Toward Sustainable and Efficient Hydraulic Fracturing: A Causal Machine Learning Approach to Geologically Informed Completion Design in Shale Oil Production

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This project aims to identify and quantify the causal effects of key completion design parameters on shale oil production in the Permian Basin in Texas. This causal inference analysis seeks to identify true causal relationships in the shale oil production process for improving operational efficiency and environmental sustainability under complex subsurface geological conditions. The project analyzes data from horizontal production wells with completion parameters and 12-month production records, along with vertical wells providing geological measurements (gamma ray, resistivity, porosity) from the Permian Basin. The project applies a causal Bayesian additive regression trees model to rigorously assess the heterogeneous causal effect of completion parameters on shale oil production, accounting for continuous treatments and complex spatial geological confounders. The results reveal that the causal effects of completion parameters depend on local geological conditions. Overall, the proppant per stage has the strongest positive causal effect on production, with optimal results occurring at 1.5 standard deviations above baseline before plateauing. Stage spacing shows diminishing returns beyond moderate widths, while tighter spacing maintains a relatively stable level. Completed lateral length exhibits a non-linear causal relationship with production, peaking at intermediate lengths before declining, suggesting diminishing returns from excessive extension. Stage intensity demonstrates a negligible impact on production outcomes. The findings provide valuable insights for completion optimization and support data-driven, causally informed strategies to improve both efficiency and environmental sustainability in hydraulic fracturing practices.

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