relevant to note that congestion issues can be handled through a post market procedure as reported, for instance, in [6]. Please, note that this is the actual practice in most European markets, as the Iberian Peninsula market [7], or EEX in Germany [1].

1.2. Literature review

Futures electricity markets have been well analyzed in the literature as effective tools for power producers to hedge against the risk of pool price volatility. Several papers have addressed this issue, see for instance pioneering reference [8] where a study of the use of forward contracts as risk management instruments against profit volatility is presented. Ref. [9] shows how the unique characteristics of electric power make risk management more complex than in the case of other commodities. Ref. [10] provides statistical techniques to minimize risk using futures contracts, and Ref. [5] addresses the optimal involvement in a futures market managing risk through the CVaR methodology.

Additionally, some authors claim that apart from risk management implications, the introduction of futures markets may have important consequences on the strategic behavior of the market participants. In particular, Allaz and Vila [11] points out that the competitiveness of a market is improved by the inclusion of a futures market, even without any price volatility. This result is corroborated in [12] by empirical observation on the British and the NordPool electricity markets. Ref. [13] establishes existence results for the Allaz–Vila market equilibrium model with asymmetric producers. Furthermore, Ref. [14] derives comparative-static predictions of the Allaz–Vila model with regard to the market structure and the number of competitors. Despite these results, the impact of futures markets on market efficiency is still contentious. Ref. [15] shows how, for a market with Bertrand competition with forward trading, prices increase if compare to the case without forward trading. In the same vein, [16] shows that the introduction of futures markets may have an anti-competitive effect if producers are able to sell in futures market at infinitely many times prior to the spot market. Ref. [17] demonstrates that the Allaz–Vila results are not valid if the production capacities of the players are endogenous and constrain the production level. This result is checked for the cases of known and unknown demand at the time of investment.

On the other hand, several alternatives can be considered to model the behavior of the producers at each stage of the market. The supply function equilibrium (SFE) approach was introduced in [18] and firstly applied to electricity markets in [19]. SFE models provide a realistic view of the market since they allow gaming in both price and quantity. However, the main drawback of this approach is its computational complexity and therefore linear assumptions [20] and mixed-integer linear programming techniques [21] are required generally for practical applications.

The Cournot equilibrium approach, which can be considered a special case of SFE, allows a realistic modeling of electricity markets with a moderate level of computational complexity. Ref. [22] provides some theoretical results pertaining to the Cournot model applied to short-term electricity markets, while [23] presents an experimental economic approach to analyze an electricity market with Cournot agents. However, the Cournot model presents relevant weakness related to the high sensitivity of its results to the demand elasticity. The CV model overcomes this difficulty and allows simulating different levels of competition in the market.

The CV model was firstly introduced by Bowley in 1924 [24] and it is well established in the microeconomic literature [25,26]. Refs. [27,28] apply a conjecture supply function approach to the electricity market of Spain, and England and Wales, respectively. Ref. [29] analyses an electricity market with CV producers of different types and provides analytical results concerning market outcomes. There are some arguments against CV models concerning the consistency of the conjectures and the possibility of multiple equilibria, see for instance [30,31]. Note that the proposed model considers the market equilibrium for a set of fixed conjectures not considering how they are obtained or whether they are consistent or not.

The multi-stage market equilibrium (futures and spot market) considered in this paper is represented by an equilibrium problem with equilibrium constraints (EPEC) where each producer solves a mathematical program with equilibrium constraints (MPEC) [32]. MPECs and EPECs have been recently proposed to tackle electricity problems. Ref. [33] proposes a linear complementarity problem to formulate an imperfect competition model for electricity producers. A bilevel model is used in [34] to analyze the effectiveness of an independent system operator if producers have market power. Ref. [35] presents a strategic gaming model where the single-producer problem is formulated as an MPEC and [36] considers through an MPEC formulation the problem of a strategic producer that trades electric energy in an electricity pool market. Ref. [37] presents a mixed-integer linear programming solution approach for the EPEC of finding Nash equilibrium in short term electricity markets and [38] studies a bilevel noncooperative game-theoretic model with LMPs. Finally, Ref. [39] shows that EPECs are also practical for modeling two-settlement electricity markets.

1.3. Contributions

Considering the above literature review, the contributions of this paper are threefold:

1 Modeling an electricity multi-market equilibrium involving the futures market and a number of spot markets cleared within the time span of the considered futures market products. Strategic producers are characterized through conjectural variation models.
2 Deriving analytical expressions to characterize such multi-market equilibrium and to obtain equilibrium outcomes. The equality and inequalities that characterize the multi-market equilibrium can be recast as an MLCP.
3 Illustrating the analytical results obtained using a variety of relevant and insightful case examples.

1.4. Paper organization

The rest of this paper is organized as follows. Section 2 describes the model components and the main assumptions made to build the proposed model. Section 3 characterizes the equilibrium in the spot market as a function of the decision variables in the futures market. Section 4 characterizes the equilibrium in the futures market subject to equilibrium in each spot market. Section 5 comprehensively analyzes a number of case examples. Section 6 concludes the