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An Agent-Based Model of the U.S. Natural Gas Infrastructure: Analyzing Disruptions

Alexander V. Outkin,
with Walter E. Bayeler, Peter H. Kobos, David J. Borns, Melissa Myerly, Vanessa N. Vargas, Eric D. Vugrin

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U.S. DEPARTMENT OF ENERGY

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Project Overview

Goals

- Understand influences of new supplies of Natural Gas (NG) and growing demand on infrastructure
- Understand the long term evolution of the Natural Gas supply chain
- Create dis-equilibrium model of the NG system's evolutions
- Identify path dependencies and lock-in effects

Approach

- Agent-based Modeling (ABM) on networks
- Represent agent behavior, determine infrastructure effects
- Calibrate to data
- Develop scenario analysis
  - Base Case
  - High & Low Shale Gas Supply
  - LNG Exports Scenario

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Model History and Development

Model Development

- Gas Allocation Model (GAM) – Short term disruption, find equilibrium "stress" levels
- Natural Gas Systems Model (NGSM) – Long term systemic shock, building the Agent Based Model

NGSM Model Calibration - agent-level, aggregate, time-series

- Agent-level: supply, demand, pipeline capacity, storage
- Available real-world data: GPCM, RBAC software
  - 660 demand notes
  - 100 supply notes
  - 440 Storage nodes
- Aggregate: prices, production and consumption, storage levels
  - In progress. EIA.

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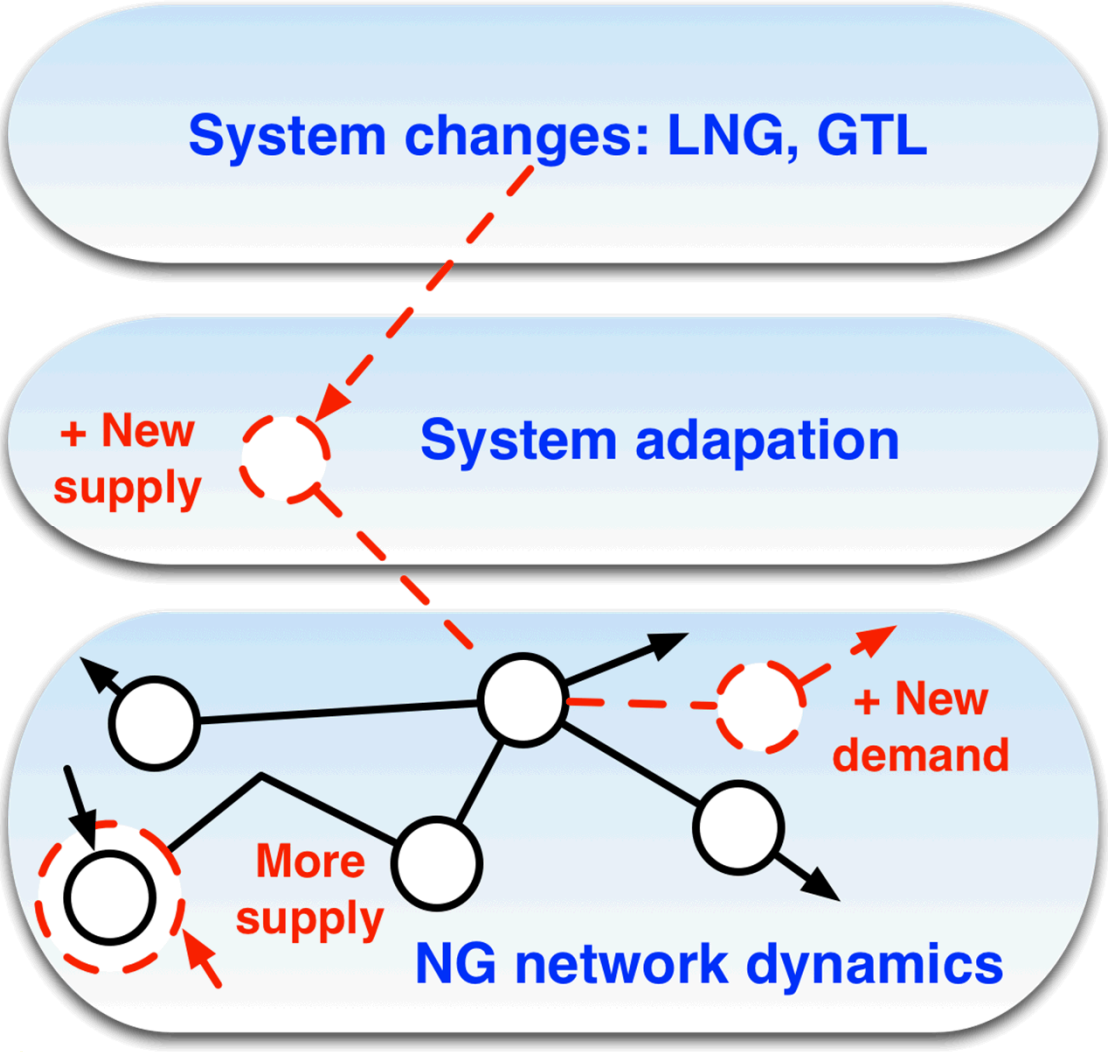
High Level NGSM Description



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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.

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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

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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

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Sub-Market Price Determination

- Find an equilibrium price for supply and demand on the aggregate NG network
  - Treat storage as independent supply-demand nodes
- 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

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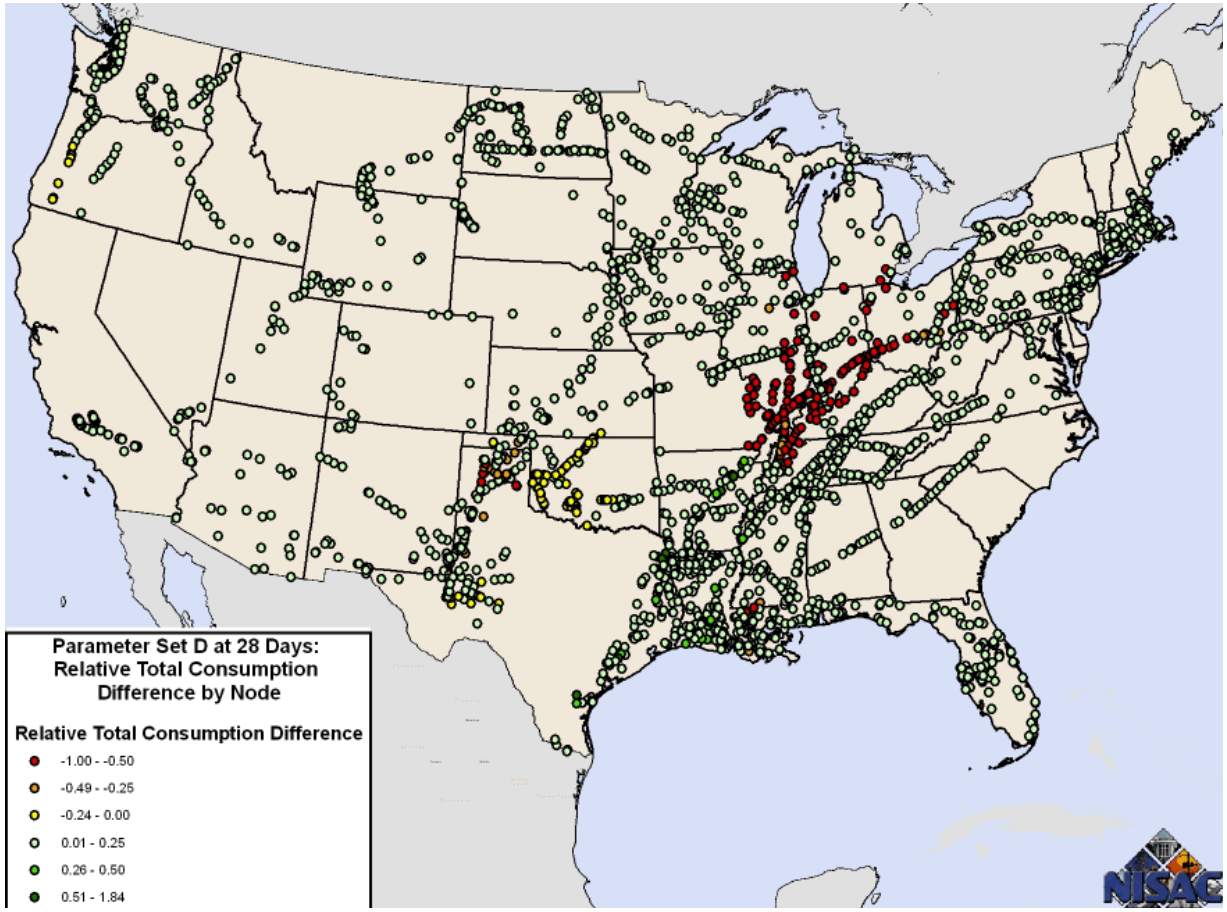
NG System Outline



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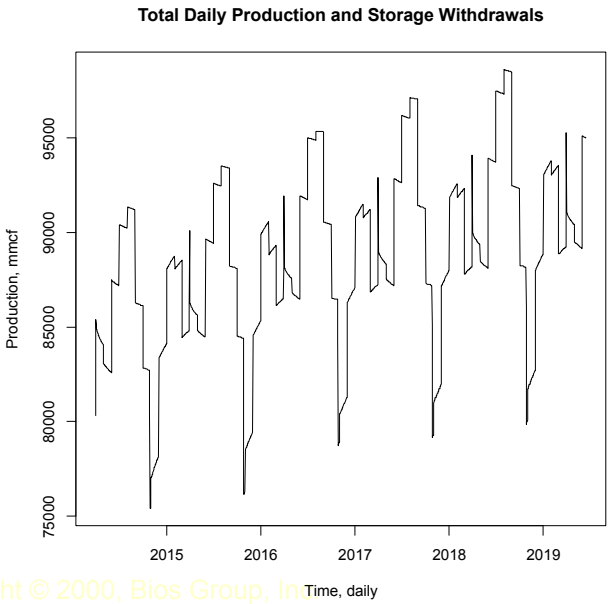
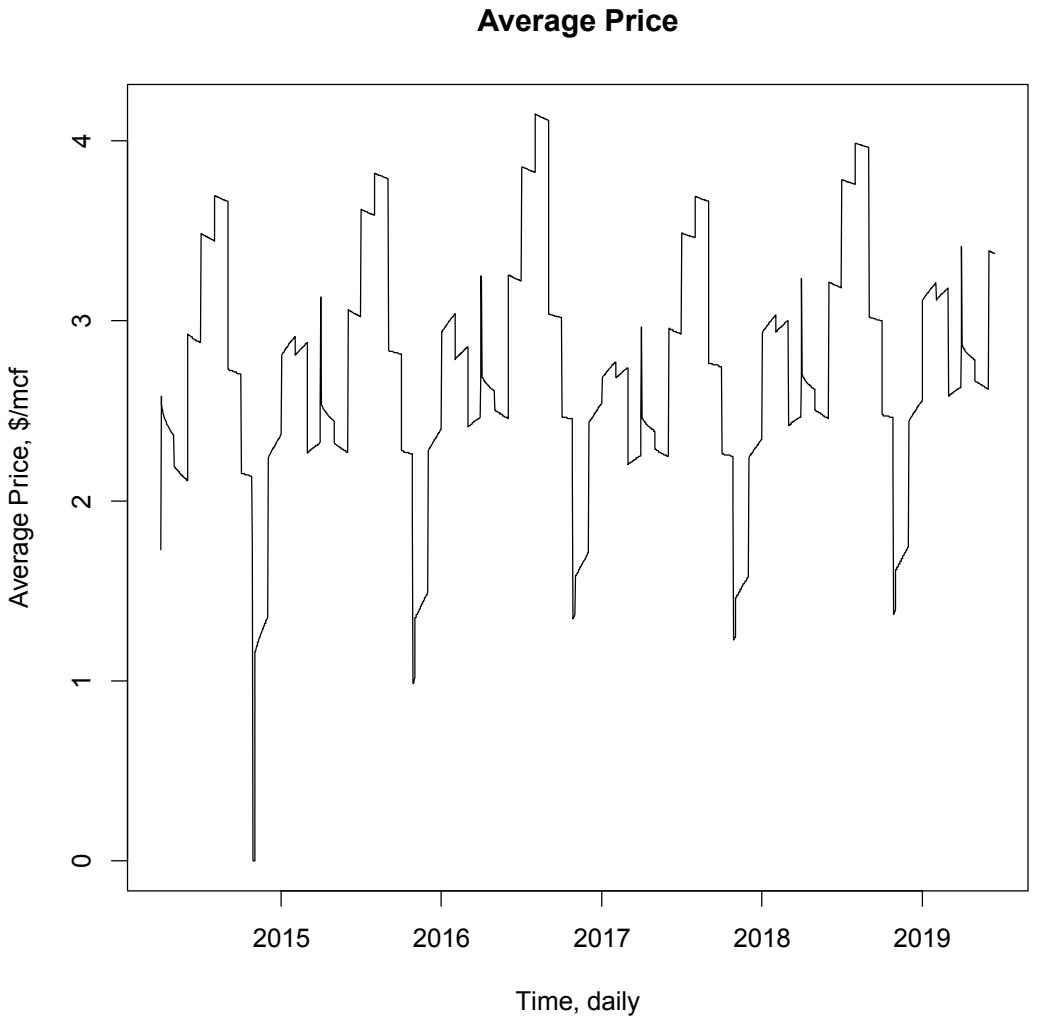
Preliminary Scenario Analysis: Base Case

- Represents GPCM data
- Consolidated Storage
- Endogenous Price Effects





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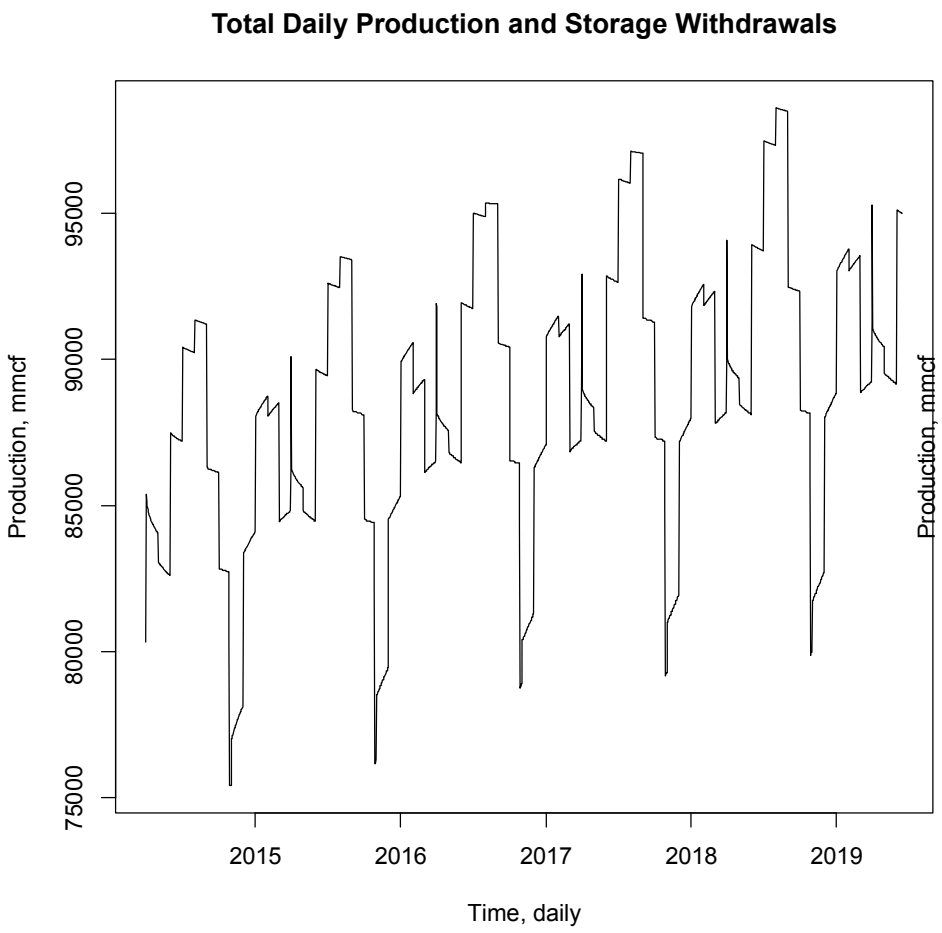
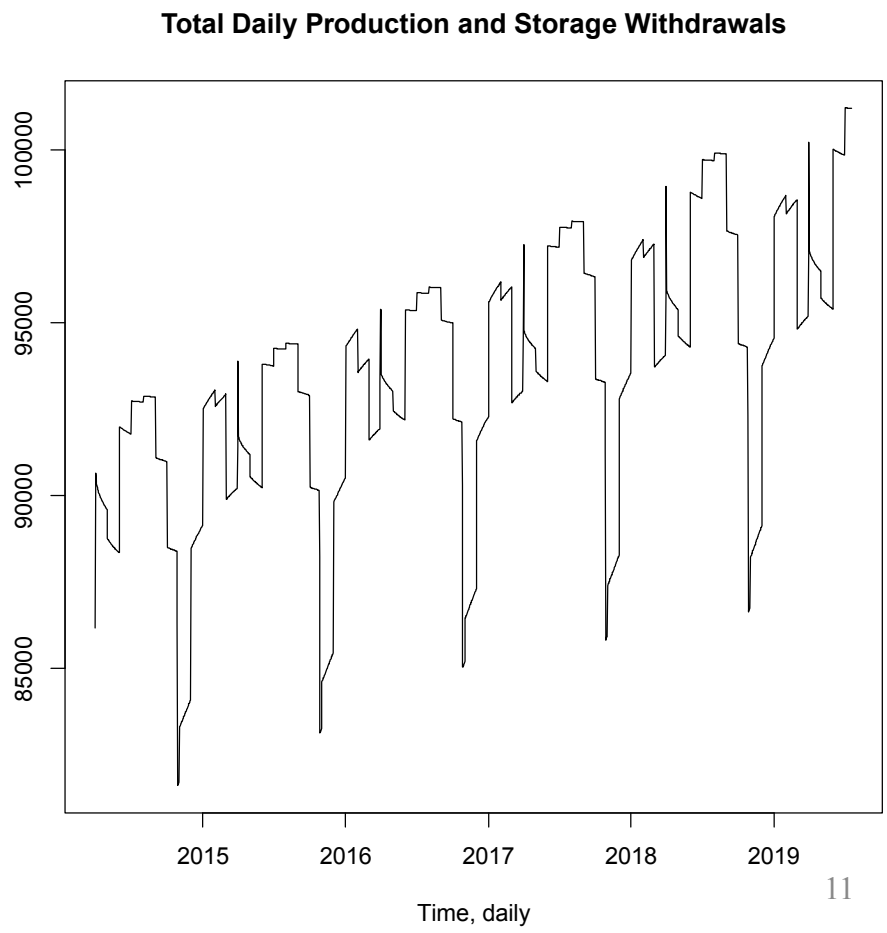
Preliminary Scenario Analysis: LNG Exports

Base



LNG



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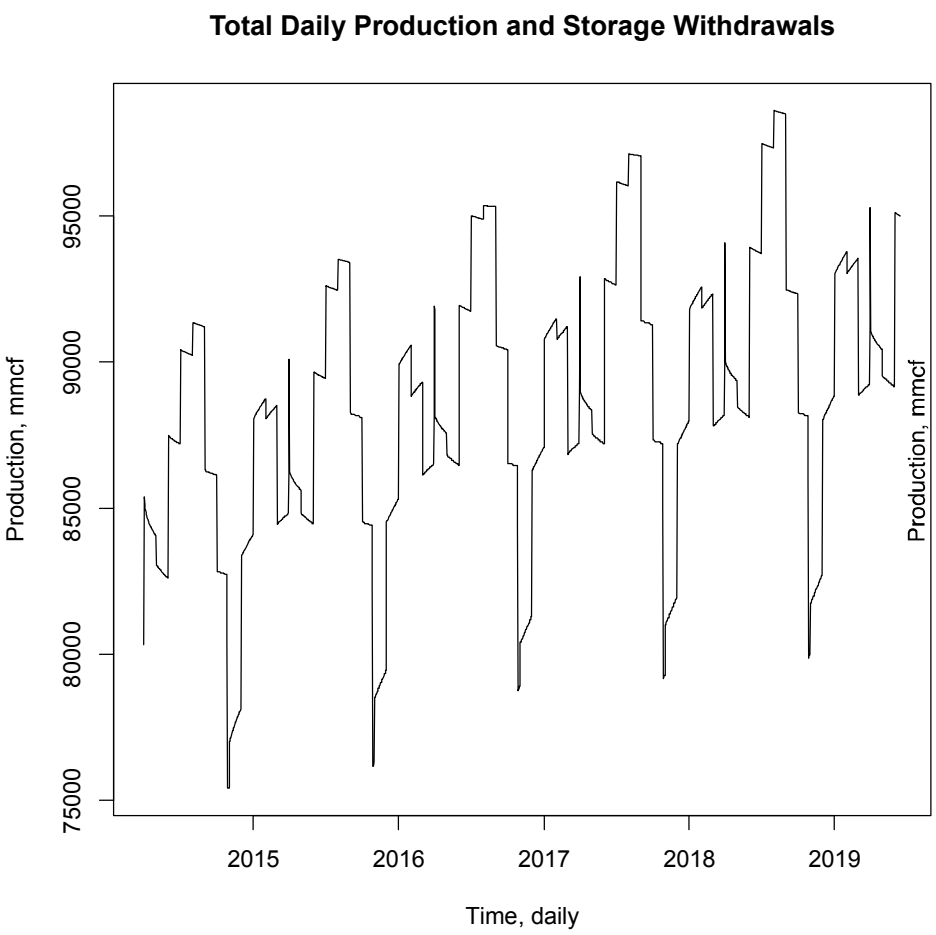
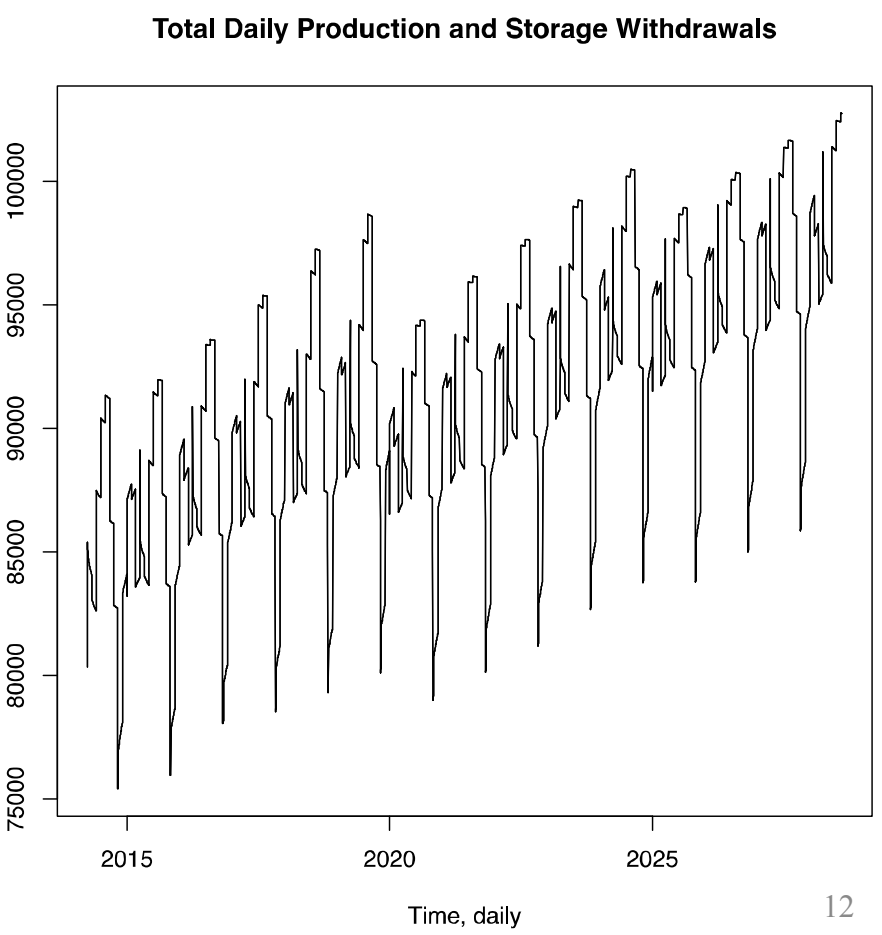
Preliminary Scenario Analysis: Low Supply

Base



Low



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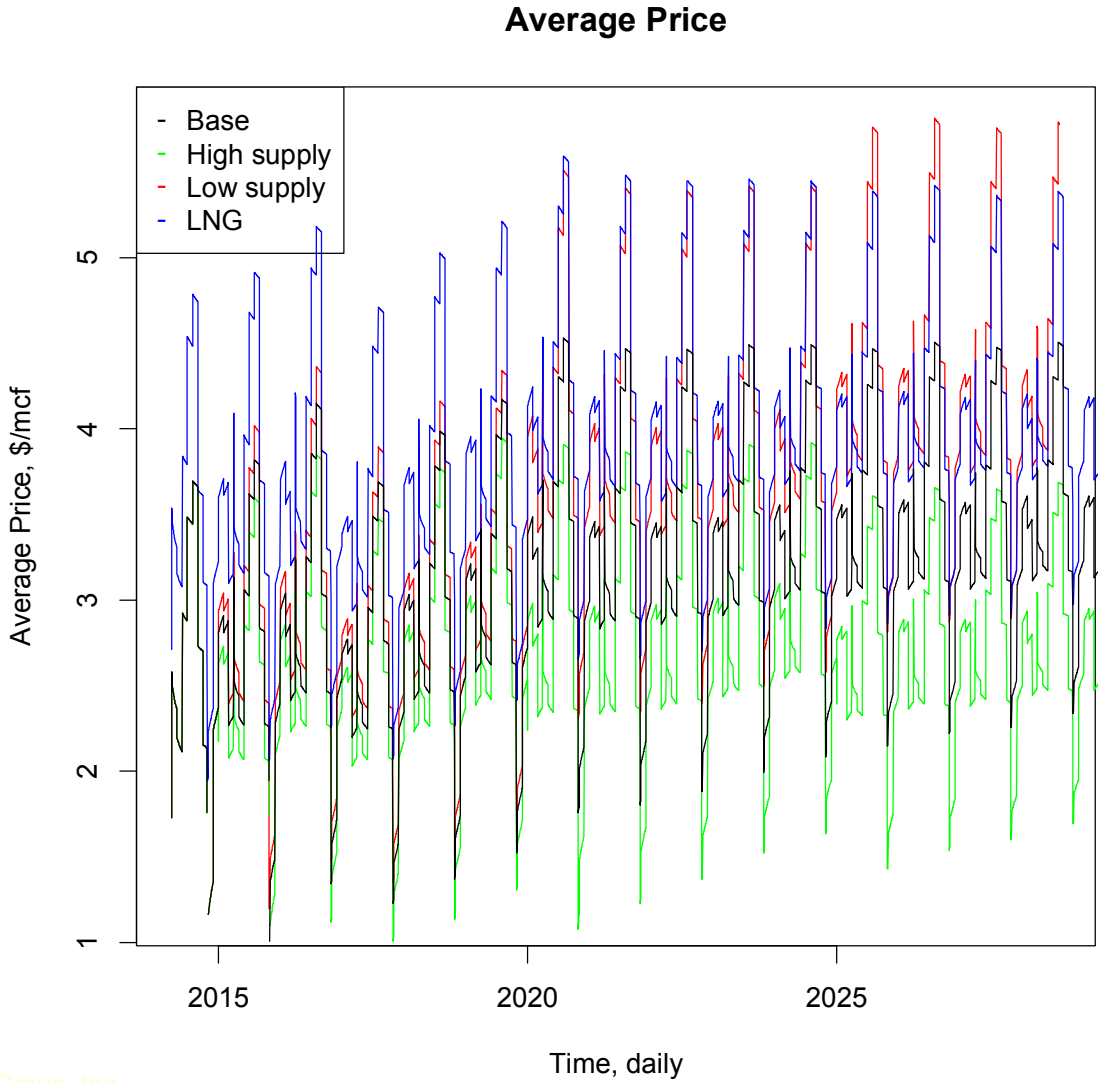
Scenario Prices



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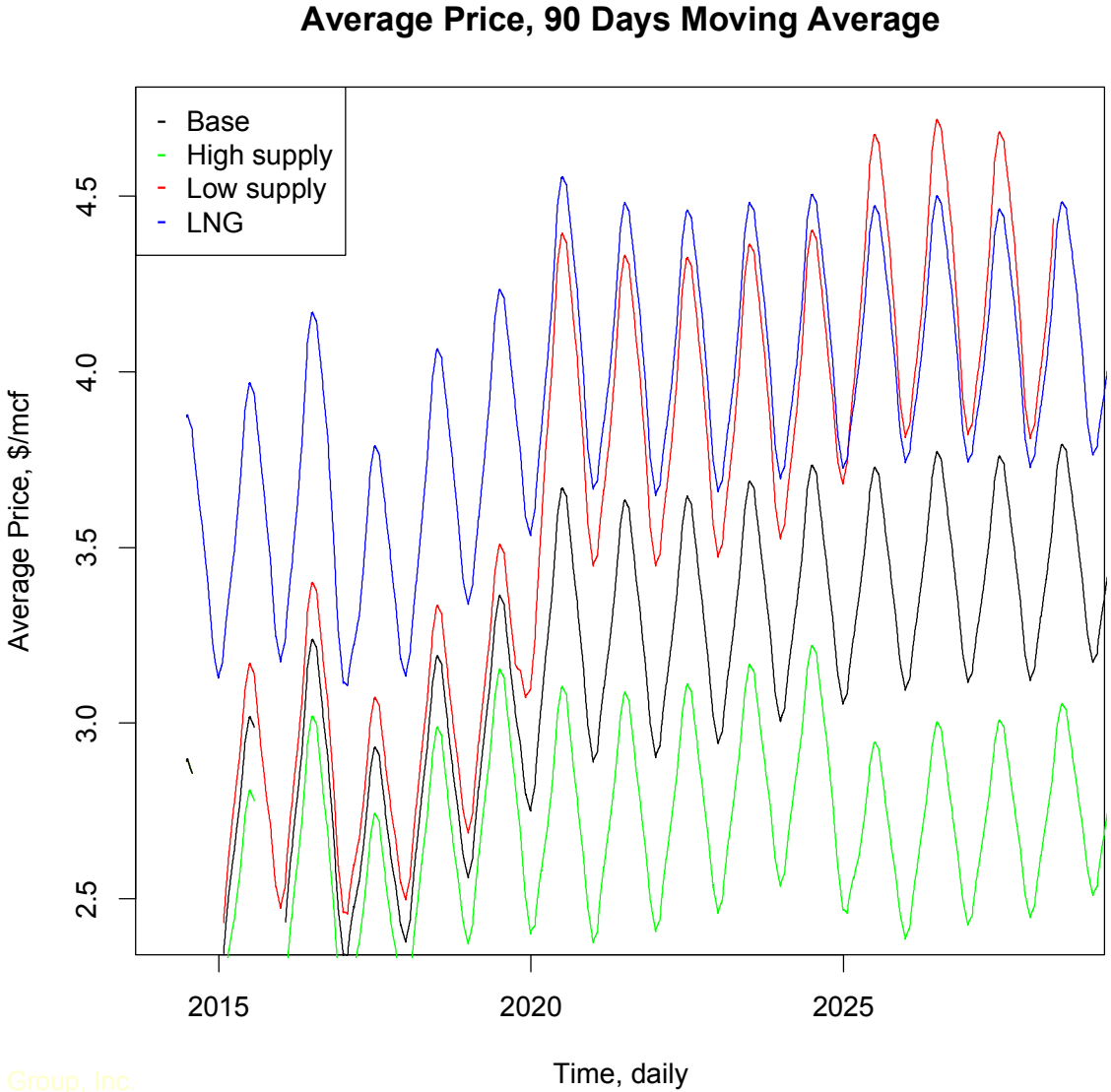
Prices, Moving Ave.



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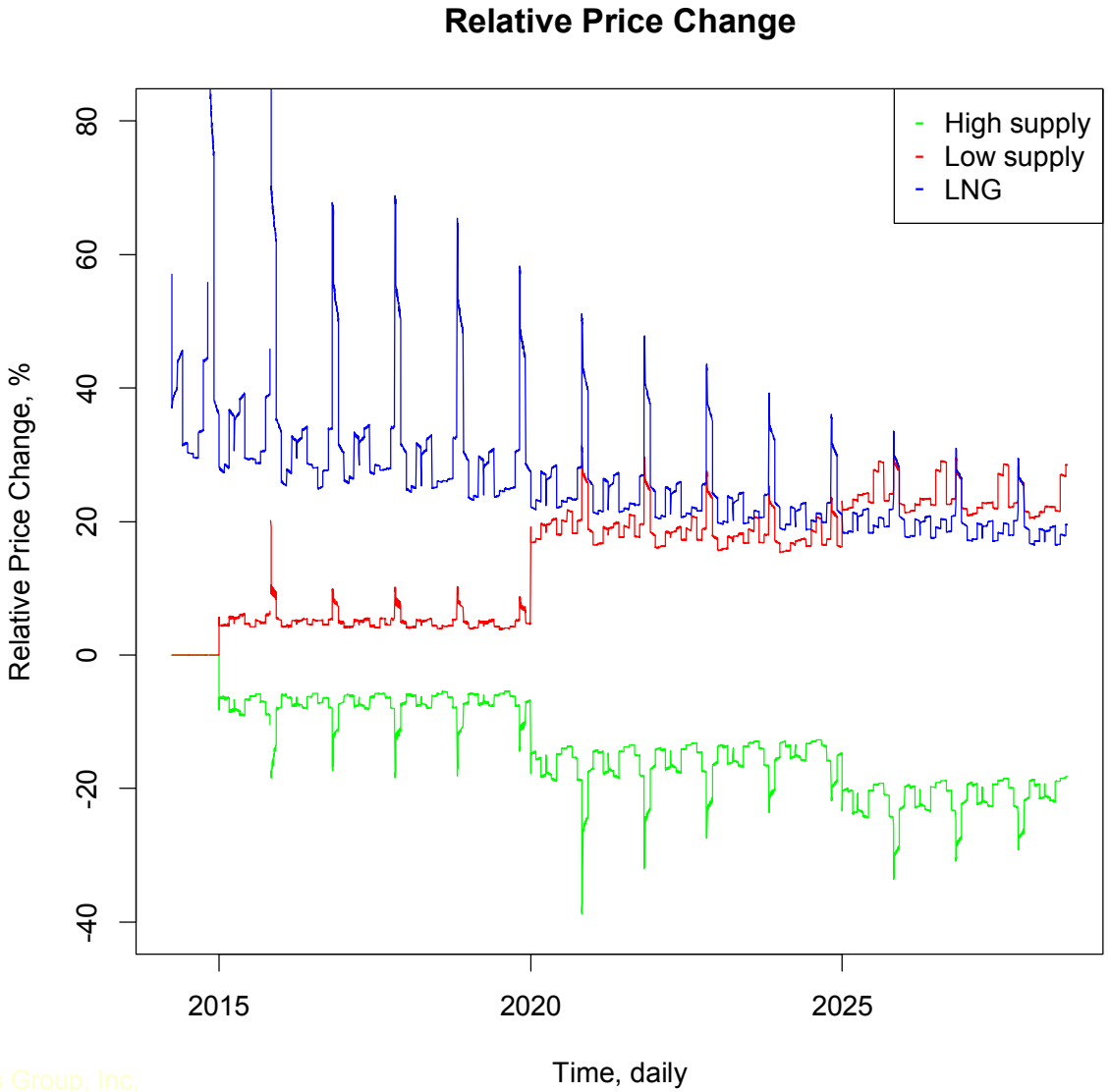
Relative Prices



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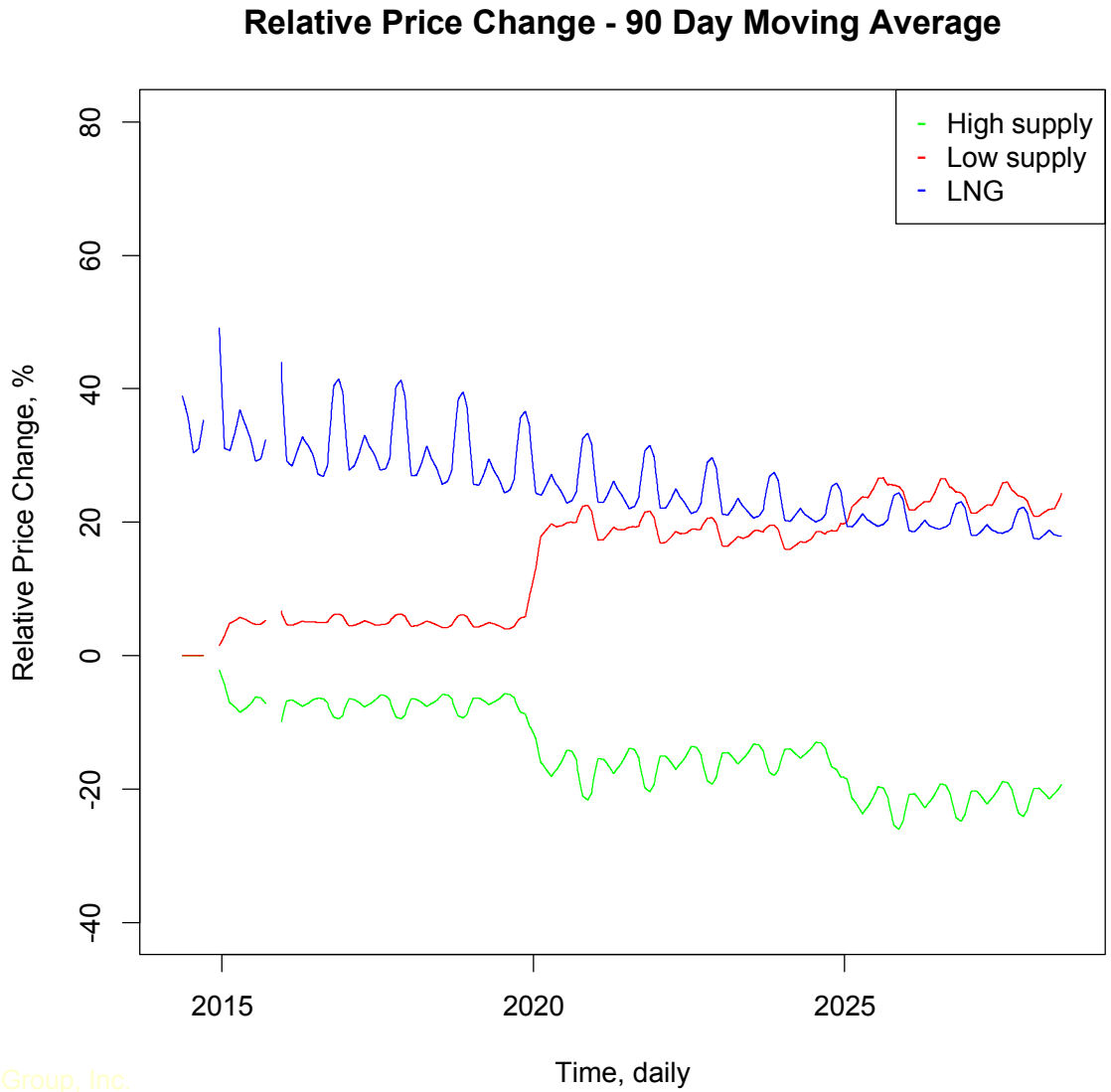
Relative Prices, Moving Average



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Preliminary Results
Base, LNG, High and Low Scenarios

	Approximate Averaged Scenario Price Range ($/mcf)			
Time Period	**Base**	**LNG**	**High**	**Low**
2014 - 2020	2.2 – 3.3	3.2 – 4.2	2.2 – 3.1	2.2 – 3.5
2020-2025	2.7 – 3.7	3.5 – 4.5	2.2 – 3.1	3.4 – 4.4
2025-2030	2.9 – 3.7	3.5 – 4.5	2.2 – 3.0	3.5 – 4.7

Base: Base case, no changes to the system
LNG: Addition of LNG terminal at Sabina Pass at 15% of total system demand
High: (Sanford Energy Modeling Forum) EMF
Low: EMF

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Results Discussion

- Demonstrated ability to represent NG price and market dynamics on daily time steps
- Conducted preliminary analysis of four scenarios:
  - Base
  - High shale
  - Low shale
  - LNG exports
- Results demonstrate significant sensitivity of the NG network to regulatory decisions (LNG approvals), individual agent decisions (storage), and quantitative and qualitative differences between different scenarios.

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Future Work

- Enable better storage decisions calibration
- Create predictive agents that attempt to achieve such objective as profit maximization at the storage level
- Develop faster price determination, and flow calculation algorithms
- Resolve bottlenecks in database input/output and results analysis
- Apply to real-world scenarios
- Enable connecting the model with macro economic models

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Thank you!

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