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The investment timing game in petroleum production: An econometric model

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Abstract

This paper uses a structural econometric model to analyze an investment timing game that takes place during petroleum production. The model I develop enables one to estimate the structural parameters governing petroleum-producing firms' investment timing decisions and therefore to assess the net effect of the information and extraction externalities they face. The econometric methodology presented in this paper can be employed to analyze any problem of dynamic multi-stage strategic decision-making in the presence of externalities.

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1. Introduction

Petroleum production is a multi-stage process involving sequential investment decisions. When a firm acquires a previously unexplored tract of land, it must first decide whether and when to invest in the rigs needed to begin exploratory drilling. After exploration has taken place, a firm must subsequently decide whether and when to invest in the production platforms needed to develop and extract the reserve. Because the profits from petroleum production depend on market conditions such as

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the oil price that vary stochastically over time, an individual firm producing in isolation that hopes to make dynamically optimal decisions would need to account for the option value to waiting before making either irreversible investment [1].

The dynamic decision-making problem faced by a petroleum-producing firm is even more complicated when its profits are affected not only by exogenous market conditions, but also by the actions of other firms producing nearby. When firms own leases to neighboring tracts of land that may be located over a common pool of reserve, as they do in US federal lands in the Gulf of Mexico [2], there are two types of externalities that add a strategic dimension to the firms' investment timing decisions and that may render these decisions socially inefficient. The first type of externality is an *information externality*: if the firms gain information about their own tracts when other firms drill exploratory wells or install production platforms on neighboring tracts, then the firms may play a non-cooperative timing game that leads them to inefficiently delay production, since the possibility of acquiring information from other firms may further enhance the option value to waiting [2]. A second type of externality is an *extraction externality*: when firms have competing rights to a common-pool resource, strategic considerations may lead firms to extract at an inefficiently high rate [3]. Because these two externalities have opposing theoretical effects on the rate of production, empirical methods are needed to determine the net effect.

In this paper, I develop and estimate a structural econometric model of dynamic strategic decision-making in the presence of externalities, and apply it to the investment timing game in petroleum production. Estimates of the structural parameters of the model enable one to assess the net effect of the information and extraction externalities and to determine which externality dominates.

2. A model of the investment timing game

In my model, each "market" k consists of a neighborhood of adjacent tracts i that were all leased to petroleum-producing firms on the same date. For each market k, the state of the market t years after the leases began is given by a vector Ω_{kt} of finite-valued state variables that are observed by all the firms in market k and as well as by the econometrician.

Each firm's time-t investment timing decision depends in part on the state of the market Ω_{kt}, which can be decomposed into the endogenous and exogenous state variables. There are two endogenous state variables upon which investment timing decisions depend: the total number of tracts in market k that have been explored before time t, and the total number of tracts in market k that have been developed before time t. These endogenous state variables capture the strategic component of the firms' investment timing decisions. The exogenous state variables X_{kt} upon which investment timing decisions depend include the exploration cost c^e and the development cost c^d and are assumed to evolve as a first-order Markov process:

$$X_{k,t+1} \overset{\text{i.i.d.}}{\sim} F_X(\cdot|X_{k,t}) .$$