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Derivatives of the nodal prices in market power screening

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ABSTRACT

This paper proposes a novel method for market power screening. This method is developed for horizontally and vertically consolidated power markets, and is based on the optimal power flow (OPF) model properties. It undertakes the calculation and analysis of a matrix of derivatives of the nodal prices with respect to generating unit offer prices. The analysis takes into consideration the influence of particular partakers and energy groups on the nodal prices. This paper presents a theoretical analysis of the partakers' and groups' profits as well as a method for the market power screening. Moreover, the issue wherein the LMP model generates prices above the highest bidding price is discussed. Illustrative case studies and case studies based on the Polish wholesale balancing power market model are also presented.

1. Introduction

In a perfectly competitive market there is complete freedom of trade. Product delivery limitations do not exist and no buyer or seller has market power. Thus, market participants cannot influence the market prices. A perfectly competitive market does not require regulations because the so called "invisible hand of the market" ensures fair trading conditions. However, for real markets, the assumption of a perfect competition fails. Power markets, in particular, wherein a finite number of partakers, and significant entry and exit barriers exist, are worth considering. In these markets, complex regulations are introduced to provide fair trading conditions because market power exists and more importantly, is exploited.

The contributions of the paper are: (i) analysis of the impact of the matrix of derivatives of the nodal prices with respect to generating unit offer prices on the nodal prices and (ii) application of the method on simple and real wholesale balancing power market case studies. The dependence of the nodal prices on the matrix may cause the exploitation of the market by the companies that are characterized by large derivatives. In my opinion, the derivative analysis can be one of the methods for understanding the market power phenomenon. Moreover, it can be used for market power screening.

2. State of the art

Market power, and its screening and mitigation for power markets are widely discussed in literature. Market power according to Mas-Collel et al. (1995), is "the ability to profitably alter prices away from competitive levels". According to the other definition in Aba Section of Antitrust Law (2005), market power is "the ability of a firm or a group of firms within a market to profitably charge prices above the competitive level for a sustainable period of time". According to the US Federal Energy Regulatory Commission (FERC) policy, both screening and mitigation are applied to render market prices just and reasonable. To obtain this goal, an appropriate methodology for these actions should be developed. As set forth in Asgari and Monsef (2010), the methods for market power detection are applied for the ex-post analysis of a situation that had existed in the market and in specific circumstances, for the ex-ante analysis of the influence of merges or fusions on further market behaviour.

A general approach to market power analysis, for the ex-post one, in particular, is based on indices (Asgari and Monsef, 2010; Bushnell et al., 1999; Kamiński, 2012; Twomey et al., 2006). A wide range

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of indices are described and applied in literature. The concentration ratio (CR) index is used for assessing the share of one, three, four, or six of the largest market partakers. The Herfindahl–Hirschman index (HHI) (Herfindahl, 1950; Hirschman, 1964) computes the sum of the squares of the market share for every market participant. The Gini coefficient (GC) measures the differences among participants' shares (Damgaard and Weiner, 2000). The Shannon–Wiener index (SWI) measures the diversities among the shares (Bhattacharyya, 2011). The pivotal supply index (PSI) takes into account the demand side and checks whether the participant is needed for meeting the demand (Bushnell et al., 1999). While the PSI index value is binary (0 or 1), the residual supply index (RSI) (Sheffrin, 2002) is continuous and may be used to assess the size of the unrealized demand. Both the PSI and RSI can be calculated for every hour in a year. The previously mentioned indices are structural ones, as they can measure the potential of the market power. On contrary, the Lerner index (Lerner, 1934) is a behavioural measure and provides information on the absolute difference between the unit profit and the market price, taking into account the marginal production costs.

A group of methods for market power screening based on market modelling using the game-theoretic approach is presented in Kamiński (2012). Game-theoretic models addressing the energy markets can be modelled using the Cournot, Bertrand, Stackelberg, Cournot with conjectural variations or the supply function equilibrium models. Agent-based simulation models can also be applied for analysing the power markets (Ventosa et al., 2005). These models are widely applied in literature. The paper (Kamiński, 2013) presents an in-depth analysis of the Polish wholesale energy market using the Cournot model with conjectural variations. The author refers to a takeover situation that was discussed in Poland and was finally blocked by the president of the Office of Competition and Consumer Protection. The model for the European energy grid analysis (ELMOD) is described in Leuthold et al. (2012). It analyses the decision of the nuclear power plant moratorium in Germany and its impact on the entire European energy market. The agent-based model for the Polish wholesale balancing energy market is used for analysing whether the retail electricity prices in Poland are to be deregulated (Pałka, 2011) or for assessing the consequences of the Bundestag decision regarding the nuclear power plant moratorium on the prices in Poland (Pałka, 2012).

Mitigation of the market power is also a significant issue in the process of energy balancing. The paper (Helman, 2006) presents an overview of the market power screening and mitigation methods that are applied to important power markets (New York, New England, Midwest, California, and PJM). These mitigation procedures are simple and are performed according to the common framework. The mitigation rules for economic withholding differ in terms of: (a) the trigger used to specify the set of generators, whose bids will be considered for mitigation, (b) the offer price limit before the generator's offer is considered for mitigation (a "conduct test"), (c) whether a market impact rule is used prior to mitigation (an "impact test"), and (d) whether a mitigated offer is set to a cost- or market-based reference price. The presentation of the methods for the mitigation of the market power in which the screening checks whether the whole group is necessary to provide the demand, is described in Kacprzak et al. (2010). The methodology is the application of the PSI index.

Despite the fact that several indices have been developed (see Table 1), the application of index analysis to complex, horizontally and vertically consolidated markets is doubtful. According to the analysis addressing the Polish wholesale energy market evolution within the 1997–2011 period, where the vertical consolidation process does not alter the value of the HHI index, the simulation analysis gives opposite results (Pałka, 2011). The results are intuitive because the HHI index does not take into account the vertical dependencies between the production and distribution sectors, while these dependencies do exist. However, during screening and mitigation simple procedures are used and the application of game-theoretic or simulation methods is beyond consideration. Therefore, a new market power screening method based on the properties of the optimal power flow (OPF) model, considering the groups' influence on the price is presented and discussed in the following sections of this paper.

3. Market model

The following assumptions are made: I take into account the trade on a wholesale balancing electricity market, in particular, the intraday market, with the ramp constraints. The demands are modelled as rigid offers. The flow of power in a grid and its allocation between the generating units are computed using the optimal power flow for direct current (OPF-DC) model (Stott et al., 2009). The nodal prices are set using the locational marginal pricing (LMP) model (Hogan, 1992). The transmission losses are neglected. A mathematical linear programming model is used owing to the ease in calculating the marginal prices.

Eqs. (1)–(7) form the analysed OPF-DC model. The power transmission grid is modelled as a graph, $G(V,E)$, where V is a set of nodes and E is a set of edges. Each node represents a location, where power can be injected or retrieved. Each generating unit and energy recipient (distributor) is associated with one of the nodes. Each edge in the graph corresponds to a transmission line connecting the two nodes.

Table 1
Limitations of the market power screening methods in brief.

Method	Market representation	Time horizon	Detail level			
			Supply	Demand	Location	Time
CR	Aggregated	Long term	Share	–	–	–
HHI	Aggregated	Long term	Share	–	–	–
GC	Aggregated	Long term	Share	–	–	–
SWI	Aggregated	Long term	Share	–	–	–
PSI	Aggregated	Short term	Share	Total	–	–
RSI	Aggregated	Short term	Share	Total	–	–
Lerner	Aggregated	Short term	Marginal price	–	–	–
Cournot	Market equilibrium	Short/mid/long term	Production	Total	–	–
Bertrand	Market equilibrium	Short/mid/long term	Production	Total	–	–
Stackelberg	Market equilibrium	Short/mid/long term	Production	Total	–	–
CSV	Market equilibrium	Short/mid/long term	Production	Total	–	–
SFE	Market equilibrium	Short/mid/long term	Production	Total	–	–
ELMOD	Algebraic equations	Short term	Offers	Offers	Plants, demand	Stage relationship
Derivatives	Algebraic equations	Short term	Offers	Offers	Plants, demand	Stage relationship