An Agent-based Modeling Approach to Non-equilibrium Dynamics Of Natural Gas Supply Shock Propagation

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37th Annual IAEE Conference, June 16, 2014
Presentation Overview

• Model Development
  • Gas Allocation Model (GAM, an existing network model) – short term disruption, find equilibrium “stress” levels
  • Natural Gas System Model (NGSM) – long term systemic shock, understand system dynamics. Agent-Based Network Model.

• NGSM Model Calibration
  • Individual nodes: supply, demand, pipeline capacity
  • Market partition into sub-markets

• Results
  • (Sub)-market equilibrium price
  • Effects of additional demand, such as LNG

• Future Work
  • Add in heterogeneous agent behavior
  • Explore agent interactions and emerging behaviors
GOALS and APPROACH

GOAL: Understand the long term evolution of the Natural Gas (NG) system

• Create dis-equilibrium model of the NG system evolution
• Understand the system transition to new steady state

APPROACH: Agent-based modeling (ABM) on networks

• Represent agents behaviors and drivers of system evolution
• Calibrate to real-world data
High Level NGSM Description

System changes: LNG, GTL

System adaptation

More supply

NG network dynamics

+ New supply

+ New demand
What Is Agent-Based Modeling?

• ABMs are used for representing complex real-world systems

• Agents are autonomous decision-making entities

• Agent interactions are situated in appropriate environment and interaction structure.
  • Agents produce, consume, trade securities, ship freight, and so forth.

• The dynamics of systems emerge from large numbers of interactions among heterogeneous agents.
NGSM Scenario Example

- **Industry Effects**
  - Transportation
    - LNG HD Vehicle
    - GTL
    - Compressed NG
  - Industry
    - NG -> Electric Power
    - Chemicals
    - Manufacturing
    - Heat

- **NG Effects**
  - NG Price
  - NG Supply
  - NG Pipeline Network

Affects economics of GTL and other NG uses
Affects economics of transportation and industrial uses
Highlights of our Approach

• Combine future projections, detailed system data, and agent-based behavior to produce an agile modeling tool
• Behaviors will be real-world and data-driven, rules of thumb, and agent learning
• Use heterogeneous behaviors of agents to tease out emerging behaviors or unexpected consequences
• **Goal:** evaluate the effects of system operator and regulator decisions and system shocks and constraints to inform strategy and policy options
NGSM Data Calibration

- Calibrated to GPCM (commercial software, created by RBAC) data released in Q1 2014
- Demand Nodes and curves
  - 660 demand nodes: Generation, Industrial, Consumer
- Supply nodes and curves
  - 102 supply nodes: Conventional, Shale, CBM
- **Result**: increase fidelity/confidence of our NGSM model
Model Calibration

Data

Compare

Predicted output

Data for calibration

Calibration:
- Optimization
- Learning

Serve as a basis for calibration

Create calibrated model

Run Model

NGSM Agent-Based and Theoretical Model

NGSM Calibrated model
Sub-Market Price Determination

• Find an equilibrium price for supply and demand on the aggregate NG network
  • Initially with no storage or seasonality
  • Then incorporate monthly data (seasonality)
• If equilibrium price cannot be achieved, split the aggregate market into sub-markets
  • Sub-market own price
• **Outcome**: Use Edmonds-Karp algorithm to determine the max-flow on the network for a given equilibrium or sub-market price
Edmonds-Karp Algorithm Application to NGSM

- Production or consumption numbers are used by Edmonds-Karp Algorithm to determine assignments of flows to appropriate pipelines.
- If any pipeline is at max-capacity, then global market equilibrium price cannot be achieved.
- **Solution**: Split the network into sub-networks, known as sub-markets, repeat as needed.
# Results – Equilibrium Price

<table>
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<tr>
<th>Month</th>
<th>Base case Price (dollars per thousand cf)</th>
<th>Largest subnet</th>
<th>Additional demand Price (dollars per thousand cf)</th>
<th>Largest subnet</th>
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**Scenario 1:** Base case, no changes to the system

**Scenario 2:** Addition of LNG terminal at Sabina Pass at 15% of total system demand
In Summary

- **Adapted** an existing NG network model to our NGSM framework
- **Enabled** market price determination on a network and sub-networks
- **Developed** an ABM modeling framework to represent the effects of regulatory decisions
- **Conclusion:** Heterogeneous agent behavior is central to understanding the effects and unintended consequences of regulatory policy
Future work

• Future Work
  • Peer review of the model and the approach
  • Agent behaviors – actions, interactions, and emerging behaviors (partially represented)
  • New node types – LNG (partially represented), vehicle transportation, and chemical manufacturing
  • Seasonality – to increase variation in output and agent interactions
Thank you!
## NG Prices for Calibration

### Natural Gas Prices
(Dollars per Thousand Cubic Feet, except where noted)

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<tr>
<th>Area</th>
<th>Wellhead Price</th>
<th>Imports Price</th>
<th>By Pipeline</th>
<th>As Liquefied Natural Gas</th>
<th>Exports Price</th>
<th>By Pipeline</th>
<th>As Liquefied Natural Gas</th>
<th>Citygate Price</th>
<th>Residential Price</th>
<th>Percentage of Total Residential Deliveries included in Prices</th>
<th>Commercial Price</th>
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Source: EIA