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Bayesian Decision Theory in Structural Geological Modeling – How Reducing Uncertainties Affects Reservoir Value Estimations

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Structural geological modeling is of central importance for the assessment of uncertain hydrocarbon accumulations in potential reservoirs. Hydrocarbon exploration and production is a high-risk, high-reward sector in which good decision making is indispensable. Actors in this field are faced with numerous uncertainties that have to be considered. We examine respective decision making from a Bayesian perspective by considering two main approaches: (1) we treat geological modeling as a Bayesian inference problem, so that additional geological information can be incorporated as likelihood functions linked to prior parameters in a probabilistic framework; (2) we base the decision-making step on value estimation by optimizing a case-specific loss function. This function is customized to reflect the decision making of differently risk-affine actors relative to previously computed reservoir value probability distributions.

We apply our approach to synthetic geological models which are constructed to represent potential hydrocarbon systems. Markov chain Monte Carlo sampling is used to approximate posterior models of reduced uncertainty. For the valuation of prior and posterior models, we also develop algorithms for automatic trap recognition and volume calculation.

Results show that the various Bayes estimators shift according to the characteristics of the underlying value distribution. While bimodality and overall uncertainty leads to separation, risk-averse and risk-friendly decisions converge and decrease in expected loss given narrower unimodal distributions. The degree of decision convergence is considered a measure for the state of knowledge and its inherent uncertainty at the moment of decision making. This decisive uncertainty does not change in alignment with model uncertainty but depends on alterations of critical parameters and respective interdependencies, in particular relating to seal reliability. Additionally, actors are affected differently by one set of information, depending on their risk affinity. It is therefore important to identify the model parameters which are most influential for the final decision in order to optimize the decision-making process.
Our results are so far applied to a generic hydrocarbon case study but transferable to other fields where decisions are based on uncertain geological models, for example in hydrogeological or geothermal exploration.