Research Statement

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My research interest lies at the intersection between Distributionally Robust Optimization and Mathematical Risk Theory. In particular, I am interested in developing new optimization and statistical techniques to solve and analyze decision problems in economics, finance, machine learning, and operations research, where risk and uncertainty are involved.

Nearly all decision-making processes are subject to risk and uncertainty. For example, retail business owners must decide the number of products to be ordered before the realization of actual demand. Financial risk managers are constantly rebalancing their investment portfolio based on estimations of future returns. To facilitate decision-making under risk and uncertainty, we need algorithms that can efficiently extract information from data, make proper risk assessments, and find optimal decisions within limited time frames.

In this research statement, I discuss my past work on stochastic optimization problems in risk-averse decision-making, highlight four main contributions from my PhD research, and outline my future research interests.

1 Past Work and Contributions

During my PhD at the University of Amsterdam, I studied decision problems in which risk and uncertainty are evaluated by state-of-the-art decision-theoretic models. More specifically, I focused on stochastic optimization problems where random objective functions are evaluated through a risk measure. Risk measures are mathematical functions that assess random outcomes in a way that more accurately captures risk aversion than the classical expected value. Stochastic optimization problems with a risk-averse objective function are challenging due to the nonlinearity of how risk measures compute probability. My first main contribution is the development of tractable optimization algorithms for solving stochastic optimization problems where the risk measures are based on rank-dependent utility (RDU) theory, introduced by Quiggin [1982]. RDU is well known in behavioral economics, and its extensions are widely used to model human decision-making behavior. As a result of my work, optimization under the RDU framework is now feasible using standard optimization packages in Python. Numerical examples are provided on my GitHub page: `https://github.com/GuanJinNL/Robust_Optimization_Risk_Measures`.

Another key challenge in solving stochastic optimization problems is addressing model uncertainty. These problems are typically defined for an unknown probability distribution. In risk-averse settings, model uncertainty is an even more severe issue, since risk measures are often sensitive to changes in the tail of the distribution. To address this, I use distributionally robust optimization (DRO), which replaces the unknown distribution with a set of plausible distributions, also known as the uncertainty or ambiguity set. However, it is generally unclear how to properly select an uncertainty set before applying the DRO methodology. Therefore, the second contribution of my PhD research is a systematic approach to constructing uncertainty sets for risk-averse stochastic optimization problems, which is important for making robust decisions in risky environments.

As a third contribution of my PhD research, I examined stochastic optimization problems in machine learning, where the goal is often to find the best learning model that trades between bias and variability. In statistics, this is also known as the bias-variance tradeoff, where variance serves as the standard measure of variability. However, variance does not always adequately represent variability within a population, since it measures deviation only relative to a single reference point (namely the expected value). This makes variance sensitive to outliers, which can deteriorate the performance of DRO models, as DRO is known for its variance regularization effect. By leveraging the connection between risk theory and DRO, I developed a new DRO model that is based on maxiance regularization, a variability measure motivated by RDU theory. This new DRO model is significantly more robust against outliers, and better suited for stochastic optimization problems involving heavy-tailed distributions.

The fourth part of my PhD research focuses on the statistical properties of Sample Average Approximations (SAA) for risk-averse stochastic optimization problems. SAA is a widely used method that estimates the optimal value of a stochastic optimization problem by replacing the unknown distribution with its empirical counterpart constructed from data. In machine learning, this approach is commonly known as empirical risk minimization. Because SAA is a statistical estimator, it is essential to examine its convergence to the true optimal value. My fourth contribution is a generic method that provides an upper bound on the probability of deviation between the SAA estimate and the true optimal value, explicitly depending on the sample size. This result enables the construction of a tight confidence interval that quantifies the accuracy of the SAA approximation, which is crucial for solving risk-averse stochastic optimization problems in practice.

2 Future research work

Currently, I am working on a follow-up to the fourth part of my PhD research, with the aim of improving the convergence rate of SAA estimation for risk-averse stochastic optimization problems. Achieving this will likely require new insights from empirical process theory and the theory of quantile processes.

Apart from investigating some of the open problems from my PhD research, I would also like to broaden my research profile in other areas of applied mathematics. In general, my research interests span the fields of Data-Driven Robust Optimization, Machine Learning Theory, Mathematical Statistics and Probability Theory, Actuarial Science and Quantitative Finance. In particular, I am interested in applications of these fields in finance, operations management, and industrial engineering.

References

John Quiggin. A theory of anticipated utility. *Journal of Economic Behavior and Organization*, 3(4):323–343, 1982.