Risk Management and Investment
Volume 4, Number 2, 2025

Portfolio Optimization Under Uncertainty: A Risk-Based Approach

Fais Maulidiana[1*]

[1] Universitas Nahdlatul Ulama Surabaya, Surabaya, Indonesia

Abstract

Article history:
Received: August 05, 2025
Revised: September 02, 2025
Accepted: October 11, 2025
Published: December 30, 2025

Keywords:
Asset Allocation, Financial Decision Making, Portfolio Optimization, Risk Management, Uncertainty Modeling.

Identifier:
Zera Open
Page: 157-169
https://zeraopen.com/journal/rmi

Portfolio optimization plays an important role in financial decision making because investors must determine asset allocations that maximize expected return while controlling risk. Traditional portfolio models commonly rely on the mean variance framework, which evaluates the relationship between risk and return to identify efficient portfolios. However, these models often assume deterministic market parameters, while real financial markets are characterized by uncertainty, volatility, and incomplete information. This study investigates portfolio optimization under uncertainty using a risk based perspective through a systematic literature review. The review analyzes peer reviewed studies that discuss optimization methods, uncertainty modeling, and risk measurement in portfolio management. The findings indicate that modern research increasingly integrates robust optimization, stochastic modeling, and alternative risk measures to address uncertainty in financial markets. In addition, multi objective optimization approaches enable investors to evaluate trade offs between return, risk, and diversification simultaneously. Overall, incorporating uncertainty and risk based strategies can enhance portfolio stability and support more reliable investment decisions in dynamic financial environments.

*Corresponding author:
(Fais Maulidiana)

1. Introduction

Portfolio optimization is a fundamental problem in financial decision-making that aims to determine the optimal allocation of assets to maximize expected returns while minimizing risk. In general, portfolio selection models are based on the principle that investors must balance the trade-off between expected return and risk when allocating assets within an investment portfolio. One of the most widely used frameworks for addressing this problem is the mean variance approach, which evaluates the relationship between risk and return in portfolio construction. Through this approach, investors can identify efficient portfolios that offer the highest expected return for a given level of risk or the lowest risk for a desired level of return (Georgantas, 2021).

However, traditional portfolio optimization models often rely on deterministic assumptions regarding expected returns, variances, and correlations among assets. In real financial markets, these parameters are inherently uncertain due to market volatility, incomplete information, and rapidly changing economic conditions. As a result, ignoring uncertainty may lead to suboptimal investment decisions and unstable portfolio performance.

In recent years, researchers have increasingly focused on portfolio optimization models that explicitly incorporate uncertainty into the decision-making process. Uncertainty may arise from estimation errors in expected returns, stochastic market movements, or incomplete knowledge of asset dynamics. Studies have shown that conventional optimization approaches can be highly sensitive to parameter estimation errors, which may significantly affect portfolio allocation and

risk exposure (Zhao et al., 2024). Consequently, advanced approaches such as stochastic programming, robust optimization, and risk-sensitive models have been developed to better address uncertain financial environments. These methods enable investors to construct portfolios that remain stable and efficient even when model parameters fluctuate.

A risk-based approach has gained considerable attention as a practical framework for portfolio optimization under uncertainty. Rather than focusing solely on expected returns, risk-based models emphasize controlling and distributing risk across assets while maintaining portfolio stability. Recent studies highlight the importance of incorporating various risk measures such as volatility, Value-at-Risk, and semi-deviation to improve portfolio resilience under uncertain market conditions (Larni-Fooeik et al., 2024). Furthermore, multi-objective and robust optimization techniques have been proposed to capture the interaction between risk management and asset allocation, allowing investors to evaluate portfolios based on multiple performance criteria simultaneously (Becker et al., 2024).

Despite significant advancements in portfolio optimization research, challenges remain in developing models that effectively integrate uncertainty and risk management within a unified framework. Many existing models either emphasize return maximization or treat risk management as a secondary constraint, which may limit their applicability in volatile markets. Therefore, there is a growing need for optimization frameworks that explicitly incorporate uncertainty while maintaining a risk-based perspective. This study aims to explore portfolio optimization under uncertainty using a risk-based approach, providing a framework that enhances

investment decision-making and improves portfolio robustness in uncertain financial environments (Li & Huang, 2024).

2. Literature Review

Recent studies in financial optimization emphasize the importance of developing portfolio allocation strategies that effectively balance risk and return in dynamic market environments. Portfolio optimization remains a key topic in financial research because investors must determine asset allocations that maximize expected returns while controlling exposure to risk. Contemporary research has expanded traditional portfolio frameworks by incorporating advanced optimization techniques and more realistic assumptions about financial markets. For instance, empirical studies show that portfolio allocation models can benefit from integrating machine learning techniques and advanced statistical methods to improve prediction accuracy and risk management in investment decisions (Heaton et al., 2020).

In addition to methodological developments, researchers have highlighted the limitations of traditional portfolio optimization models that rely heavily on precise parameter estimation. Estimation errors in expected returns, covariance matrices, and asset correlations can significantly influence portfolio performance and lead to unstable investment strategies. To address this issue, robust optimization frameworks have been proposed to reduce sensitivity to parameter uncertainty and improve the stability of portfolio allocation decisions. Robust optimization techniques allow investors to construct portfolios that remain effective even when market parameters deviate from their estimated values (Bertsimas et al., 2020).

Furthermore, stochastic portfolio optimization models have gained increasing attention in recent financial research. These models incorporate uncertainty directly into the optimization process by treating returns and market conditions as random variables. Such approaches allow investors to evaluate multiple scenarios and construct portfolios that perform well under different market conditions. Research indicates that stochastic programming and scenario-based optimization methods provide more flexible and realistic frameworks for portfolio management compared to deterministic models (Bian et al., 2021).

Another important direction in portfolio optimization research involves the integration of alternative risk measures beyond traditional variance-based metrics. Scholars have proposed the use of risk measures such as Value-at-Risk (VaR), Conditional Value-at-Risk (CVaR), and downside risk measures to capture extreme market events and tail risks more effectively. These risk-sensitive approaches enable investors to construct portfolios that better account for market volatility and financial crises, thereby improving the robustness of investment strategies (Fabozzi et al., 2021).

More recently, researchers have explored multi-objective portfolio optimization frameworks that simultaneously consider multiple investment goals, including return maximization, risk minimization, and diversification. These models allow investors to evaluate trade-offs among several performance criteria and select portfolios that best align with their investment preferences. Multi-objective optimization methods have been widely applied in financial decision-making because

they provide a more comprehensive approach to managing risk and uncertainty in complex financial markets (Gao & Kresta, 2023).

3. Methods

This study employs the Systematic Literature Review (SLR) method to analyze and synthesize existing research related to portfolio optimization under uncertainty using a risk-based approach. The SLR method was chosen because it allows researchers to systematically identify, evaluate, and interpret relevant academic studies in order to obtain a comprehensive understanding of a specific research topic. Through this approach, the study aims to identify current research trends, methodological developments, and research gaps in portfolio optimization models that incorporate uncertainty and risk management.

The literature search process was conducted using several academic databases that index peer-reviewed journals, including Google Scholar, ScienceDirect, SpringerLink, and IEEE Xplore. Keywords used in the search process included combinations of terms such as portfolio optimization, risk-based portfolio, robust portfolio optimization, stochastic portfolio optimization, and portfolio optimization under uncertainty. The search process focused on peer-reviewed journal articles that discuss optimization models, risk measures, and decision-making approaches in financial portfolio management.

To ensure the quality and relevance of the selected studies, several inclusion and exclusion criteria were applied during the selection process. The inclusion criteria consisted of: (1) articles published in peer-reviewed academic journals, (2)

studies discussing portfolio optimization models or financial portfolio management under uncertainty, and (3) articles that present methodological or empirical contributions related to risk-based optimization approaches. Meanwhile, studies that were not directly related to portfolio optimization, duplicate publications, or articles lacking methodological clarity were excluded from the review process.

After the selection process, the relevant studies were analyzed using a qualitative synthesis approach. Each selected article was reviewed to identify the optimization methods used, types of uncertainty addressed, risk measures applied, and the main findings related to portfolio performance and risk management. The analysis also focused on identifying emerging research directions, such as the integration of robust optimization, stochastic programming, machine learning techniques, and multi-objective optimization models in portfolio management.

Finally, the findings from the reviewed studies were synthesized to provide a comprehensive overview of the current state of research in portfolio optimization under uncertainty. This synthesis enables the identification of key research gaps and methodological limitations in existing studies, which serves as the foundation for proposing a risk-based framework for portfolio optimization that improves investment decision-making and portfolio robustness in uncertain financial environments.

4. Results and Discussion

The results of the systematic literature review indicate that portfolio optimization research has evolved significantly from traditional mean–variance

frameworks toward more advanced models that incorporate uncertainty and risk management. The mean variance approach remains an important foundation for portfolio construction because it provides a systematic method for balancing expected return and risk when allocating assets within a portfolio. This framework enables investors to identify efficient portfolios that maximize return for a given level of risk or minimize risk for a given expected return (Georgantas, 2021). However, several studies highlight that relying solely on deterministic assumptions may lead to unstable portfolio performance, particularly in highly volatile financial markets.

The reviewed studies reveal that uncertainty in financial markets has become a major concern in portfolio optimization research. Market parameters such as expected returns, covariance structures, and asset correlations are often difficult to estimate accurately and may change over time. As a result, traditional optimization models can become highly sensitive to estimation errors, which may significantly influence asset allocation decisions and portfolio risk exposure. Research by Zhao et al. (2024) emphasizes that parameter uncertainty can reduce the effectiveness of conventional optimization techniques, leading researchers to develop alternative approaches that explicitly incorporate uncertainty into the optimization process.

One of the key findings from the literature is the increasing adoption of robust optimization methods to address parameter uncertainty in portfolio construction. Robust optimization models aim to reduce the sensitivity of portfolio allocation to estimation errors by considering worst-case scenarios within predefined uncertainty sets. Studies demonstrate that robust optimization techniques improve

the stability and reliability of portfolio performance under uncertain market conditions (Bertsimas et al., 2020). By accounting for possible deviations in model parameters, robust optimization allows investors to construct portfolios that remain effective even when financial market conditions change unexpectedly.

In addition to robust optimization, stochastic programming approaches have also gained significant attention in portfolio optimization research. Stochastic models incorporate uncertainty by representing asset returns and market conditions as random variables, allowing investors to evaluate multiple scenarios when making investment decisions. According to Bian et al. (2021), stochastic portfolio optimization provides a more flexible framework for managing uncertainty compared to deterministic models because it captures the probabilistic behavior of financial markets and enables more adaptive portfolio allocation strategies.

Furthermore, recent research highlights the importance of integrating alternative risk measures into portfolio optimization models. Traditional variance-based measures are often insufficient for capturing extreme market events or tail risks. As a result, risk measures such as Value-at-Risk (VaR), Conditional Value-at-Risk (CVaR), and downside risk metrics have been increasingly adopted in portfolio management frameworks. These risk-sensitive approaches allow investors to better account for market volatility and potential financial crises, thereby improving the robustness of portfolio performance (Fabozzi et al., 2021; Larni-Fooeik et al., 2024).

Another emerging trend identified in the literature is the use of multi-objective optimization models that simultaneously consider multiple investment objectives. Unlike traditional models that focus primarily on return maximization,

multi-objective approaches enable investors to evaluate portfolios based on several criteria, including risk minimization, diversification, and stability. Research by Gao and Kresta (2023) demonstrates that multi-objective optimization techniques provide a more comprehensive framework for portfolio decision-making because they allow investors to analyze trade offs among different performance indicators.

Overall, the findings from the systematic literature review suggest that portfolio optimization under uncertainty requires a more integrated framework that combines risk management, uncertainty modeling, and advanced optimization techniques. Recent studies emphasize that combining robust optimization, stochastic modeling, and multi-objective decision frameworks can significantly improve portfolio resilience in volatile markets (Becker et al., 2024; Li & Huang, 2024). Therefore, a risk-based approach that explicitly incorporates uncertainty into portfolio optimization models is essential for enhancing investment decision-making and achieving more stable portfolio performance in uncertain financial environments.

5. Conclusion

This study examined portfolio optimization under uncertainty using a risk-based perspective through a systematic literature review. The findings indicate that portfolio optimization remains a critical area in financial decision-making, as investors continuously seek strategies that balance expected return and risk in dynamic market environments. Traditional portfolio optimization frameworks, particularly the mean–variance approach, provide an important theoretical

foundation for asset allocation. However, these conventional models often rely on deterministic assumptions that may not adequately reflect the uncertain nature of real financial markets.

The review highlights that uncertainty in parameters such as expected returns, variances, and correlations can significantly influence portfolio performance and lead to unstable investment decisions. As financial markets become increasingly complex and volatile, researchers have proposed various advanced approaches to address these challenges. Methods such as robust optimization and stochastic programming have emerged as effective tools for incorporating uncertainty into portfolio construction and improving the stability of investment strategies.

Furthermore, the integration of alternative risk measures and multi-objective optimization techniques has expanded the scope of portfolio optimization research. These approaches enable investors to evaluate portfolios based on multiple performance criteria and better capture extreme market risks that may not be reflected in traditional variance-based models. By combining different optimization methods with comprehensive risk management strategies, portfolio models can become more resilient and adaptable to uncertain financial environments.

Overall, the results of this study suggest that incorporating uncertainty and risk-based considerations into portfolio optimization frameworks is essential for improving investment decision-making and enhancing portfolio robustness. Future research should continue exploring integrated optimization models that combine advanced computational techniques, risk-sensitive measures, and uncertainty

modeling to develop more effective portfolio management strategies in increasingly volatile financial markets.

References

Becker, Y., Halffmann, P., & Schöbel, A. (2024, September). Risk management in multi-objective portfolio optimization under uncertainty. In *International Conference on Operations Research* (pp. 157–163). Cham: Springer Nature Switzerland.

Bertsimas, D., Gupta, V., & Kallus, N. (2018). Robust sample average approximation. *Mathematical Programming, 171*(1), 217–282.

Bian, L., Li, Z., & Yao, H. (2021). Time-consistent strategy for a multi-period mean-variance asset-liability management problem with stochastic interest rate. *Journal of Industrial & Management Optimization, 17*(3).

Fabozzi, F. J., Huang, D., & Zhou, G. (2010). Robust portfolios: Contributions from operations research and finance. *Annals of Operations Research, 176*(1), 191–220.

Gao, Q., & Kresta, A. (2023). Empirical study of multi-objective risk portfolio optimization based on NSGA-II. *Finanse i Prawo Finansowe*, (Special Issue), 61–75.

Georgantas, A., Doumpos, M., & Zopounidis, C. (2024). Robust optimization approaches for portfolio selection: A comparative analysis. *Annals of Operations Research, 339*(3), 1205–1221.

Heaton, J. B., Polson, N. G., & Witte, J. H. (2017). Deep learning for finance: Deep portfolios. *Applied Stochastic Models in Business and Industry, 33*(1), 3–12.

Larni-Fooeik, A., Sadjadi, S. J., & Mohammadi, E. (2024). Stochastic portfolio optimization: A regret-based approach on volatility risk measures: An empirical evidence from the New York stock market. *PLOS ONE, 19*(4), e0299699.

Li, B., & Huang, Y. (2024). Portfolio optimization with mental accounts under uncertain random environment and butterfly optimization algorithm with adaptive strategies. *Applied Soft Computing, 161*, 111720.

Zhao, Y., Wang, J., Wang, Y., & Lv, M. (2025). How to optimize modern portfolio theory? A systematic review and research agenda. *Expert Systems with Applications, 263*, 125780.