Modeling Complexity in Energy Systems: A Fuzzy Logic Approach

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Overview

In this paper I attempt to deal with some of the shortcomings in traditional energy models, specifically 1- energy systems exhibit a high level of complexity due to lags, feedback effects and hetregeneity among different actors 2- they exhibit a high level of uncertainity and ambiguity, complicating those actors' behaviors. By combining a multi-agent modelling approach with a fuzzy logic rule system for describing agent behaviors, the fuzzy logic rule system allows for describing agent behaviour using simple "IF-THEN" rules which simplify the modelling process and has greater tolerance for uncertainity and ambiguity in the rule formulation. I apply this to the case of oil producers and consumers to examine the feasibility of the model. The results show that a fairly small amount of rules can describe much of the cyclicality in the oil market, and that the effect of shale oil producers entering the market with their larger decline rates and short lead times can change the pattern of these cycles significantly. Further, the incorporation of shale oil producers can either lead to a significant increase in prices in the long run or significant decline, depending on the competitive behaviour of those producers.

Methods

The approach is based on two principles:

1- Allowing for hetregeniety and flexibility in describing the energy system. This is accomplished using a modular-approach (Figure 1). The different components and actors are modelled seperatly 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 substituting into other sources of energy when prices are high, such modification of consumer agents will not require us to modify any part of the programming of producer agents (unless we optionally want to add rules to take substitution into account).

2- There is a large amount of uncertaintity in the system, whether this includes uncertainity in the data we use to model, uncertainity that the agents face when making expectations and decisions, or uncertaintity about the proper behaviour to model for the agents. The fuzzy logic approach allows us to deal with this 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 a large number of rules easily, and then the fuzzy logic module will also deal with determining what the variables mean (e.g. high price could be anything above 120% of producers' cost , which varies by producer) and weight the rules accordingly, noting that the module places variable weights on interpretation e.g. can interpret price to be (0.7 high) and expected-demand to be (0.4 high), giving a weight to the output decision in investment to be (0.6 high), thus allowing for more human-like responses to conflicting factors.

As seen in Figure 1, we model different regions of the world based on location and resource type (North-America/Shale , Middle-East/On-Shore etc..) and assign regions to agents, at each period agents determine investement, bargain with each-other and observe changes in price and supply/demand equilibrium. The paraamters describing the agents are taking from various estimates when possible or hypothesized, while the rules are set using a search algorithm that determines which rules result in matching real world variables (supply and demand volatility, price volatility etc..). Finally we test different scenarios to examine the effect of hetregeniety in production on overall system behaviour and test for various scenarios with shale producers being introduced in the system.

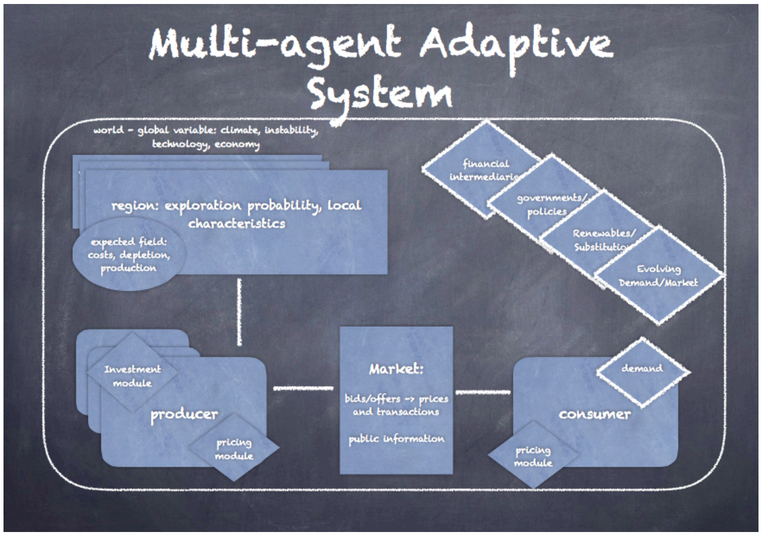

Figure 1: Modular Approach to Building a Multi-Agent Energy System

Results

The purpose of this paper was two-fold, the first is to examine the feasibility of a modular multi-agent modelling approach using fuzzy logic rules to describe energy systems, and the second to examine whether taking into account the complexity in the system (mainly through feedbacks and hetregeniety) has significant bearings on the overall modelling result such that they need to be taken into account.

On the first objective, we show that using a comparatively small number of rules and lmited data (which we aim to expand later on) we can match some of the historical cyclicalty patterns in the real-world endogenously. On the second, we see that these endogenous cycles are mainly a function of hetregniety, lead-times and decline rates. The cyclicality almost disappears when lead-times are remved from the production regions, and they change dramatically when adding different kinds of oil resources (e.g. shale oil). Figures 2 show some examples, of particular note is that should shale oil producers behave in a more restratined manner, they could help increase prices in the long-run by reducing periods of over-supply through their higher decline rates. The opposite is true should they over-compete for market-share with other producers (not shown).

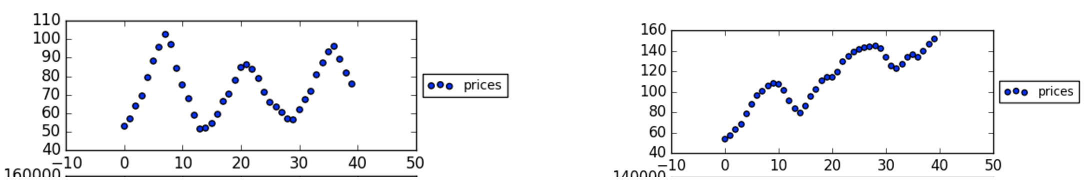

Figure 2: (Left) price cyclicality without shalre producers (right) with restrained shale producers

Conclusions

One benefit of using the Fuzzy Logic formulation is that the model can be swiftly be modified and evaluated by experts since it is based on linguistic rules as opposed to equations approach. The modelling exercide shows the importance of dealing with complexity in modelling energy systems, that for the case of oil supply the introduction of shale can have a very significant effect which varies greatly depending on the behaviour of the producers. This approach has the potential to be used as a scenario evaluation tool which can be validated at the micro and macro level both empirically and through expert evaluation of the rules and paramteres which has added transperancy through the use of linguistic rules and variables. The modular design allows the addition of various modules and actors such as multiple energy sources, government policies and financial markets.