The Oil Supply Curve is Not Smooth with Agent Heterogeneity: Modelling Investment and Oil Production Decisions.

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Overview

Researchers from the Brandeis University, in collaboration with King Abdullah Petroleum Studies and Research Center (KAPSARC) are testing an agent-based oil supply model that explains oil market imbalances and price volatility. This research contributes to the literature on agent-based models (ABM and complexity) of economic systems, showing how heterogeneity, path dependency, and learning by agents can affect investment, production, and ultimately market prices – today and in the future. Our approach considers both the traditional VAR explanations (Killian, Hamilton, et. al.) of supply / demand shocks – exogenous and endogenous – and the longer standing Adelman empirical frameworks that incorporates the market structure / game theory behavior of major players. We argue that parsing the investment and production decisions of producers (agents) gives us the information to simulate the actions of key energy players with different costs, profit, and production objectives. The heterogeneity of oil agents' endogenous investment behavior results in lagged investment cycles and differential production patterns from fields throughout the world which, of course, leads to supply: demand imbalances and price volatility.

The underlying premise is that actions of heterogeneous agents can be modeled and that the differences matters. Producers throughout the world have different cost structures, fields ownership, reserves, lags, and profit expectations. This affects longer term production cycles and, of course, prices. The endogeneity of investment decisions based upon field data, combined with a variety of price expectation paths helps explain the dispersion of actual investment cycles (NPV estimates) that lead to varying production patterns (extraction and decline rates) in future years. The investment and production patterns of Saudi Arabia, other OPEC producers, and Russian is quite different from larger IOC deep water projects, or shale producers. The heterogeneity of oil producers' investment decisions matters when we model the oil supply curve. The investment, production, and cash flow actions of National Oil Companies, Independent Oil Companies and Shale producers, operating in fields with different costs affects oil supply curve and, of course, prices.

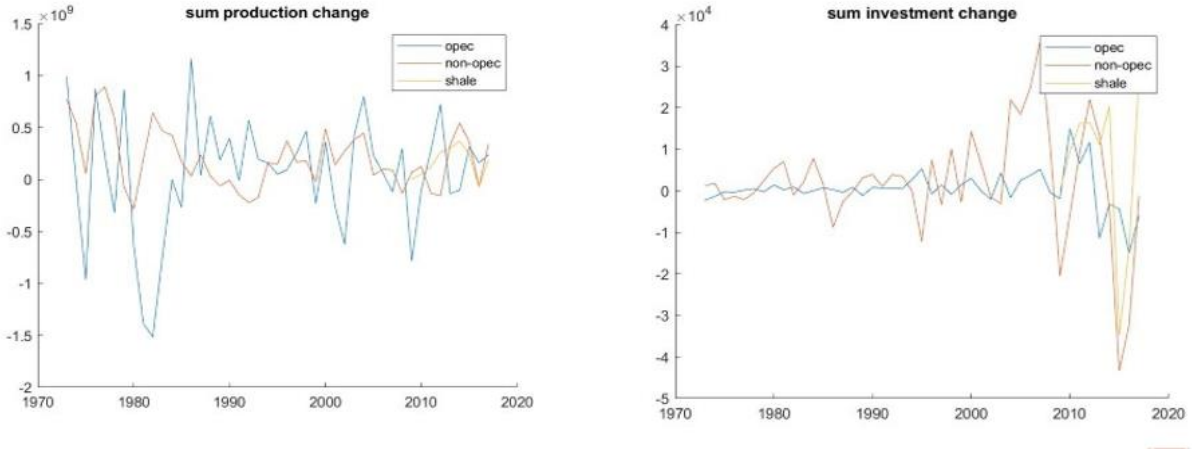
We use field level data to estimate a generalized agent investment functions derived from heterogeneous cost, reserves, lags, and profit expectations to explain the differences of oil production decisions of key agents; and their responses to changing market situations. It is our premise that a simple profit maximizing function, or field production assumptions, do not explain the varying investment decisions of our generalized energy agents. Agents learn and respond to each other and market conditions. We also recognize that there are many factors beyond field level data affecting investment decisions, particularly new climate policies, however modeling heterogenous agent supply curve reveals why supply:demand oil market imbalances are not necessarily surprises but a result of separate investment / productions decisions.

Method -- Changing characteristics: Investment, Production, lags, decline rate NPV of fields.

Not all oil and gas fields have the same characteristics and not all operators have the same profit or production objectives; and many producers face financial constraints. Many analysts use traditional competitive market assumptions to model investment and production decisions of independent operators (NPV) while others try to glean the actions / production of key players (oligopolistic competition). We look at a combination of probabilistic factors -- capex costs, estimate reserves, lags, decline rates, price expectations and NPV estimates -- using field level data, to derive heterogeneous investment functions for generalized energy agents operating over different time horizons, with variable market power.

1. We know that investment, production, and breakeven costs are divergent, cyclical, and volatile across geography and fields (see figure below). The challenge is how to explain and derive investment decisions and then production levels for different regions and operators across to the world – heterogenous oil suppliers. We show how field level data and price / profit expectations explains investment cycles. It is no surprise that other factors drive investment and production decisions, nonetheless, we can explain the cyclicality of agent investment decisions and production changes from field data.

AGENTS HETEROGENEITY



As seen in the Figure above the heterogeneity of our generalized agents' investment / production actions across the world is based on geography and resource characteristics (North American/Shale, Middle East/OPEC, Non-OPEC producers). Regions, fields, and operators define the decisions of our first set of agents; then, when the generalized model specification explains investment behavior, we can delve into finer levels of agent differentiation. There are, of course, different historical periods (OPEC through 1970s, Iran-Iraq war, followed by oversupply in the 1990s, post 2001, and the 2008 boom / bust) that affect investment / production cycles and expectations / surprises (Kilian, et. al.). Our focus is on testing the validity of agent-based model using simple behavioral statements (parameters) to simulate investment and production patterns across operators-- OPEC, Non-OPEC, and Shale agents -- to explain the changing oil supply curve and resulting price volatility.

2. We recognize that there much complexity in our energy system, whether we look at uncertainty in the field data we use to estimate models, uncertainty that the agents face when they form price expectations and make large, longer term investments, uncertainty in future demand, or uncertainty regarding individual agents' reaction to changing climate / political policies. Our agent-based supply model allows us to deal with a wide range of investment decisions by describing generalized probabilistic agent decisions using the following rule format:
Questions

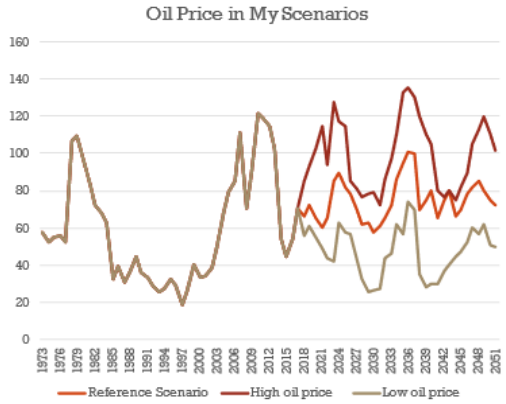
IF *price* IS *high* THEN *my-investment* IS *high*
IF *cash-flow* IS *low* THEN *my-investment* IS *low*
IF *expected-demand* IS *high* THEN *my-investment* IS *high*

We use this common language framework to describe the more probabilistic investment rules and estimate specific agent behavioral statements to show how agents interpret field and market variables (e.g., high price could be anything above 120% of producers' cost, which will vary by producer). Using this granularity, we are then able to calibrate investment actions by agents separately and show how investment / production rules replicate actual decisions at different points in time. This agent-based modeling approach allows for more human interpretation / interactive responses to changing perceptions and risk assessments of each player in oil supply market. Again, we want to show that differential investment behavior of agents affects the oil supply curve.

Results

Our preliminary results show that the differing characteristics of regional-fields matter – endogenous agent decisions regarding investment, lead-time, and probability of success affect producer reactions to and expectations of prices and supply-demand balances. Our model helps explain the boom-and-bust investment cycles due to field costs and price expectations. In other words, the actions of agents across regions and the heterogeneity of investment / production decisions generate oil market cycles, surprises, and market imbalances. Or price volatility and cycles in response to investment and production decisions (see graph / slide below).

RESULT 1: ENDOGENOUS CYCLE SCENARIOS



- To construct the demand scenarios, I use Killian's index of real global activity as a demand proxy
- The high scenario consists of a bootstrap with 75% of the being above the median– the low scenario consists of 75% below the median.
- We can expect an eventual increase in price from the suspended investment due to low prices –
- The price movement range might be more limited than the past due to shale oil – excess reserves for all agents

The purpose of this research is first to unpack the complexity in the investment behavior of energy suppliers and to show how investment and production behavioral has changed over time (not a fixed NPV function). Second, to see how shifting agent investment behavior can be modeled in an agent-based framework to simulate market cycles.

We show that investment behavior is heterogenous across regions / agents. It appears that these endogenous cycles are largely a function of producer heterogeneity, lead-times, decline rates, costs, price expectations, and investment decisions and cash flow.

For the second objective, we believe that the rapid increase (decrease) in shale production changes the structural adjustment of oil supply, investment, and price volatility in a more complex matter (e.g., shorter lead times, finance constraints, and field development). However, the changing oil market dynamics involve the interaction of all producers / agents with different investment actions and production levels. More profit maximizing US shale oil producers operate differently than NOCs, or low-cost Middle East OPEC producers who are slowly diversifying their energy economies. Our model shows how agent actions / interactions alter the dynamics of oil supply curves.

Conclusions

Understanding the post-shale oil market requires that we include the uniqueness of the shale-oil investment / production process and specify the difference between shale-agents and traditional energy players. If cycles are endogenously generated due to production constraints (lags and declines), then the shale boom and shifting OPEC production quotas is not simply a result of technology, or supply shocks. We show how differentiating investment behaviour of agents is critical to deciphering the shape of our investment, production, supply curve and price cycles.

A multi-agent approach gives us the flexibility to model the heterogeneity of energy producers and to describe the differences in energy agent behaviours, production profiles, and company / country objectives. Such heterogeneity requires an increase in the modelling specification (in terms of data needs and agent behaviour). The agent-based structure lets us incorporate many players governed by different decision rules and probabilistic behaviors that can be described, modified, and evaluated as markets and situations change; as they always will.

Our agent-based model shows the importance of dealing with complexity in our energy systems, particularly now that we enter an era of climate related energy policies. Unpacking the heterogeneity of investment and agent behavior lets us see how endogenous actions affect market volatility and cycles. The model shows how the actions of agents, particularly shale and NOCs are critical, and that their investment decisions change the trajectory of supply curves and energy markets.

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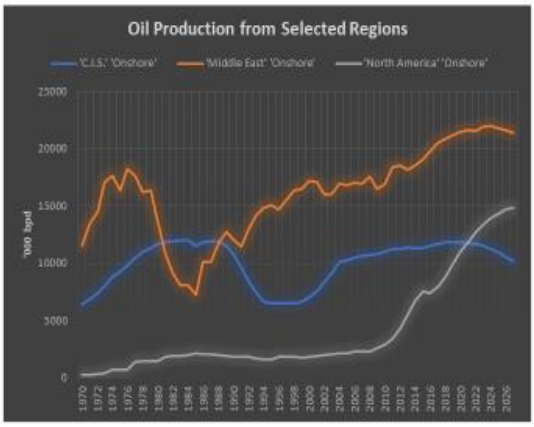
Appendix: additional data Investment and NPV estimates (author calculations)



Breakeven scatter