Re-Fracturing the Appalachian Basin:

An Economic Analysis

Our Backgrounds

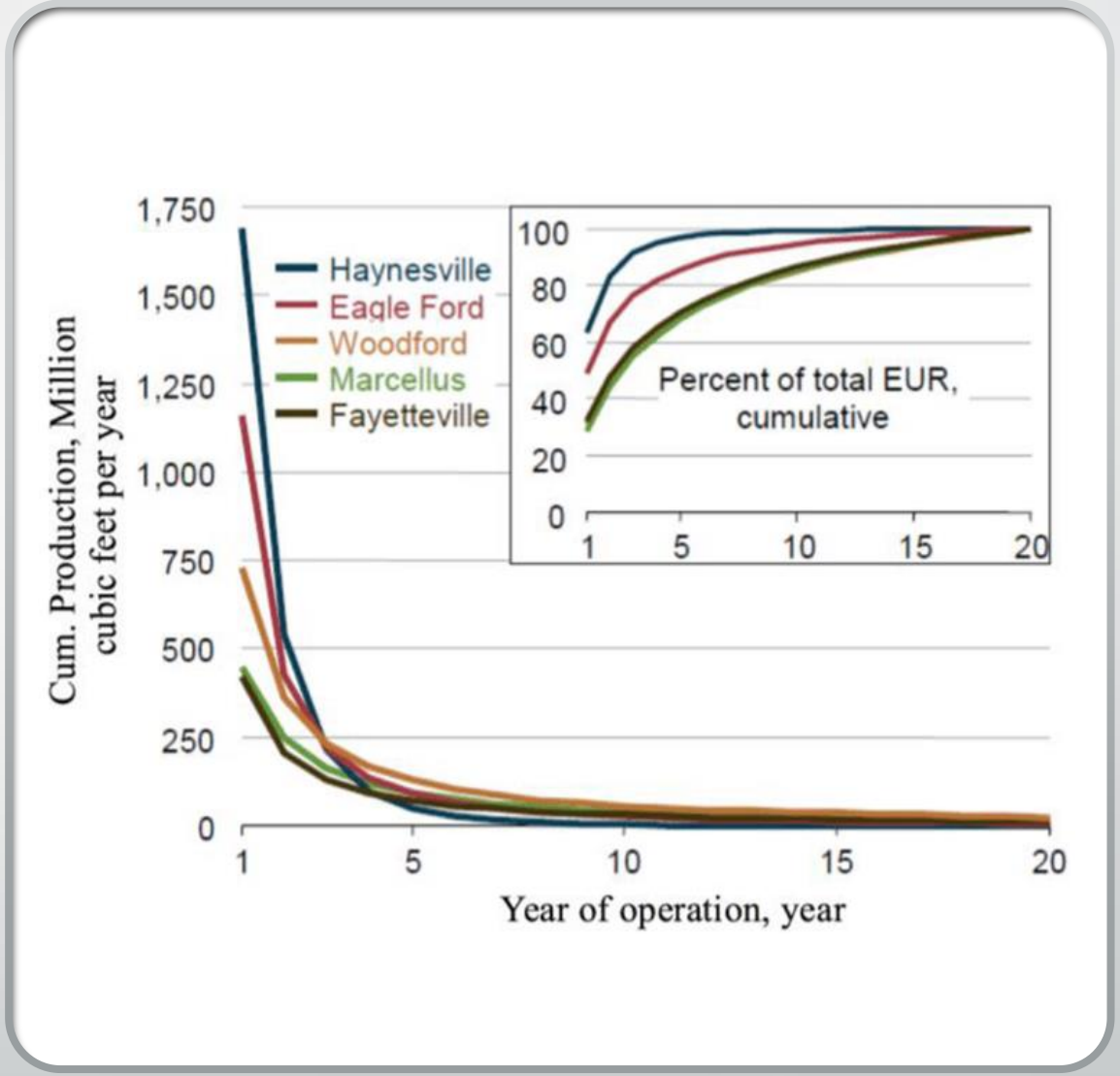
- Kade Kiselica
- Marathon Oil Company
  - Eagle Ford – Drilling
  - STACK/SCOOP – Reservoir
  - Bakken – Production
- Taylor Jennings
- Southwestern Energy
  - Marcellus – Production
  - Fayetteville – Facilities/Midstream
  - Marcellus – Facilities

Objectives

- Discuss Re-Fracturing Methodology:
  - Unconventional Assets
  - Conventional Assets
- Identify Specific Screening Criteria for Re-Completion Candidates
- Develop Economic Model to Quantify Impact
- Perform Probabilistic Modelling to Further Economic Conclusions

Introduction to Re-Fracturing

- 45-55% Rate Decrease
  - Within 5-6 months
- 77-89% Rate Decrease
  - 3 Years After Completion
- Significant Delay of Ultimate Recovery
- Re-Fracturing Provides a Quantifiable Production Uplift

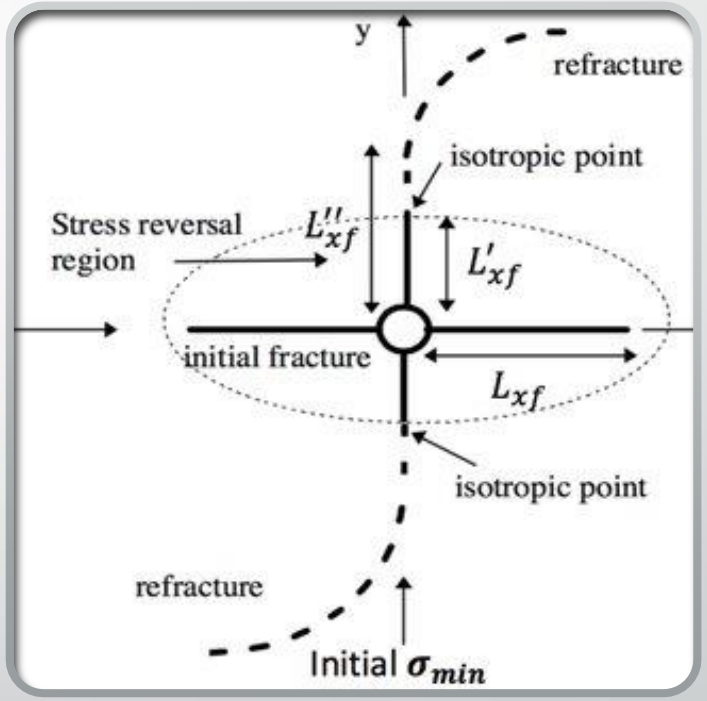


Re-Fracturing Impact

- Production Decline is a Function of Fracture Closure and Damage
- Re-Fracturing in Dual Porosity Systems:
  - By-Passes Formation Damage
  - Restores Crushed/Displaced Proppant
  - Re-Opens Natural Fractures
  - Increases Stimulated Reservoir Volume (SRV)

Stress Re-Orientation

- Maximum Horizontal Stress Rapidly Decreases with Production
  - Due to Depletion in the Direction of Fractures
- Minimum Horizontal Stress Slowly Decreases
  - Results in Stress Reversal Near Fractures
- New Fractures Propagate Obliquely
- Additional Thermally Induced Fractures



Re-Fracture Design Comparison

Unconventional

- Increase Fracture Length
- Remedy Fracture Closure
- Create New Fracture Networks

Conventional

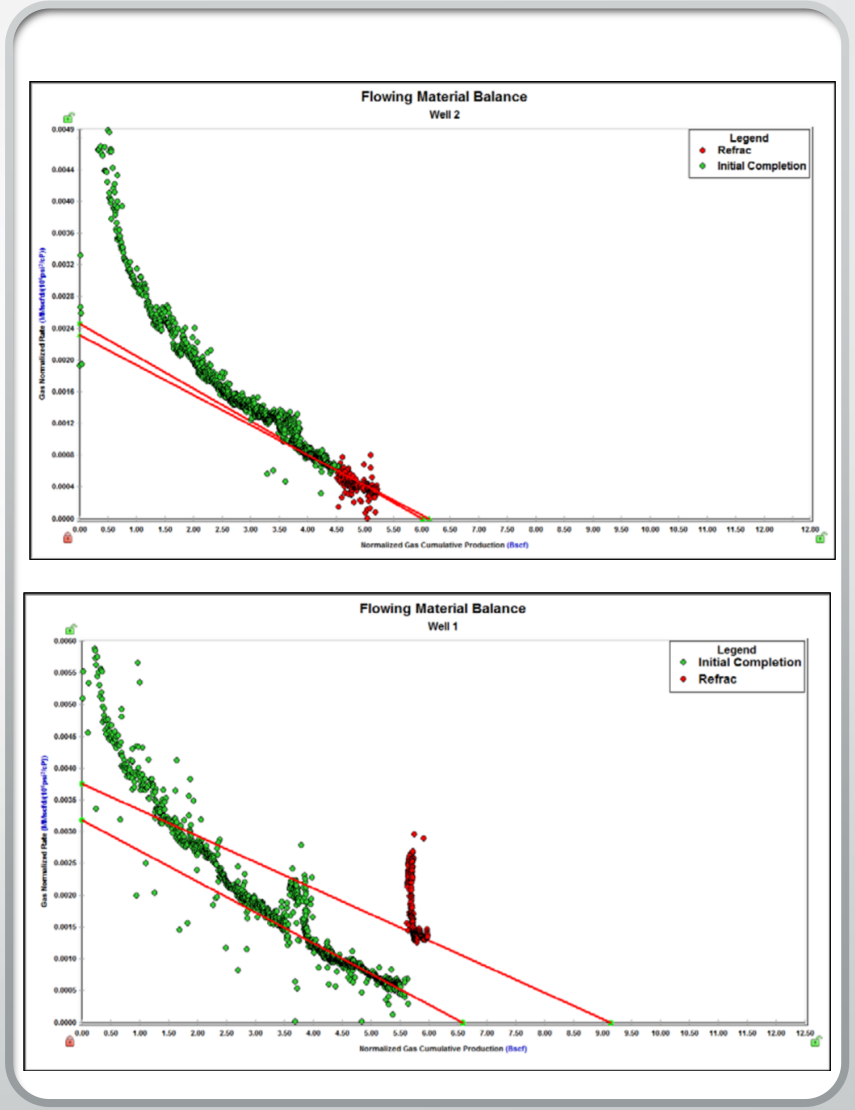
- Increase Fracture Conductivity
  - Larger Proppant Size
  - Greater Proppant Concentration
  - Higher Quality Proppants
- By-Pass Formation Damage
- Improve Sand Control

Re-Fracture Candidacy Metrics

- Well Performance
- Well Depletion
- Proximity to Other Wells
- Original Completion Design
- Performance of Newer Offset Wells
- Wellbore Integrity
- Expected Re-Completion Costs

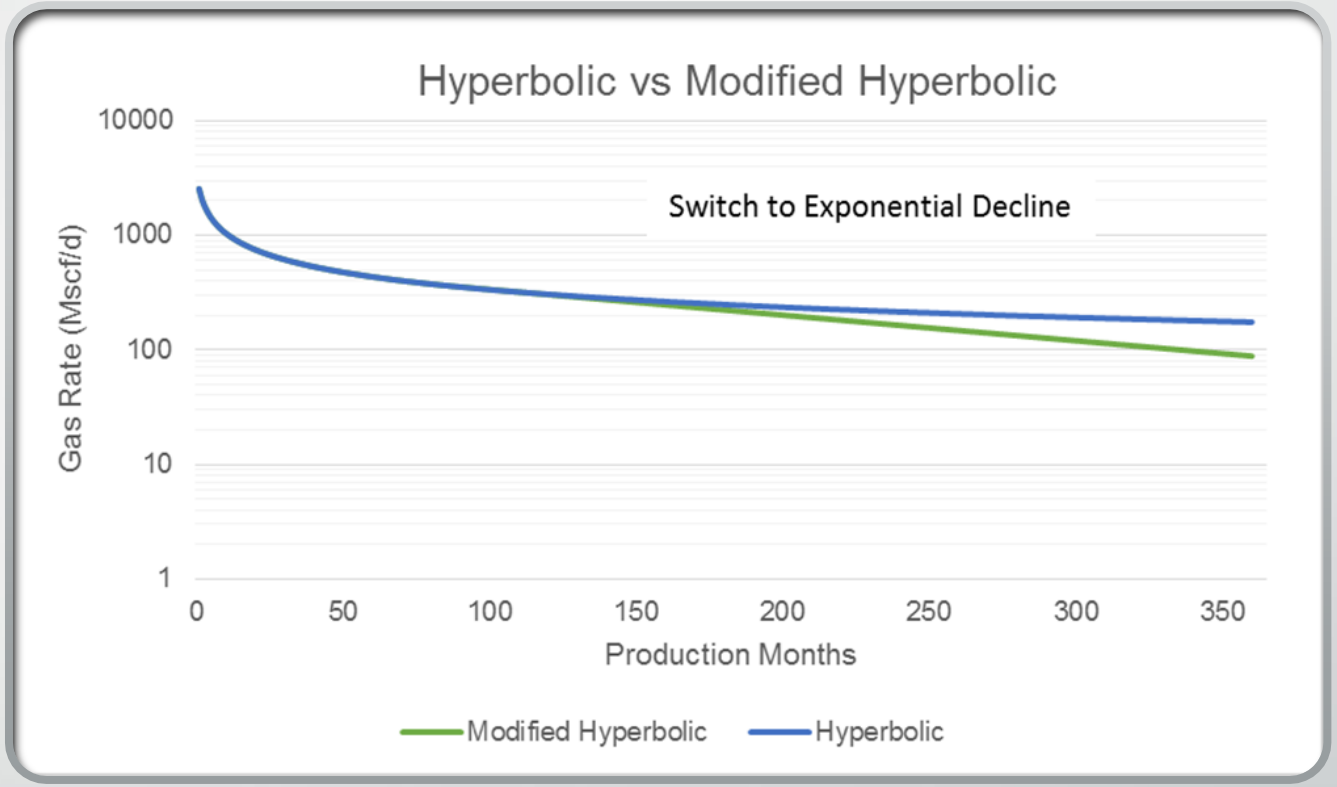
Performance Evaluation

- Four Possible Outcomes:
  - Additional Volume of Reserves
  - Accelerated Production of Reserves Previously Contacted
  - Loss of Reserves Previously Contacted
  - No Change in Production or Reserves



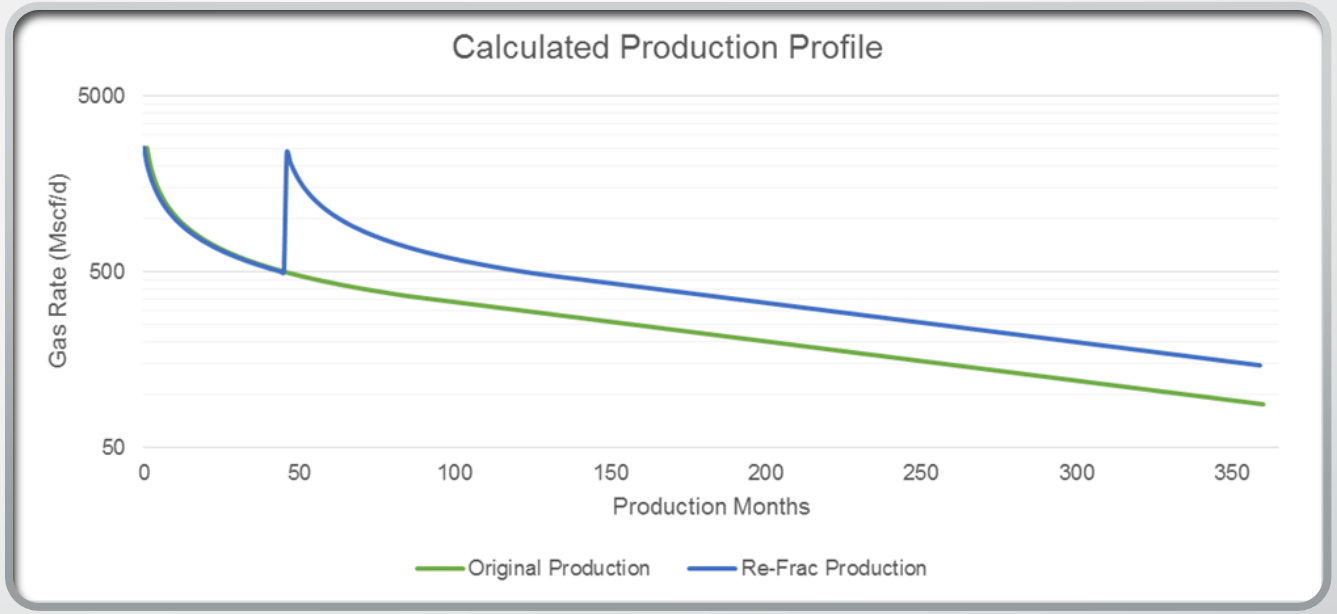
Developing a Model

- Utilized Modified Hyperbolic Decline
  - Prevents Overestimation of Reserves
  - Switch When De = 8%
- Allows for Modeling of Base Production



Predicting Re-Frac Performance

- Incremental Performance Evaluated
  - Allows for Economic Modeling
- Re-fractured Modified Hyperbolic Decline
  - Utilizes Different Decline Parameters
- Re-Fracture Performance Data Derives from SPE 173340
  - Bakken & Eagle Ford
    - Oil Wells



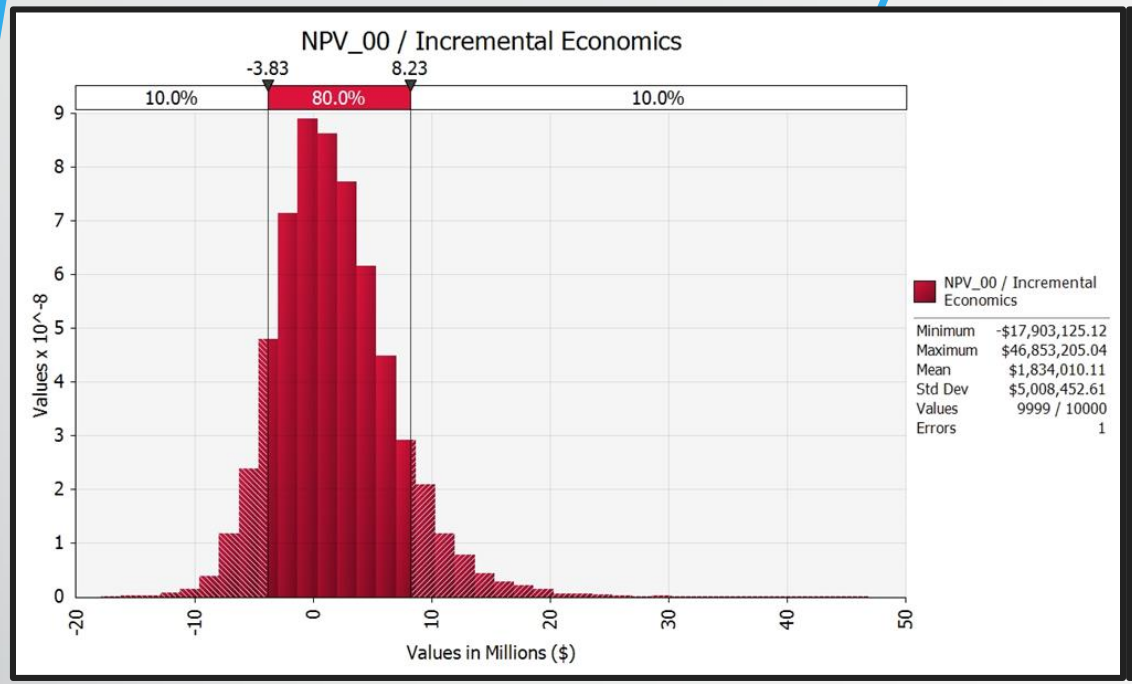
Creating Gas Well Performance

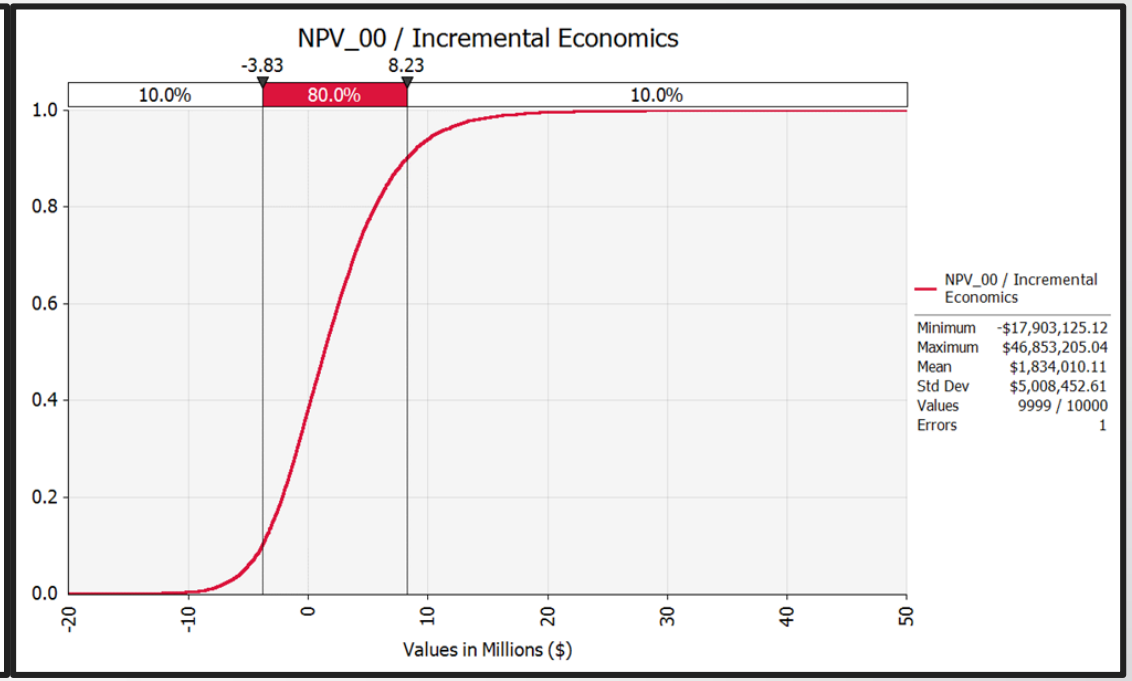
- Utilized Public Data to Fit an Average Type Curve (Marcellus/Utica)
- Developed Performance Uplift Parameters from Oil Well Data
- Applied Parameters to Gas Well Production Forecasts

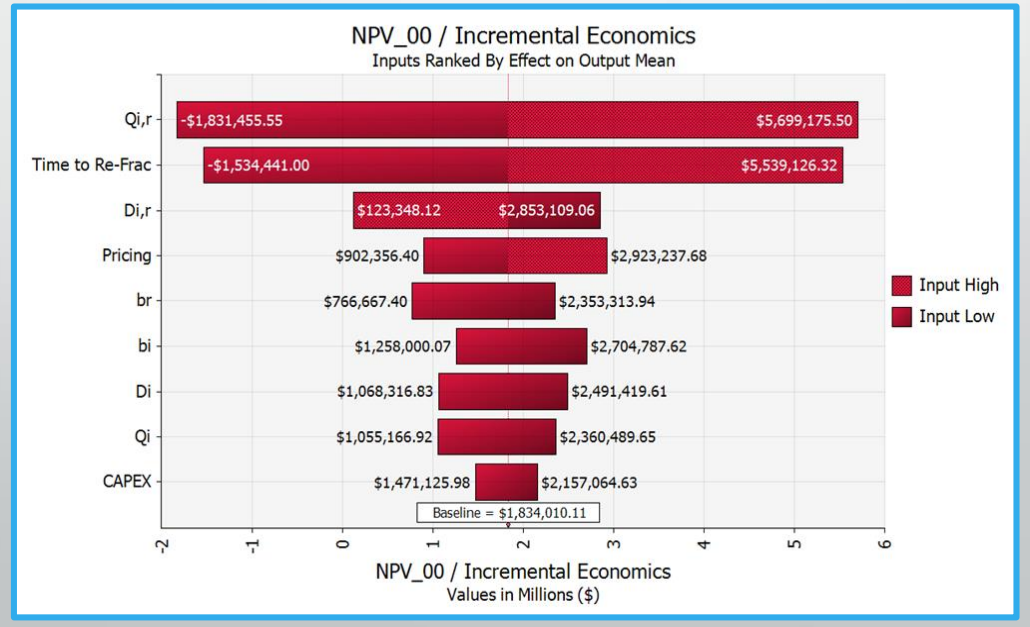
Transitioning to Probabilistic Modeling

- Developing Monte Carlo Simulation
  - Define Distributions
    - Provides a Range of Values
    - Presents a Wide Array of Possible Outcomes
    - Outcomes Presented in a Confidence Interval
  - Correlation Correction
    - Enhance Accuracy by Modeling Parameter Dependency
    - Created by Ranking Input Parameters
    - Correlation Coefficient ($\sqrt{r^2}$) Measures Correlation Strength

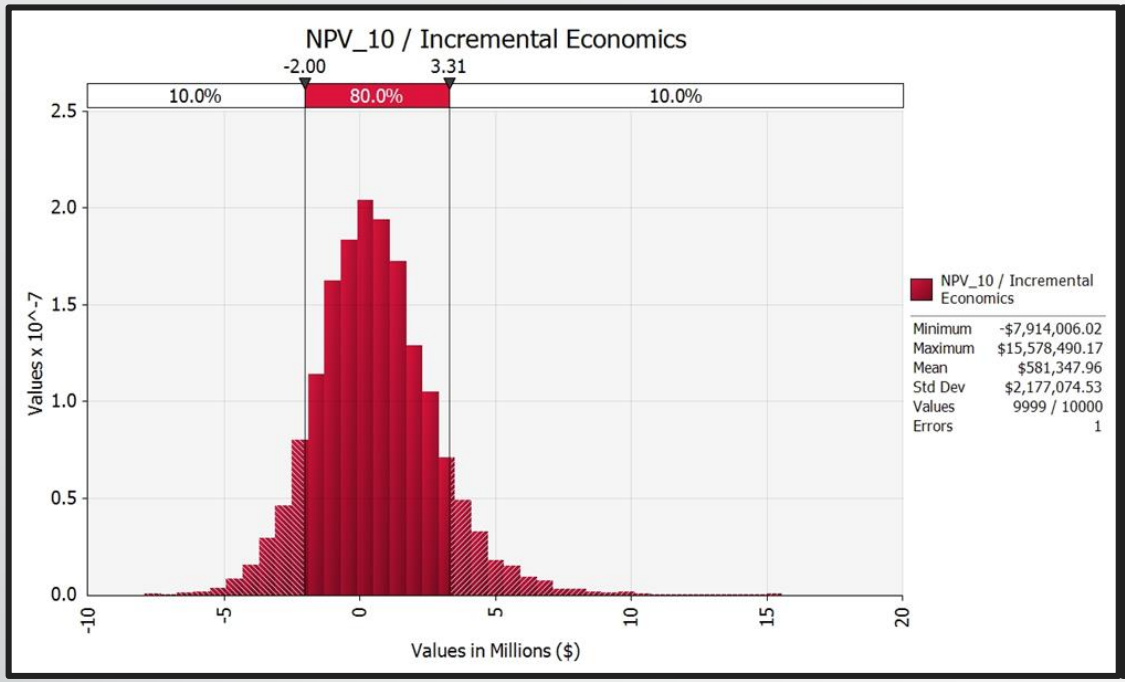
Gas Well Analysis: Undiscounted NPV

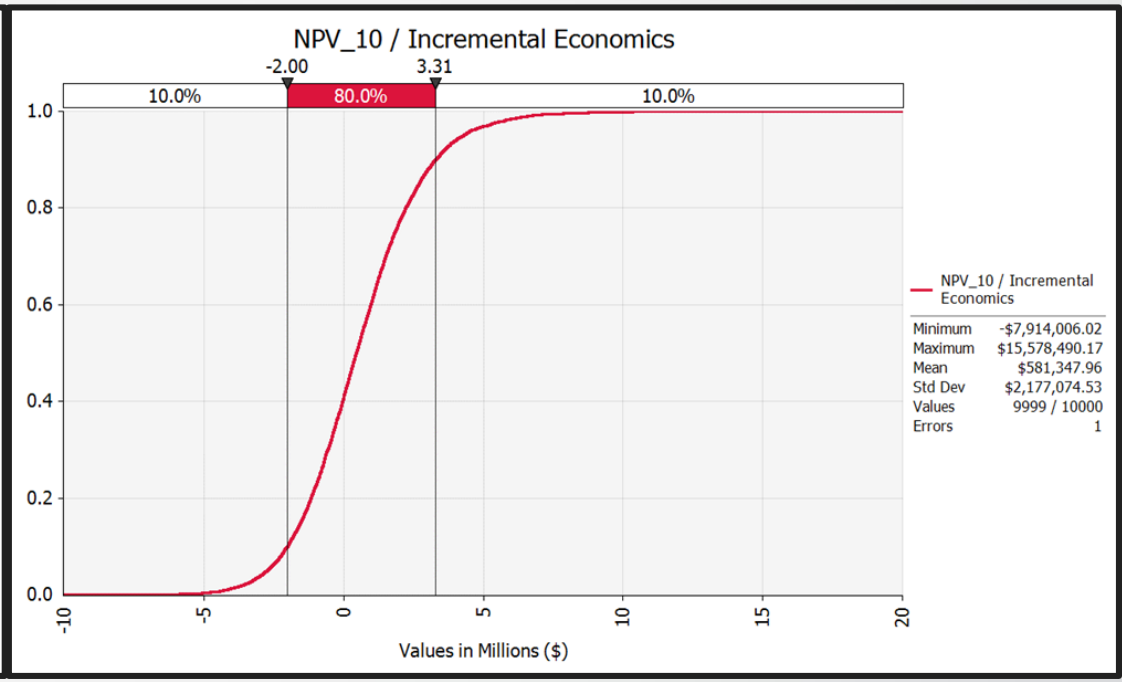


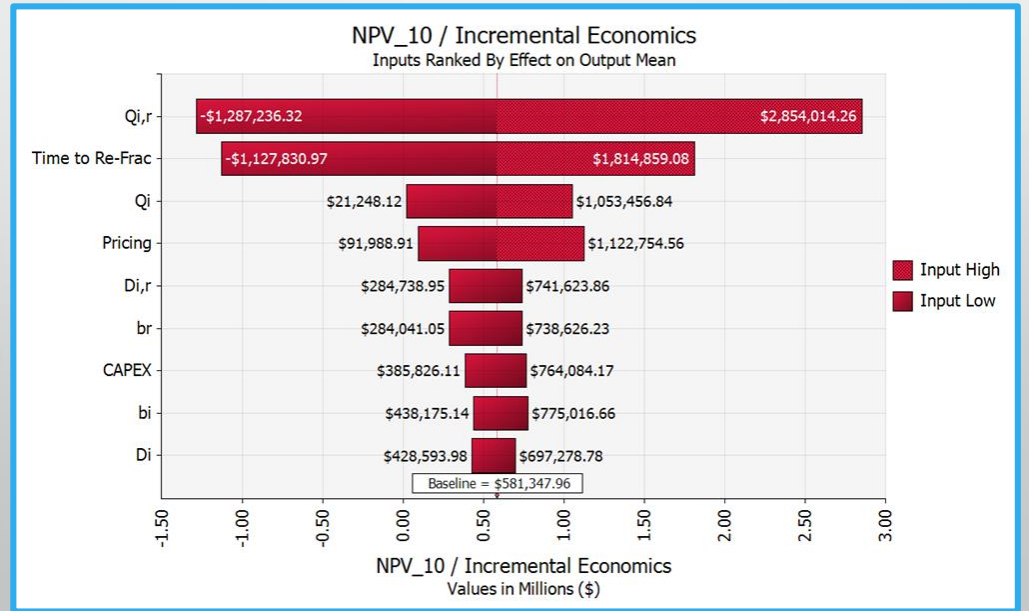




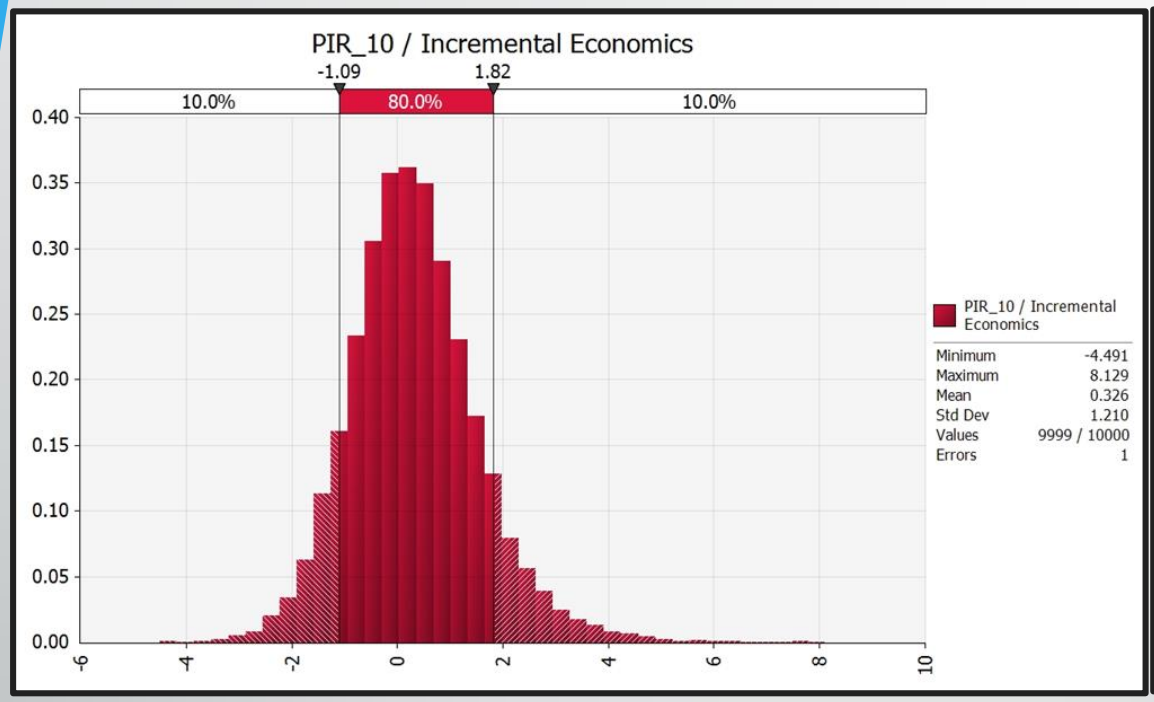
Gas Well Analysis: Discounted NPV

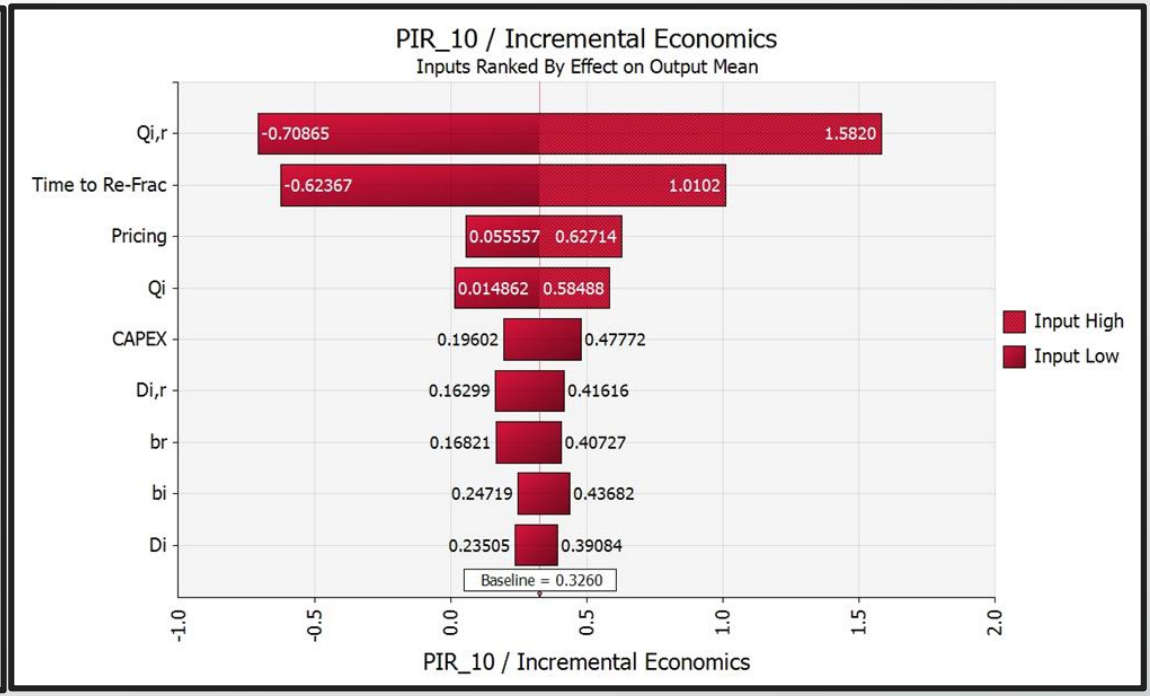






Gas Well Analysis: Discounted PIR

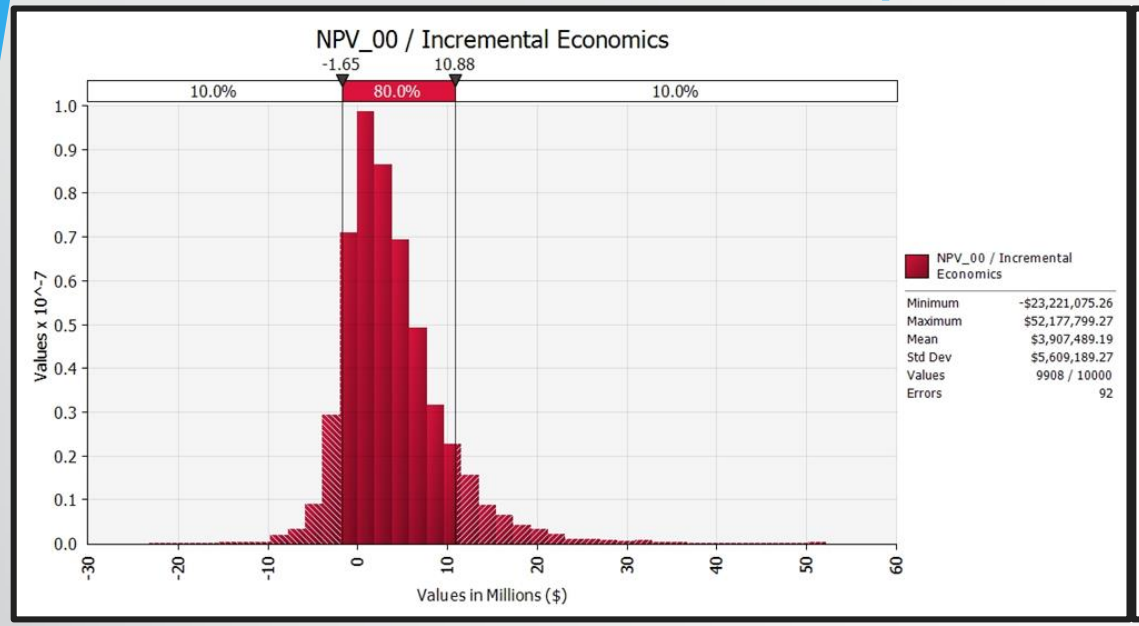


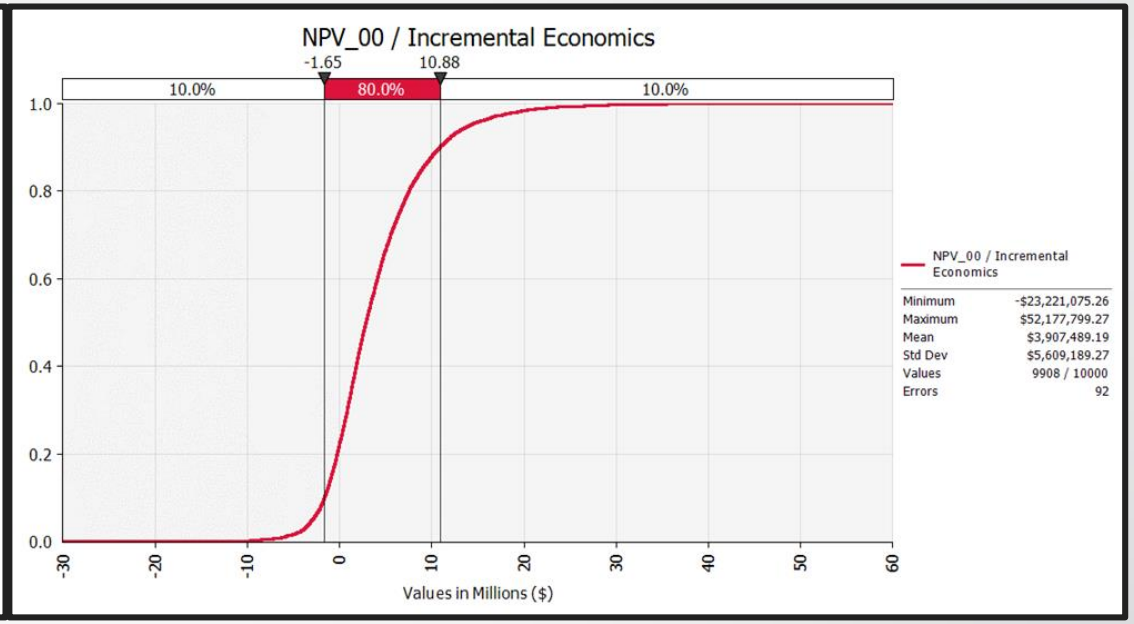


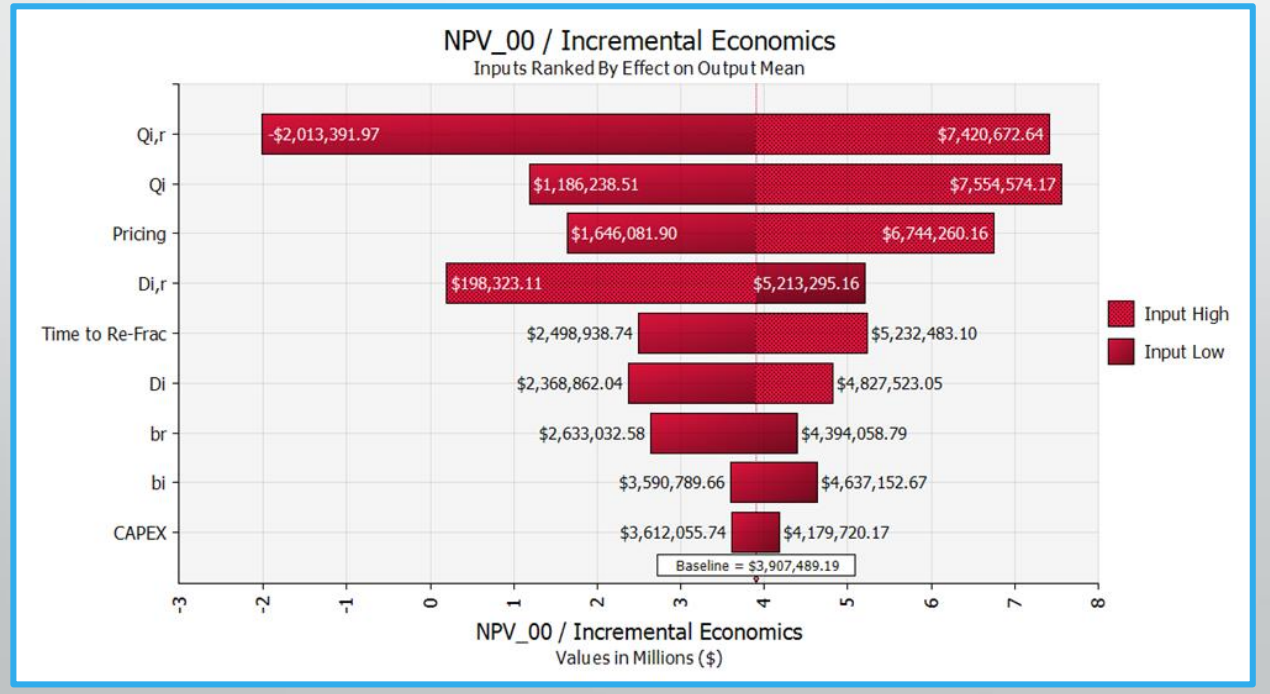
Gas Well Analysis: Summary

	Mean NPV	Mean PIR	Chance of Success
Undiscounted	$1.8MM	-	62%
Discounted	$0.58MM	.326	59%

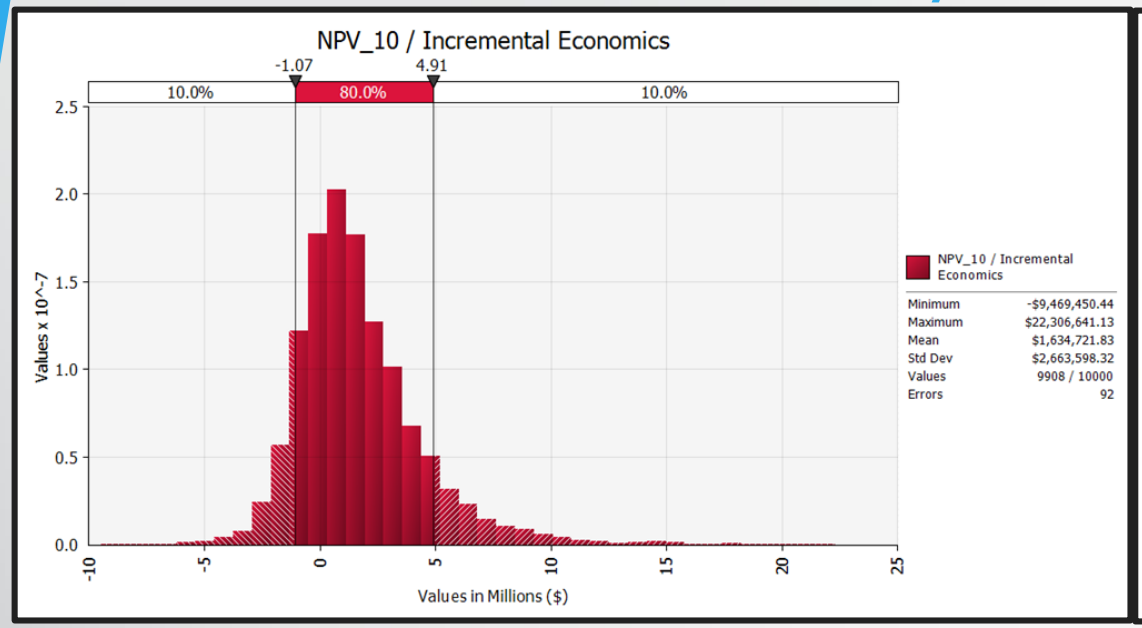
Oil Well Analysis: Undiscounted NPV

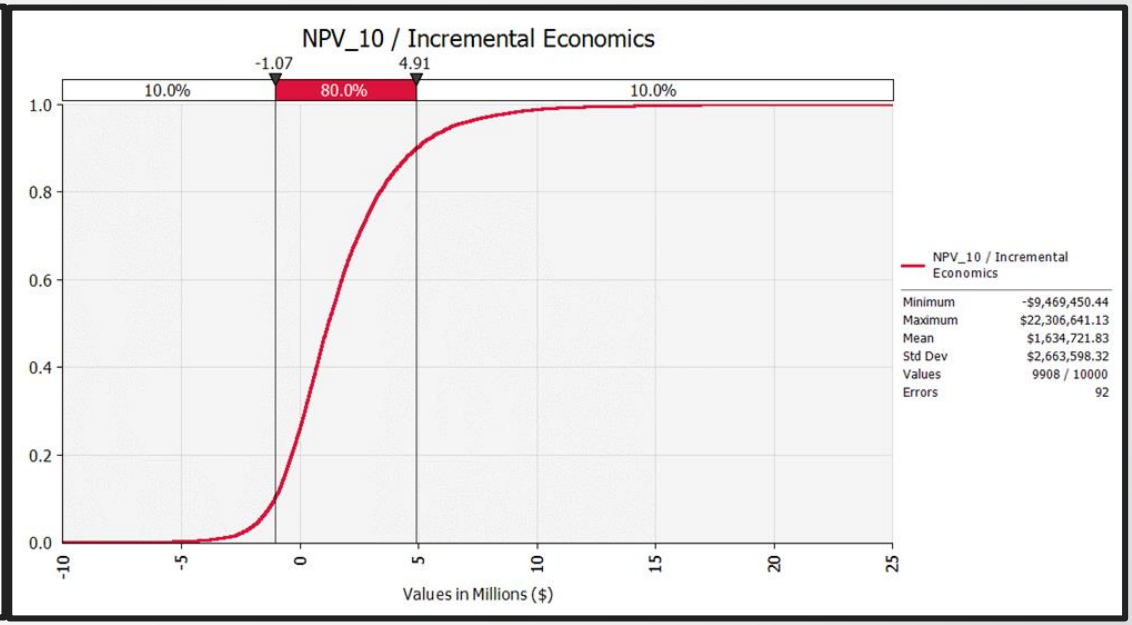


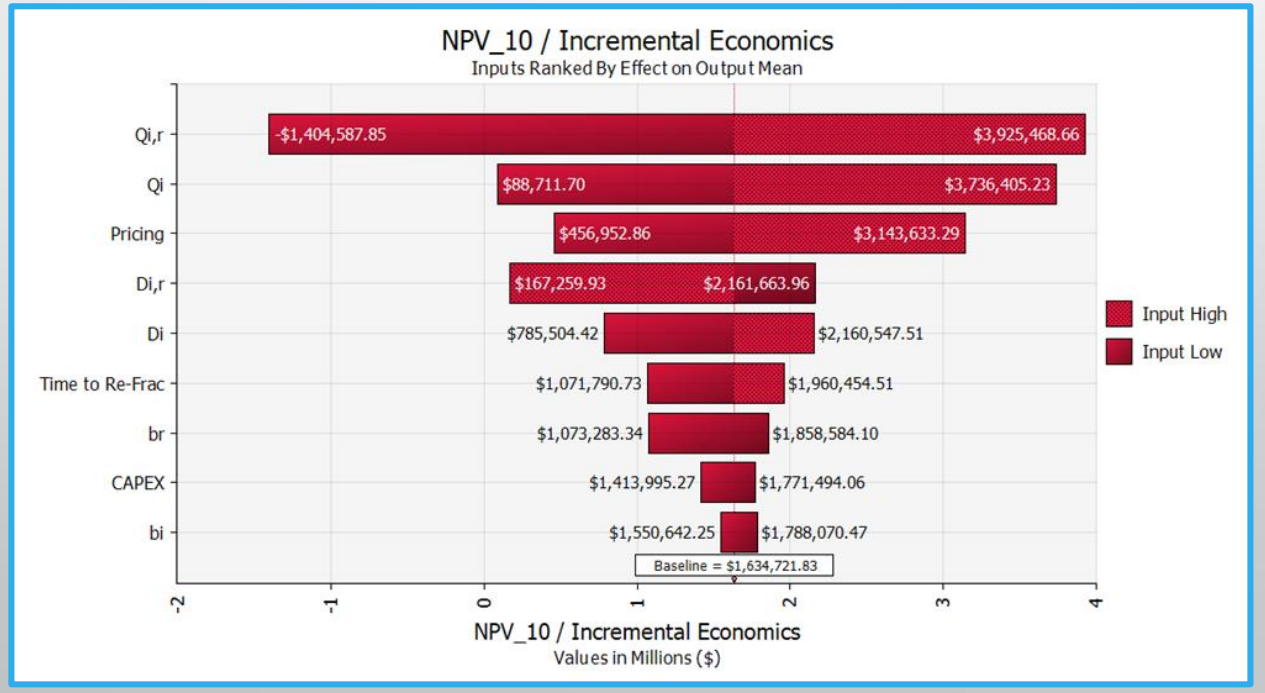




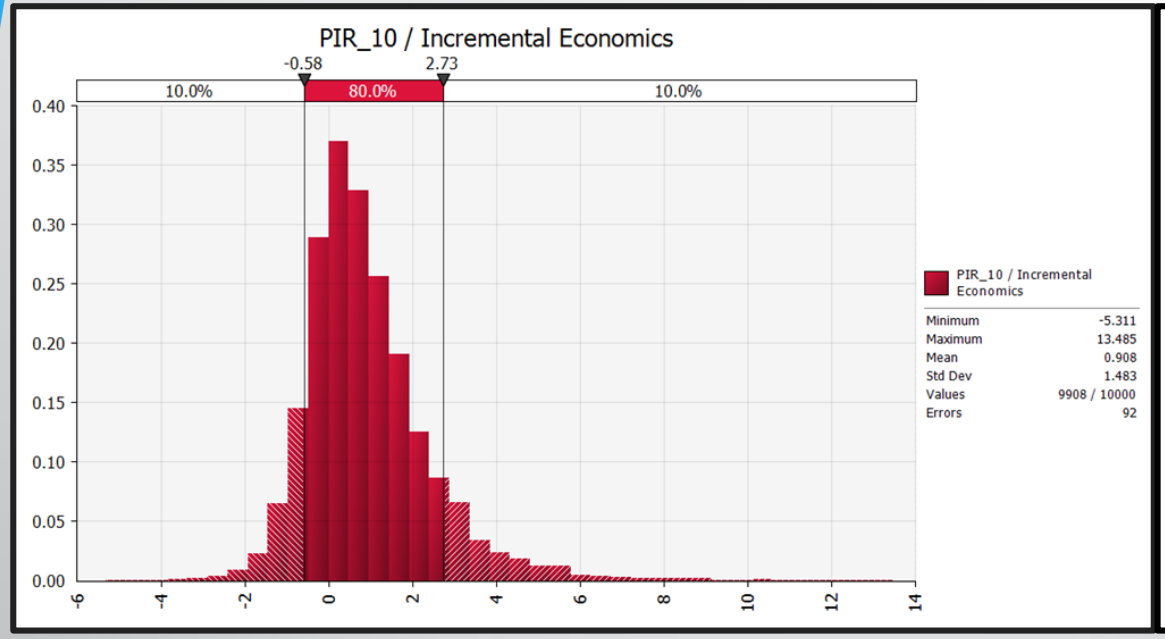
Oil Well Analysis: Discounted NPV

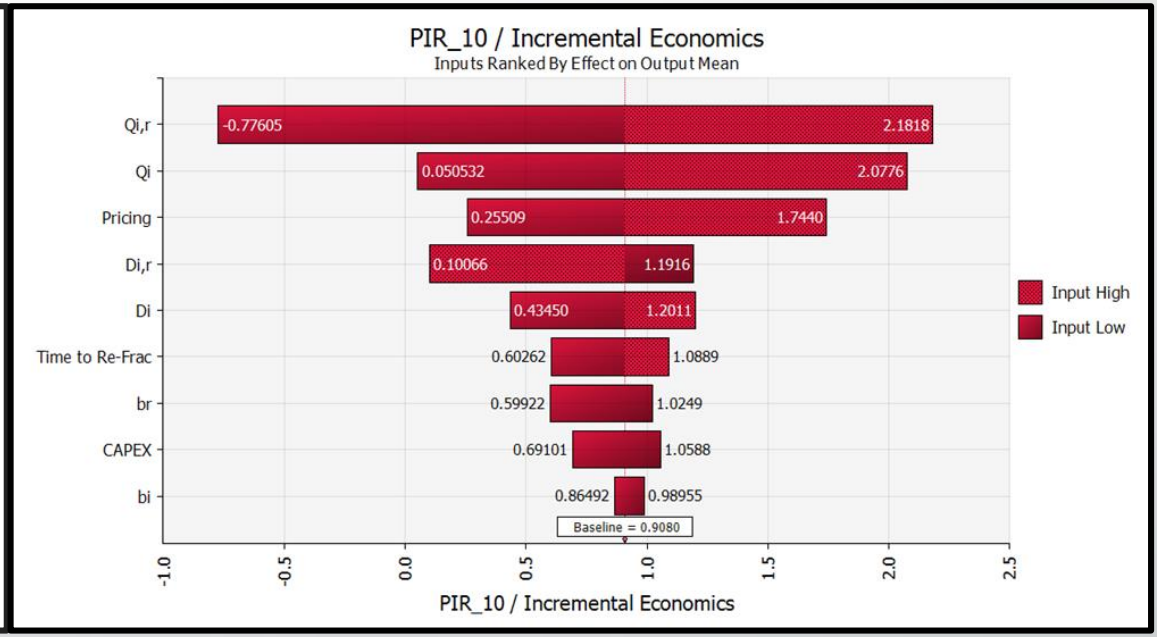






Oil Well Analysis: Discounted PIR





Oil Well Analysis: Summary

	Mean NPV	Mean PIR	Chance of Success
Undiscounted	$3.9MM	-	77%
Discounted	$1.6MM	.908	63%

Economic Model Limitations

- Developed Using Public Data
  - Horizontal Unconventional Wells
  - Economic Performance Can be Scaled Down for Vertical Shale Wells
- Models Only Consider Two Cases:
  - Dry Gas
  - Oil
    - Interpolate Performance in Liquids-Rich Gas Wells
- Model is Not Analogous for Conventional Reservoirs
  - Would Require Testing and Data Sharing
  - Could be Modeled With Outlined Methodology

Conclusions

- Viable Method to Gain Production from Existing Wells
- Probabilistic Modeling Provides a Range of Potential Outcomes
  - Oil Wells Show Better Economic Metrics
    - NPV_{10} Range: $-1.1MM to $4.9MM
    - Discounted Chance of Success: 63%
  - Dry Gas Wells Still See Economic Uplift
    - NPV_{10} Range: $-2.0MM to $3.3MM
    - Discounted Chance of Success: 59%

Questions

References

- Asala, H. L., Ahmadi, M. and Taleghani, A. 2016. Why Re-Fracturing Works and Under What Conditions. SPE Annual Technical Conference and Exhibition, Dubai, UAE, 26-28 September. SPE-181516-MS. https://doi.org/10.2118/181516-MS.
- Brady, J., Daal, J., Marsh, K., et. al. 2017. Impact of Re-Fracturing Techniques on Reserves: A Barnett Shale Example. SPE/AAPG/SEG Unconventional Resources Technology Conference, Austin, Texas, USA, 24-26 July. URTEC-2668825-MS. https://doi.org/10.15530/URTEC-2017-2668825.
- Oruganti, Y., Mittal, R., McBurney, C. J., et. al. 2015. Re-Fracturing in Eagle Ford and Bakken to Increase Reserves and Generate Incremental NPV: Field Study. SPE Hydraulic Fracturing Technology Conference, The Woodlands, Texas, USA, 3-5 February. SPE-173340-MS. https://doi.org/10.2118/173340-MS.
- Reese, J.L., Britt, L.K., and Jones, J.R. 1994. Selecting Economic Refracturing Candidates. SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 25-28 September. SPE-28490-MS. https://doi.org/10.2118/28490-MS.
- ShaleProfile. 2019. Marcellus (PA) & Utica (OH) - update through June 2017, https://shaleprofile.com/2017/09/28/marcellus-pa-utica-oh-update-through-june-2017/ (accessed 4 March 2019)

Appendix: Correlation Coefficient Matrix

	Qi	Qi,r	bi	br	Di	Di,r
Qi	1	0.69	-0.53	-0.42	0.57	0.32
Qi,r	0.69	1	-0.32	-0.43	0.31	0.57
bi	-0.53	-0.32	1	0.72	-0.31	-0.4
br	-0.42	-0.43	0.72	1	-0.27	-0.41
Di	0.57	0.31	-0.31	-0.27	1	0.45
Di,r	0.32	0.57	-0.4	-0.41	0.45	1