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Dynamic oligopolistic games under uncertainty: A stochastic programming approach☆

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Abstract

This paper studies several stochastic programming formulations of dynamic oligopolistic games under uncertainty. We argue that one of the models, namely games with probabilistic scenarios (GPS), provides an appropriate formulation. For such games, we show that symmetric players earn greater expected profits as demand volatility increases. This result suggests that even in an increasingly volatile market, players may have an incentive to participate in the market. The key to our approach is the so-called scenario formulation of stochastic programming. In addition to several modeling insights, we also discuss the application of GPS to the electricity market in Ontario, Canada. The examples presented in this paper illustrate that this approach can address dynamic games that are clearly out of reach for dynamic programming, a common approach in the literature on dynamic games.

JEL classification: C61; C73; D43; L94

Keywords: Dynamic games; S-adapted open-loop equilibrium; Stochastic programming; Electricity markets

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1. Introduction

We consider stochastic equilibrium problems in which players have a significant stake in technology, and meet their production commitments by investments in a variety of technologies. For example, consider an electric power market consisting of a few players (suppliers), each of whom generates power using a variety of generators. These generators cannot be installed instantaneously, and as a result, investment precedes production by several months, and sometimes, even years. Under these circumstances, players make their investment decisions under uncertainty. The degree of uncertainty may depend on macroeconomic conditions as well as market-specific characteristics. The stochastic programming (SP) methodology is based on modeling alternative economic scenarios that may unfold in the future. For the sake of computational tractability, these scenarios are restricted to a finite set, and with each scenario one associates a non-zero probability of occurrence.

The focus of this paper is on the development of models that may be used to predict investment, production, and price trajectories associated with alternative economic scenarios that may unfold. However, these trajectories depend upon the behavior of the players. We will study three alternative behavioral assumptions. In the first formulation, the players make decisions based on collection of probabilistic scenarios, which we refer to as a game with probabilistic scenarios (GPS). Here the trajectories (investment, production, price) will depend on the scenario that unfolds; trajectories will be required to obey a non-clairvoyance condition which states that decisions cannot depend on information revealed in the future. In the SP literature, this condition is also referred to as the non-anticipativity requirement.

The second formulation we investigate is called a game with expected scenarios (GES) where investment decisions are based on an expected scenario (as though the world is deterministic). Once the investment decisions are made in a given period, one of the possible scenarios unfolds, and players make their production decisions in response to the specific scenario that unfolds. This type of behavior is not uncommon in some industries where the inclusion of uncertainty within an investment model leads to a very complicated and sometimes intractable model. For example in the electric power industry, one can invest in a variety of generators (nuclear, hydro, coal, gas, etc.) and the resulting capacity expansion models can be rather complex (e.g., WASP-IV, 2000; Murphy et al., 1982). Due to the difficulties associated with modeling uncertainty within a complex capacity expansion model, players may decide to replace the probabilistic scenarios by an expected scenario, thus leading to a GES game. Nevertheless, we recognize that since operation (generation) decisions are undertaken when better demand information becomes available (i.e. the scenario unfolds), the production game adapts to the scenario that unfolds. Finally, we study a third formulation which we call a hybrid game (HG) which combines features from the GPS and GES games.

There are a variety of types of non-cooperative equilibria for dynamic games. In this paper we focus on the *S-adapted open-loop equilibrium*. This equilibrium concept was introduced by Zaccour (1987), and Haurie et al. (1990). In such an equilibrium each player adopts a strategy that specifies its (production and investment) decisions for