Modelling Complexity in Oil Markets: Post-Shale Cycles

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Overview

Researchers from the Brandeis International Business School, in collaboration with King Abdullah Petroleum Studies and Research Center (KAPSARC) are building an agent-based simulation model that encompasses the considerable scenario building efforts of Shell, et. al. on energy and climate models (Shell, BP, IEA, EIA, IPCC). This research contributes to the literature on the complexity of economic systems, showing how heterogeneity, path dependency, feedback loops, and learning by agents can dramatically alter the outcomes predicted by traditional (equilibrium) economic models (e.g., how NOC or IOC agents react to shale production and drilling rig activity). It also provides scenario-analysis tools to model the dynamics of energy markets and the transitions from oil and gas production fields (regions) using historical data.

The underlying premise is that an agent-based model that uses a flexible structure can simulate market interactions and explain the role of various players in energy cycles and surprises. In other words, the actions of agents matter – the changing behavior and heterogeneity of players such as National Oil Companies, Independent Oil Companies and Shale producers, affect energy supply dynamics. An agent-based approach enhances our understanding of the data-rich general equilibrium scenario models that employ a more fixed econometric structure. It allows us to run many "what if" simulations by changing our common language assumptions (e.g. behavior rule: invest more in shale if prices are high/over $50 a barrel; expand low cost oil & gas fields if expected demand is peaking in five years) without re-estimating underlying relationships. By using summary data and behavioral relationships derived from scenario models and our general understanding of market players, particularly shale producers, the agent-based framework looks at, and simulates, the fuzzy behavior of different players (producers) operating across today's markets. Fuzzy embraces rules that describe the ambiguity in perception/uncertainty of market players (agents).

We use an agent model to analyze how shale oil producers entering/exiting the market change investment and price cycles. We show that shale producers' larger decline rates and short lead times can alter the pattern of these cycles significantly. Further, the incorporation of shale oil producers may either lead to a significant increase in prices in the long run or significant decline, depending on the competitive behavior, and reaction, of other producers.

Methods

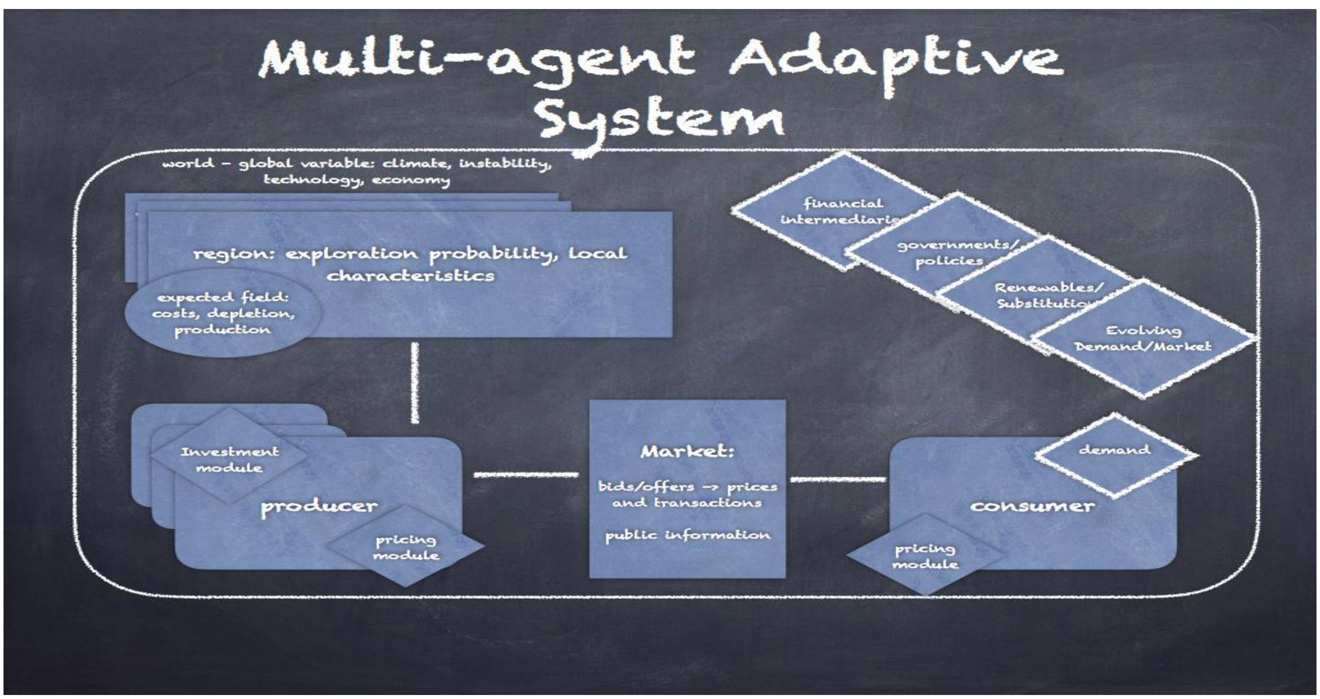

Figure 1: Modular Structure of Agent-Based Supply Model

The agent-based approach is based on two principles:

1- Allows for heterogeneity and flexibility in describing the energy system. This is accomplished by using a modular-approach (Figure 1). The different components and actors are modelled separately as agents/world objects with set rules for interaction, this makes it easier to switch on/off modules. For example, we can change the number of consumer agents and their demand rules to incorporate substitution into other sources of energy when prices are high. Such modification of consumer agents does not require us to modify the behavior or programming of producer agents (unless we want to add “reaction” rules to take substitution into account).

2- There is a large amount of uncertainty in the energy system, whether this involves uncertainty in the data we use To estimate the model, uncertainty that the agents face when describing price expectations and investment decisions, or uncertainty about the modeled behavior of individual agents. The fuzzy logic approach allows us to deal with a wide range of uncertainty by describing each agent using the following rule format:

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*

This allows us to describe many rules easily, and then the fuzzy logic module will let us determine what the variables mean (e.g. high price could be anything above 120% of producers’ cost, which varies by producer) and then allows us to weight the rules accordingly. The module structure lets us put variable weights for each agent; e.g. one producer can interpret price to be (0.7 high) and expected-demand to be (0.4 high), giving a weight to the output decision and investment to be (0.6 high). Others will have different weights and perceptions. This approach allows for more human / interactive responses to varying perceptions and risk assessments.

As seen in Figure 1, we model different regions of the world based on location and resource characteristics (North-America/Shale, Middle-East/On-Shore, etc..) and assign regions to agents. For each period agents determine investment, bargain with each-other and observe changes in price and supply/demand equilibrium. The parameters describing the agents are taken from various data estimates when possible or hypothesized. The rules use a search algorithm that estimates rule parameters that more or less match real-world variables (supply and demand volatility, price volatility etc..). Finally, we plan to test different scenarios to examine the effect of heterogeneity of production on energy system cycles and test for various scenarios with/without the introduction of shale producers.

Results

Our preliminary results show that the differing characteristics of regional-field producers (agents) matter -- such as depletion/lead-time and exploration-success probability – along with producer reactions to prices and inventory (investment); we can explain and replicate the boom and bust cycle due to over and under-supply. In other words, the actions of agents across regions and the heterogeneity of production generate endogenous market cycles [Figure 2].

The purpose of this paper is two-fold; first to show that incorporating the complexity in the energy supply system (mainly through feedbacks and heterogeneity of agents, such as shale and NOCs) has a considerable impact on the modelling results and significantly affects cycle dynamics (in contrast to general equilibrium models, surprise/shock analysis, or situations where producers can ramp up production quickly). The second objective is to use this model to analyse the structural shifts in the market due to the varying characteristics of shale production and individual agents.

Regarding our first objective, we show that using a comparatively small number of rules and limited data (which we are expanding) that we can match the cyclicality of the real-world energy markets over the past twenty years. It appears that these endogenous cycles are largely a function of producer heterogeneity, lead-times, decline rates and investment. In other model simulations, the cyclicality almost disappears when lead-times are removed from certain production regions; and they change dramatically when we add different oil field resources (e.g. shale oil).

For the second objective, we show that shale production does bring about a structural shift in supply volatility and price regimes. This shift depends on the producer/agent behavior - should shale oil producers learn to behave in a more restrained manner, they could help increase prices in the long-run by reducing periods of over-supply through their higher decline rates [Figure 3]. The opposite is true should they over-compete for market-share with other producers. The model shows that agent actions / interactions and learning matter a great deal.

Continue to UPDATE graphs and analysis for September IAEE presentation

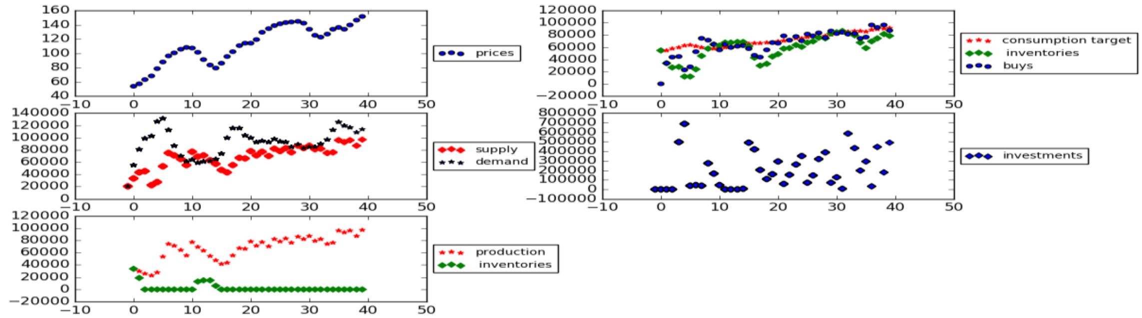

Figure 2: Endogenous Cycle Creation in Agent-Based Model

Figure 3: (Left) price cyclicality without shale producers (right) with restrained shale producers

Conclusions

Understanding the post-shale oil market requires that we include the uniqueness of the shale-oil production process and specify the difference between shale-agents and traditional market players. If cycles are endogenously generated due to production constraints (lags and declines), then the shale boom is not simply a result of technology, or supply shocks. We show how shale has shifted the parameters of producer constraints and may fundamentally change the shape of those cycles.

A multi-agent approach gives us the flexibility to model the heterogeneity of energy producer markets 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 Fuzzy Logic formulation allows us to deal with the problem, as large numbers of behaviors can swiftly be described, modified and evaluated by experts using linguistic rules as opposed to equations.

The modelling exercise shows the importance of dealing with complexity in our energy systems. For oil supply, the introduction of shale probably has a significant, and variable, effect depending on the behavior of other producers. Shale agent behaviour has disrupted energy markets and is changing longer term production decisions and oil prices.

This is a multi-party research initiative to design, implement, and test the flexible/modular modelling tool for the energy market, energy participants, and policy makers. The model shows how the actions of agents, particularly shale and NOCs are important, and that their actions may change the trajectory of energy markets.

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