

# Multi-Stage Stochastic Programming with CVaR: Modeling, Algorithms and Robustness

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## **Abstract:**

We formulate a multi-stage stochastic linear program with three different risk measures based on CVaR and discuss their properties, such as time consistency. The stochastic dual dynamic programming algorithm is described and its drawbacks in the risk-averse setting are demonstrated. We present a new approach to evaluating policies in multi-stage risk-averse programs, which aims to eliminate the biggest drawback – lack of a reasonable upper bound estimator. Our approach is based on an importance sampling scheme, which is thoroughly analyzed. A general variance reduction scheme for mean-risk sampling with CVaR is provided. In order to evaluate robustness of the presented models we extend contamination technique to the case of large-scale programs, where a precise solution cannot be obtained. Our computational results are based on a simple multi-stage asset allocation model and confirm usefulness of the presented procedures, as well as give additional insights into the behavior of more complex models.

## **Keywords:**

Multi-stage stochastic programming, stochastic dual dynamic programming, importance sampling, contamination, CVaR