ANATOMY OF A SHALE BOOM: THE ROLES OF LONG-LIVED CAPITAL, LEASING, AND PRODUCTIVITY DIFFERENCES

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Overview

The US shale boom was enabled by three key factors which are unique to the North American context: (1) private ownership of mineral rights by landowners, (2) a competitive oilfield services sector that owns long-lived capital required to develop resources, and (3) extremely low barriers to entry for heterogeneous E&P firms in markets for mineral rights. These factors are widely cited when prospects for non-US shales are discussed, but economists still have yet to incorporate them into a formal, economic model of a depletable resource to understand how each shapes the evolution of a shale boom.

Recent papers do address some of these factors separately, but none assemble a unified model of the three agents in a dynamic optimization context. The recent Anderson, Kellogg, and Salant (2014) paper modifies the classic Hotelling model of optimal extraction of a depletable resource to rationalize historical co-movements of price, drilling, and production. The model's simple production function, however, is unable to mimic the smooth ramp-up of drilling activity that has been observed in shale. While a number of empirical papers examine leasing in a static context (Brown et al., 2015; Herrnstadt et al., 2015; Timmins and Vissing, 2014; Vissing, 2015; Vissing and Timmins, 2015), dynamic models of optimal extraction leave out leasing. Instead they generally assume that the owner and exploiter of a mineral resource are the same. For large fields with a single owner this is not a problem, but in shale ignoring leasing leaves out an important set of agents (landowners) whose welfare is substantially impacted by mineral resources.

To understand how the three drivers of the North American shale boom mentioned above affect the evolution of a play, I add three elements to the Anderson et al. (2014) model. First, I add a competitive oilfield services sector that uses long-lived capital (rigs) and labor to drill wells. Second, I adapt the Acemoglu and Hawkins (2014) model of random matching and bargaining between multi-worker firms and labor to a leasing context. Third, I incorporate heterogeneity in firms' productivity and cost into the model, which leads to different sizes of lease-portfolios and rates of drilling. I calibrate the model to data on the Eagle Ford Shale from Drillinginfo and compare the model's results to historical data on the dynamics of drilling, production, leasing as well as costs and price.

After describing the problem faced by each agent, I characterize the equilibrium path in continuous time for two cases: physical exhaustion and economic exhaustion of resources. The model allows me to able to consider three important questions. First, what is the role of long-lived capital in smoothing out the boom-bust cycle? Second, in the absence of a centralized market, how are lease-prices determined and resource rents distributed? Third, how does the distribution of firms' productivity shape the cross-sectional distribution of lease-portfolio sizes and investment behavior?

Methods

Optimal control

Numerical simulations using parameters calibrated to the Eagle Ford Shale.

Results

Introducing rigs (capital) into the model contributes two important features. First, the relatively inelastic supply of capital equipment like rigs and pumping trucks functions as both a brake on initial drilling as well. This allows the model to mimic the smooth rise in drilling observed in the Eagle Ford Shale without resorting to ad-hoc "rush-to-drill" costs. It also helps sustain drilling when prices fall. With capital included, firms can fulfil the Hotelling rule that oil rents rise at the rate of interest by increasing the capital-labor ratio and pushing down short-run marginal costs over time. This mirrors what we see in practice where the presence of pre-existing capital reduces the lifecycle investment cost during later stages of development.

In the mineral-rights market, lease prices are determined by expectations about the path of Hotelling rents and lease-market tightness. Even when there is no uncertainty (and therefore no option value for leases), firms may purchase acreage they do not immediately drill because they can exploit landowners' opportunity cost of rejecting an offer and waiting for the next one. The possibility of such arbitrage is consistent with the rapid leasing of acreage in the Eagle Ford Shale and the delay between leasing and drilling we have seen empirically. In the model, when hydrocarbon resources are physically exhausted, leases are always all purchased—a leasing-analog to physical resource exhaustion. When resources are economically exhausted, leases are not always all purchased, which is economic exhaustion.

The fact that the development of shale has been dominated by smaller independent producers corresponds to low barriers to entry into the US market for mineral leases. The large number of producers has helped ensure markets are competitive and that the distribution of productivity is heterogeneous. In my model, firms pay a fixed cost of entry and then learn their productivity. A zero-profit condition pins down the number of firms, and preliminary results suggest that heterogeneity in productivity leads to different sized lease-portfolios.

Conclusions

To capture the three defining features of the North American shale boom, I incorporate long-lived capital, search in lease-markets, and heterogeneity in firms' productivity into a depletable resource framework. There have been recent advances in understanding the economic drivers of shale, and this paper's model helps to tie these elements together in a consistent way. In particular, the framework helps us better understand how and why resource rents are split between E&P companies, oilfield services, and private landowners, and it provides a way to model the economic forces that determine the dynamics of a shale boom. A model like this one will help analysts understand how institutions and economic factors—not just geology—will drive the evolution of shale in places beyond North America.

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