***A Structural Econometric Model of the Dynamic Game Between Petroleum Producers in the World Petroleum Market***

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## Overview

The current world energy consumption level is more than double what its level was in the 1970s and is projected to increase even further in the future. Forecasts estimate over 50 percent increase in world energy consumption over next 30 years. Even though Non-OECD countries are mainly responsible for this growth in consumption, the OECD members are also projected to experience significantly higher energy consumption.

Fossil fuels supply more than 80 percent of the energy consumed in the world. Oil and natural gas provide a large share of energy consumption and getting access to secure sources of oil and natural gas is of huge importance for any economy. The production and consumption of oil, natural gas, and shale raise concerns about climate change, fossil fuel price volatility, energy security, and possible fossil fuel scarcity. The impact of oil, natural gas, and shale on the future development of wind, solar, and other renewable energy sources is a concern as well.

In this paper we develop and estimate a structural econometric model of petroleum firms' strategic and dynamic exploration, development, production, merger, and acquisition decisions.

Among the questions that we address in this paper are:

* How do economic factors, strategic factors, and government policies affect the investment, production, merger, and acquisition decisions of a firm in the petroleum industry?
* How are investment, production, merger, and acquisition decisions of one energy firm influenced by the investment and production decisions of other firms?
* How do different government policies such as a carbon tax and production quotas affect the evolution of the oil and gas industry?
* How do changing geopolitical landscapes, such as the privatization of state-owned oil companies, affect the evolution of the oil and gas industry?
* How do changes in OPEC policy affect the evolution of the oil and gas industry?
* How do increased costs of mergers affect the evolution of the oil and gas industry?
* How do new technologies, such as new batteries for electric vehicles that may reduce the share of oil and gas in the energy market, affect the evolution of the oil and gas industry?
* How should government policies be designed to increase both the profits of energy firms as well as the benefits to consumers and society?

## Methods

The methodology we use is to develop and estimate a structural econometric model of the dynamic game among oil and gas producers. We apply this model to panel data on firm-level oil and gas exploration, development, production, mergers, acquisitions, and reserves along with data on oil and gas prices to study the behavior of the top 50 oil and natural gas producing companies.

We estimate the structural econometric model in two steps. In the first step, we characterize the equilibrium policy functions for the firms' decisions regarding exploration, development, production, merger, and acquisition as functions of state variables by using reduced-form regressions correlating actions to states. We also estimate the transition density for the state variables. In the second step, we use a simulation-based minimum distance estimator proposed to estimate the parameters which include the production profit parameters, the merger fixed cost parameters, the acquisition fixed cost parameters, and the selling value parameters. Since the expected value of the value function when a firm buys or merges with another firm enters into a firm's value function, we solve for the value function using a fixed point.

We use the parameter estimates from our structural econometric model to simulate several counterfactual scenarios to analyze the effects of government policies, such as a carbon tax and production quotas; changing geopolitical landscapes, such as the privatization of state-owned oil companies, changes in OPEC policy, and increased costs of mergers; and new technologies, such as new batteries for electric vehicles that may reduce the share of oil and gas in the energy market, on the oil and gas industry.

## There are several advantages to using a dynamic structural model to analyze the investment, production, merger, and acquisition decisions of petroleum-producing firms. First, unlike reduced-form models, a structural approach explicitly models the dynamics of investment, production, merger, and acquisition decisions. Second, our dynamic games model models the strategic nature of these decisions as well.

## A third advantage of the structural model is that with the structural model we are able to estimate the effect of each state variable on the expected payoffs from exploration, development, production, merger, and acquisition decisions, and are therefore able to estimate parameters that have direct economic interpretations. Our dynamic model accounts for the continuation value, which is the expected value of the value function next period. With the structural model we are able to estimate parameters in the payoffs from exploration, development, production, merger, and acquisition, since we are able to structurally model how the continuation values relate to the payoffs fromeach of these decisions.

## A fourth advantage of our structural model is that we are able to model the interdependence of petroleum-producing firms’ value functions. When a firm mergers or acquires another firm, the value of the other firm it merges with or acquires is given by that firm's value function, which is the present-discounted value of the entire stream of per-period payoffs for that other firm, and which accounts for the options that other firm has to explore, develop, produce, merger and/or acquire. Thus a firm's value function depends on the expected value of other firms it has the option to merge with or acquire. As a consequence, the firms' value functions are interdependent.

## A fifth advantage of our structural model is that we can use the parameter estimates from our structural model to simulate various counterfactual scenarios. We use our estimates to simulate the world petroleum market under counterfactual scenarios for government policy and economic development.

## Results

The production decisions of oil and gas producers are dynamic because petroleum is a nonrenewable resource; as a consequence, current extraction and production affects the availability of reserves for future extraction and production. The exploration, development, merger, and acquisition decisions of petroleum producers are dynamic because they are irreversible investments, because their payoffs are uncertain, and because petroleum producers have leeway over the timing of these investment decisions. Since the profits from these investment and production decisions depend on market conditions such as the oil price that vary stochastically over time, an individual firm operating in isolation that hopes to make dynamically optimal decisions would need to account for the option value to waiting before making these irreversible investments.

The decisions of petroleum-producing firms are not only dynamic but strategic as well. Petroleum producers consider not only future market conditions but also their competitors' investment and production activities when making their current decisions. Since the production decisions of other firms affect the prices of oil and natural gas, and therefore affect a firm's current payoff from production, and since the investment and production decisions of other firms affect future values of state variables which affect a firm's future payoff from producing and investing, petroleum-producing firms must anticipate the production and investment strategies of other firms in order to make a dynamically optimal decision. Uncertainty over the production and investment strategies of other firms is therefore another reason there is an option value to waiting before investing that makes the decision dynamic rather than static.

## Conclusions

## The results presented in this paper are of interest to academics, policy-makers, and business practitioners, including oil companies, alike.