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An analysis of capacity and price trajectories for the Ontario electricity market using dynamic Nash equilibrium under uncertainty ☆

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Abstract

This paper studies investments in the Ontario Electricity Market which is currently being restructured. Our methodology is based on the concept of S-adapted open-loop Nash equilibrium. We examine the evolution of capital investments and pricing behavior of suppliers as uncertain electricity demand evolves over time (in Ontario). This study is particularly interesting since we compare the implications of two policies: (i) the current setting in which Ontario Power Generation (OPG) retains its generation units; (ii) the policy (set up in 2003) that required the divestiture of the largest supplier, OPG, and aimed to increase the number of independent suppliers in Ontario. We mainly focus on the independent generators like Bruce Nuclear. We use the tools of Stochastic Programming to compute the S-adapted open-loop Nash equilibrium market outcomes. We find that in the three-player market total capacity installation and market prices are higher than the ones in the five-player market. That is higher capacity may not necessarily alleviate exercise of market power. We also confirm the prediction by the National Energy Board that in a market with five major players, OPG's market share may reduce to a percentage between 35% and 40%.

JEL classification: C61; L94; L10

Keywords: Electricity markets; Capacity investment; Dynamic game; Uncertainty

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1. Introduction

This paper studies capital investment decisions in production of electricity in the Ontario wholesale market. In the Ontario context we consider stochastic equilibrium problems in which players have a significant stake in technology, and meet their production commitments by investing in a variety of technologies.

Our main goal is to analyze equilibrium predictions of capital investment decisions and price trajectories. In particular we focus on strategic behavior of independent generators NUGA and Bruce Nuclear and understand how they adjust their capital investment choices when the market share of Ontario Power Generation (OPG) possibly reduces. We study two cases in terms of number of suppliers: a three-player market and a five-player market. In Ontario, a five-player market is/was possible as a result of divestiture of the largest supplier OPG. Below we explain the reasons under which we consider two policies of the market structures. We will also focus on noncooperative Nash equilibrium rather than dominant firms with competitive fringe equilibrium. The former is relevant, because independent generators (e.g., non-utility generators, NUG) own gas-fired technologies, which are often price-setters. We will employ the S-adapted open-loop Nash equilibrium concept, which is more appropriate to handle dynamic games considered in this paper. The sensitivity analysis of this study also explores the roles of salvage value, depreciation rates and demand growth rates on the equilibrium predictions.

The formulation that we use is called 'games with probabilistic scenarios (GPS)', which is based on Genc, Reynolds, and Sen (2007) (hereafter, GRS). In the GPS setting the players make production and investment decisions based on collection of probabilistic scenarios. The trajectories (investment, production, price) will depend on the scenario that unfolds, and they will be required to obey a non-clairvoyance condition which states that decisions cannot depend on information revealed in the future. In contrast to the formulation provided in Haurie, Zaccour, and Smeers (1990), GRS adopt an equivalent scenario-based formulation. The resulting equilibrium conditions are easily applicable for problems with significant lags, and moreover, this formulation is amenable to solution methods for complementarity problems. This helps avoid recursive value function approximations which is the source of the curse of dimensionality in dynamic programming. GRS propose several oligopolistic dynamic games, including GPS. The paper by GRS is mainly devoted to demonstrating that stochastic programming (SP) provides a viable computational framework for extremely large dynamic games that are well beyond the scope of dynamic programming.

This paper takes the next step by addressing a realistic case-study arising from the turmoil of re-structuring the electricity market in Ontario, Canada (the home province of the University of Guelph). Whereas the GRS paper was methodological, this paper focuses on policy issues related to restructuring the Ontario market. This work adopts the same spirit as Pineau and Murto (2003), who study investment and production decisions in a medium time horizon in the Finnish electricity market. Their approach uses variational inequalities and the market is assumed to evolve along a sample-path adapted open-loop information structure. Furthermore, their modeling assumptions and structures are very different. Within the context of the GRS paper, the study of Pineau and Murto (2003) is similar to the model we refer to as Games with Expected Scenarios (GES of the GRS paper), where the players assume that the future will evolve according to some expected values, and a sample path is used to study the trajectory of investment and production decisions. In contrast, the GPS model presented in the GRS paper presumes that the firms are cognizant of uncertainty, and account for it within their decision-making process. Indeed, the GRS paper argues that GPS is the more tenable model, and we continue with this framework in the current paper.