The Shale Gas Phenomenon: Utilizing the Power of System Dynamics to Quantify Uncertainty

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Objective

Quantify the key technical and economic drivers in the United States' (U.S.) Natural Gas (NG) exploration markets. The analysis does this by quantifying conditions in the NG exploration system that can lead to innovations and transitions in U.S. NG supplies [Fig. 1].
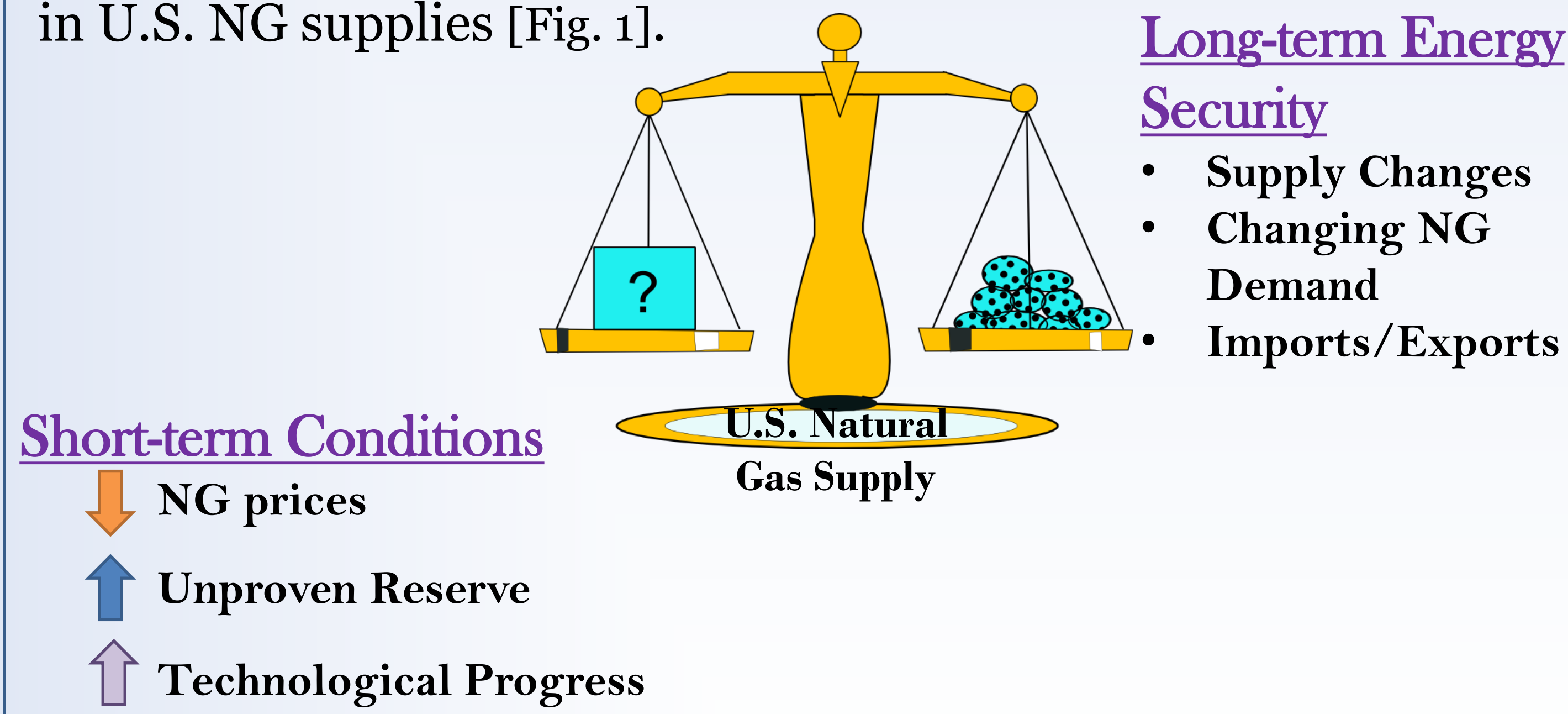
Long-term Energy Security
- Supply Changes
- Changing NG Demand
- Imports/Exports

U.S. Natural Gas Supply

Short-term Conditions
- ↓ NG prices
- ↑ Unproven Reserve
- ↑ Technological Progress

Figure 1. Key Drivers in United States Natural Gas Market

Dynamic Behavior Loops [Fig. 2]

- Discovery for the supply-side of market
- Demand growth
- Technology impacts on exploration, extraction, and cost
- Substitution among NG sources: Shale gas, Conventional gas (Conv.) + Tight gas, and Coalbed Methane (CBM)
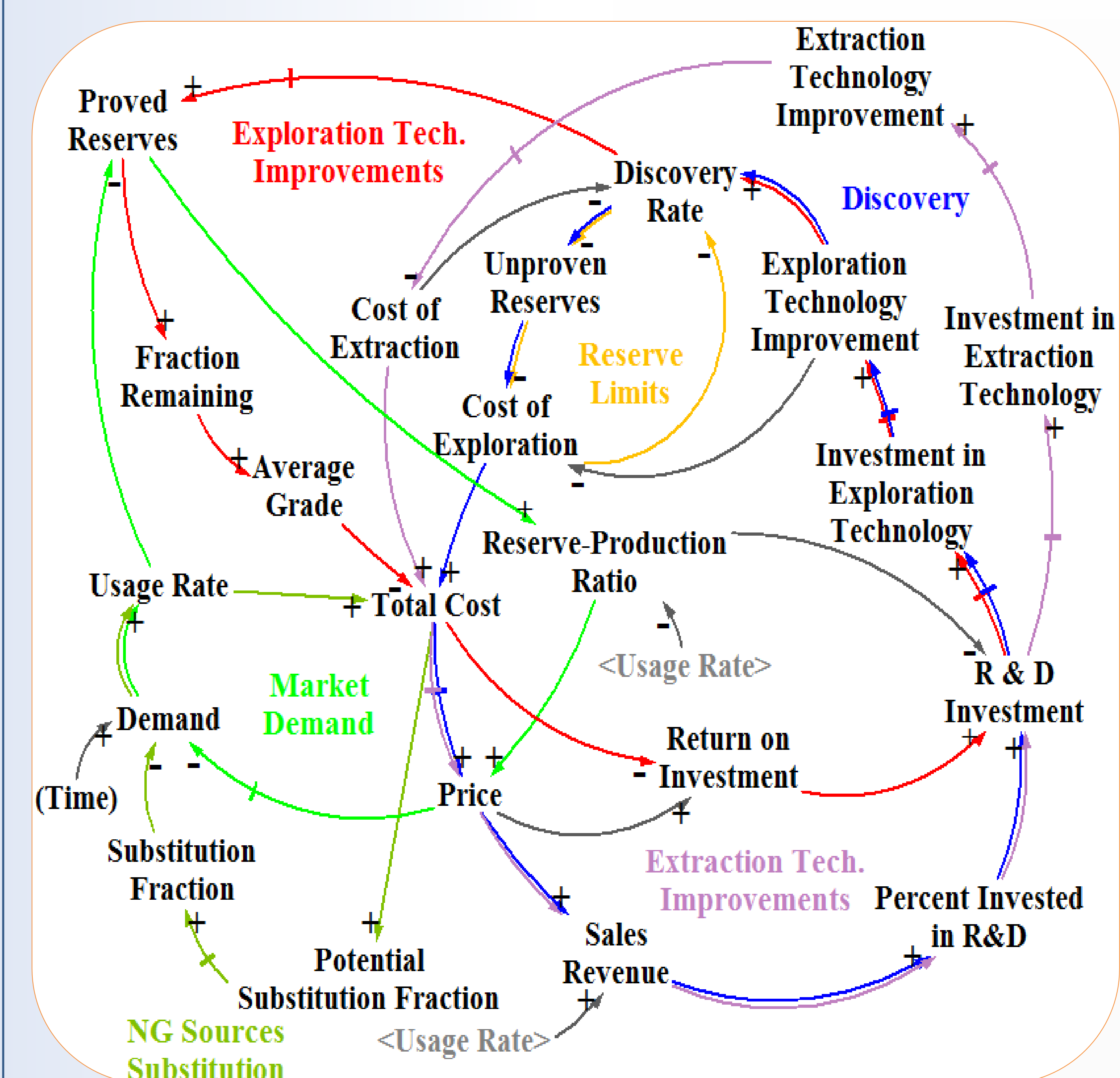
Figure 2. Causal Loop Diagram illustrating NG exploration market

Confidence Building

*Did you build the **RIGHT Model**?*

*Did you build the **MODEL Right**?*

The confidence building process was performed using five testing levels to address those two questions. These levels include System Mapping (correct structure & actors), Quantitative Modeling (observed behavior modes), Hypothesis Testing (feasible decision rules & boundaries), Uncertainty Analysis (realistic sensitivities), and Forecasting & Optimization (quantitative & predictive) [Fig. 3].
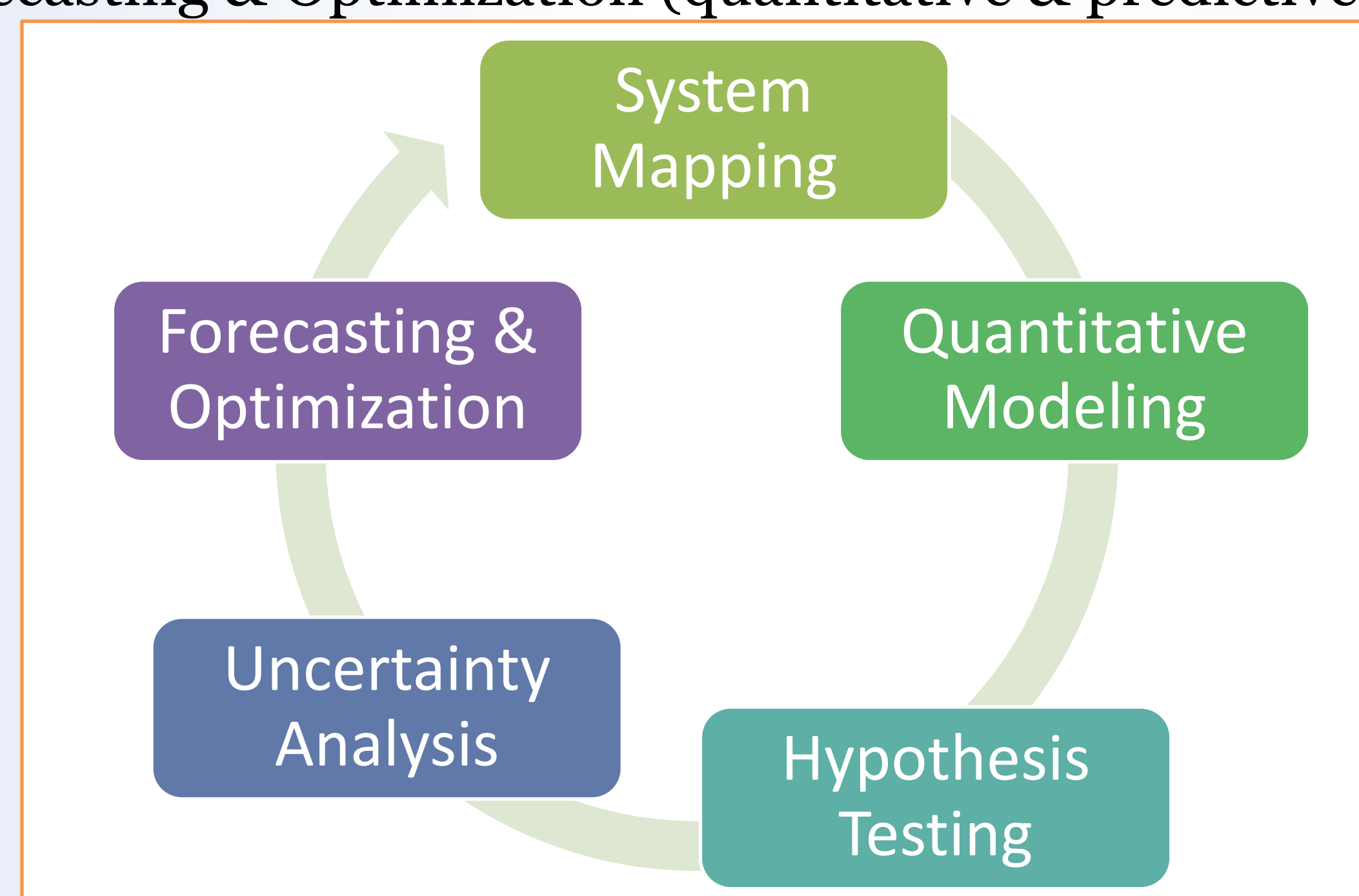
Figure 3. Levels of Confidence in Pragmatic Approach, Built Confidence in the Model's Structure and Parameters

Key Assumptions

- Unproven Reserve increases are discrete and exogenous
- NG price is a singular value, weighted average cost function of all three natural gas types
- Total production cost for each source type is proportional to exploration cost
- The cost of exploration rises as resources are depleted
- Quantity demanded is a function of current price & exponential growth in use over time
- Exploration investments determined by sales revenue generated
- No interdependencies between gas & oil

Sensitivity Analysis & Calibration

The singular sensitivity analyses were performed using two approaches to assess the potential risks: Tornado Plot [Fig. 4] and a triangular distribution to develop the probability distribution plot [Fig. 5].
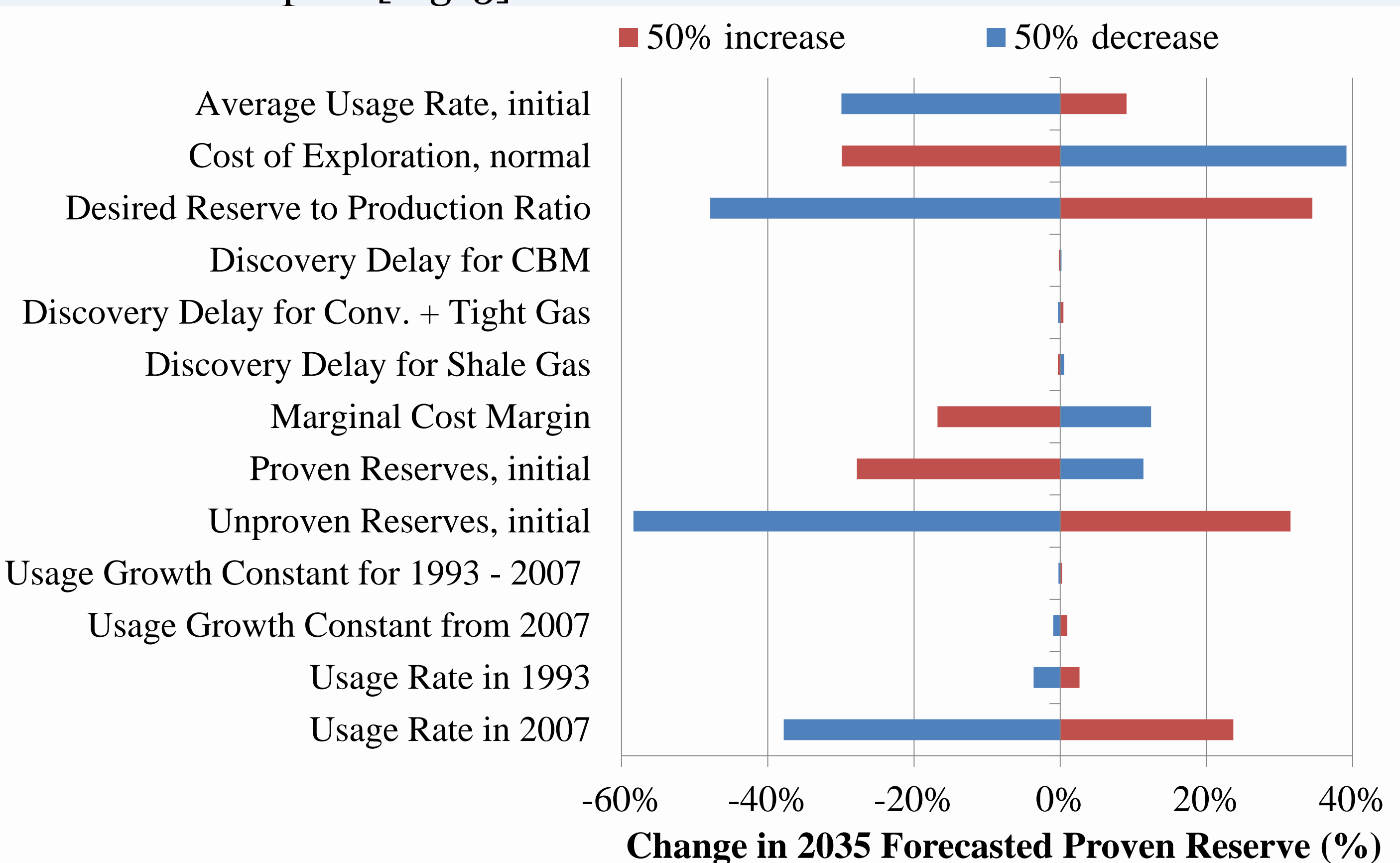
Figure 4. Tornado Plot, 50% increase & decrease in core parameters

Total Proven Reserves
Triangular Distribution Assumptions-
Initial Unproven Reserve Parameter
Min: 1,101,650 bcf
Peak: 2,203,300 bcf
Max: 3,304,950 bcf

Total Proven Reserves
Triangular Distribution Assumptions-
Desired Reserve to Production Ratio
Min: 19.075 yr.
Peak: 38.15 yr.
Max: 57.225 yr.

- Total Reserves (High)
- Total Reserves (Average)
- Total Reserves (Low)
- Total Reserves (90 Percentile)
- Total Reserves (25 Percentile)
- Total Reserves (75 Percentile)
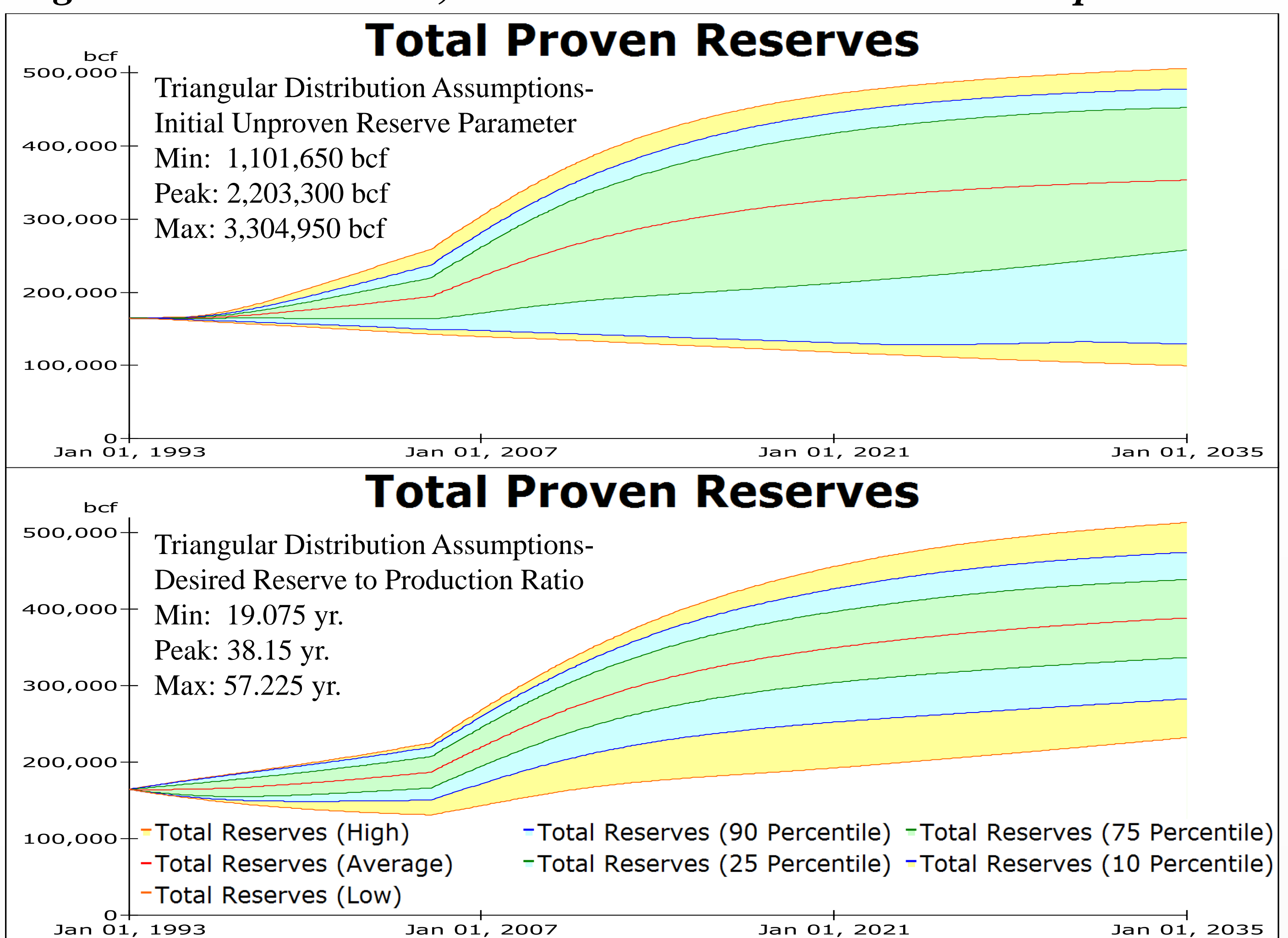- Total Reserves (10 Percentile)

Figure 5. Probability Distribution of Initial Unproven Reserve (top), Desired Reserve to Production Ratio (bottom) parameters using Latin Hypercube Sampling

Preliminary Results

The simulated proven reserves have close correspondence to U.S. Energy Information Administration (EIA) historical estimates of NG proven reserves, which is reflective model dynamics matching U.S. NG exploration market [Fig. 6].
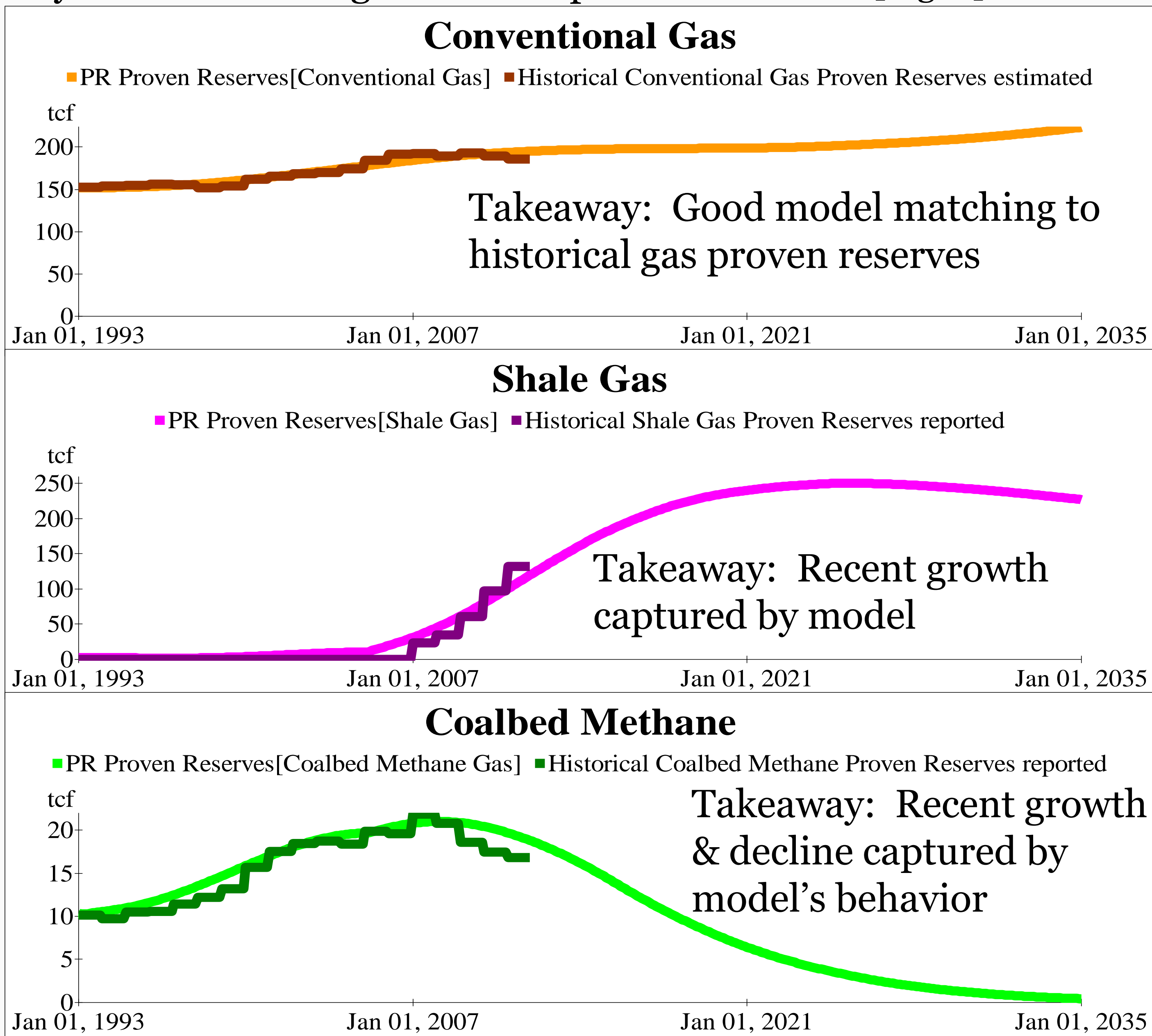
Conventional Gas
Takeaway: Good model matching to historical gas proven reserves

Shale Gas
Takeaway: Recent growth captured by model

Coalbed Methane
Takeaway: Recent growth & decline captured by model's behavior

Figure 6. Simulated & EIA Historical Proven NG Reserves

Takeaway Messages and Future Research

- Model is sensitive to initial Unproven Reserves and Desired Reserve to Production Ratio
- Model has low sensitivity to changes in Discovery Delay & NG usage growth constant (in the exponential growth function)
- Influence of technology is important, to research further
- Future Research will look at different policy scenarios

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