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The value of information in electricity investment games

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Abstract

In this paper we look at the assumptions behind a Cournot model of investment in electricity markets. We analyze how information influences investment, looking at the way common knowledge of marginal costs, expectations on the competitors' marginal costs, expectations on the level and duration of demand, and conjectures on the others' behavior, influence the value of a project. We expose how the results are highly dependent on the assumptions used, and how the investment Nash–Cournot game with perfect and complete information implies such a degree of coordination between players that the outcome of the game would be classified by any regulation law as collusive behavior. Furthermore, we introduce the concept of Nash Value of Complete Information. As an example we use a stylized model of investment in liberalized electricity markets.

Keywords: Cournot; Electricity; Investment

1. Introduction

With liberalization, the electricity industry changed from a regulated monopoly, vertically integrated, and managed as to maximize social welfare, to a complex system of interacting players in which each one of them attempts to maximize profit (within the limits of the new market rules, generally overseen by a regulator). Generally, the new structure of this industry has been designed to generate a self-sustainable system of interacting firms who are able to decide how much to generate in each hour, and how much to invest in order to guarantee the long-term sustainability of the industry.

Such an important change in the nature of the electricity industry came with a shift in the modeling tools used to analyze decision making. These tools evolved from the centralized optimization paradigm of the unit commitment problem and investment planning to the decentralized paradigm based on game theory, including Bertrand games (e.g., Bunn and Oliveira, 2003), supply function games (e.g., Green and Newbery, 1992; Anderson and Philpott, 2002) and Cournot games (e.g., Ramos et al., 1998; Borenstein and Bushnell, 1999; Bunn and Oliveira, 2007). The complexity of the new problems faced by the newly privatized industry has required the use of other techniques such as risk analysis (e.g., Fleten et al., 1997), real options (e.g., Frayer and Uludere, 2001; Botterud, 2004; Botterud et al., 2005; Bøckman et al., 2008; Dyson and Oliveira, 2007), agent-based simulation (e.g., Nicolaisen et al., 2001; Bunn and Oliveira, 2001; Son and Baldick, 2004; Guerci et al., 2005; Chen et al., 2006) and system dynamics (e.g., Larsen and Bunn, 1999; Dyner and Larsen, 2001), among others.

The Cournot model of imperfect competition has arguably been the most successful one, mostly due to its mathematical tractability and ability to represent well short-term problems. For example, it has been used to model inter-temporal decision making (e.g., Allaz and Vila, 1993) and geographical competition (e.g., Hobbs, 2001). Moreover, the Cournot model has been extended by the conjectural variations approach (e.g., Day et al., 2002; Song et al., 2003; Centeno et al., 2003b, 2007), in order to

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use it in practice. The conjectural variations method explains how the players' perceptions of the reaction functions of their opponents are important for the outcome of a game.

However, due to the lack of robustness of equilibrium models when applied to capacity expansion problems, imperfect competition is usually not used to study capacity expansion (Centeno et al., 2003a). For this reason, only a few game theoretical models of imperfect competition have looked at the investment problem (e.g., Ventosa et al., 2005) by using a Stackelberg (Ventosa et al., 2002) or a Cournot approach (e.g., Chuang et al. 2001; Pineau and Murto, 2003; Centeno et al., 2003a; Murphy and Smeers, 2005).

These models tend to rely on very strong assumptions regarding the information available to the players and their reasoning abilities. More specifically, games based on the concept of Nash–Cournot equilibrium rely on the basic assumption of common and complete knowledge of the structure of the game (payoffs, number of players, rules of the game). In these models it is assumed that all the players know all the payoffs associated with each decision (both for them and for their competitors). There is a complete and common knowledge of the other players' costs, profits and reaction functions.

The main advantage of these strong assumptions is the development of transparent and solvable models, which are indeed realistic for the analysis of short-term decisions such as spot and forward markets, bidding behaviors in auctions and short-term pricing policies. In fact, the assumption of complete information is not as questionable in short- and mid-term models as in long-term models. However, their usefulness in the context of investment in electricity markets is problematic, let us see why:

(a) In reality there is no complete knowledge of costs. Even though there may be a consensus around the merit order of the different technologies at a given moment, it is harder to defend that firms *agree* on the future costs. The Nash–Cournot models proposed so far for electricity markets assume that the firms agree on the level of marginal cost that should be used in the model, i.e., if a firm is modeling an investment it uses the same cost parameters (marginal costs) as the other firms in the industry.
(b) It is also difficult to argue that firms can agree on the expected level and elasticity of demand. Even though the level of demand in the short and medium terms can be forecasted with great accuracy, a very long-term forecast (over 30 years) is harder to be common knowledge of the industry. Moreover, the low elasticity of demand and the relatively small range of retail price variation make it hard to assume that there is a common knowledge of elasticity of demand. This elasticity tends to be based on guess work or, at the most, selected in such a way that the model produces acceptable outcomes (prices and levels of production).
(c) Common knowledge of reaction functions. It is assumed that everyone agrees on the conjectures a player holds on the other players' behavior. This means that the players tell each other how they perceive the other players will behave.
(d) From (a), (b) and (c) it is easy to conclude that a Nash–Cournot equilibrium implies a level of explicit coordination of behavior and information sharing between players that is not acceptable under any regulation law (see appendix for details).

The aim of this paper is to evaluate how these assumptions influence the way a firm values a project. More specifically, we want to analyze how important is the assumption of perfect rationality in models of investment. Within this framework we analyze how information influences investment, looking at the way common knowledge of marginal costs, expectations on the competitors' marginal costs, expectations on the level and duration of demand, and conjectures on the others' behavior, influence the value of a project. We relax these assumptions, one by one, and analyze how the main results of our analysis change. The results obtained in this study are for a very simple case (from Murphy and Smeers, 2005) which is enough for a qualitative analysis but of course cannot be used to obtain quantitative conclusions.

We show that, in games, complete information can have a negative value and that misinformation can have the same impact on consumer welfare as explicit collusion by generation companies. Sensitivity analysis also reveals that a small forecasting error in the long-term marginal costs can have a very significant impact on the technological mix of the industry, most particularly when it implies a change in the merit order of the technologies (the rank of technologies by generation cost). Similar conclusions arise from the analysis of the parameters relating to electricity demand, such as the level of peak demand and its duration. We show that the model is extremely sensitive to the level of demand and just a small change carries a very strong impact on the level of investment. This is particularly disturbing as this parameter cannot be estimated with any reasonable certainty: this implies that any long-term models of investment are dependent on an unknown parameter to which the model is very sensitive. The duration of peak demand has also a significant impact on the level of investment (again, this parameter is associated with high uncertainty).

The paper is structured as follows. In Section 2, we present a background on modeling investment in electricity generation and, more specifically, we introduce the simple investment game used in this paper. In Section 3, we present the concept of the Nash Value of Complete Information (NVCI). In Section 4, we present the computational experiments. Finally, Section 5 concludes the paper.

2. A dynamic investment game model for electricity markets

Following Murphy and Smeers (2005), we model investment in electricity markets as a dynamic Cournot