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Exploring the Evolution of Robust Portfolio Optimization: A Scientometric Analysis

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Abstract

In the wake of recent turbulent events in the global economy, the need for robust methods to navigate uncertainties in financial markets has become increasingly apparent. Robust portfolio optimization (RPO) offers a solution by devising investment strategies that perform well even under adverse scenarios of uncertain inputs such as returns and covariances. This paper conducts a systematic review of recent developments and extensions in the field of RPO. Leveraging bibliometric analysis and visual mapping techniques, we scrutinize 1085 articles published between 2000 and 2023. Our analysis traces the evolution and trends within RPO, examining the interconnectedness among articles, authors, sources, countries, and keywords. The insights gleaned from our study can guide future research endeavors in this domain and aid practitioners in making more informed investment decisions.

Keywords:
Bibliometric Analysis, Financial Markets, Robust Portfolio Optimization, Uncertainty, Scientometric Analysis

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1. Introduction

The capital market represents the country's international development and is a critical tool for determining its economy's main direction (Fooeik et al., 2022; Ghanbari et al., 2022). Individuals, brokers, and fund managers invest billions of dollars annually in the capital markets. Thus, choosing which options to invest in to get the highest return with the least investment risk has become an important issue among economic activists (Kalayci et al., 2019). Constructing a portfolio of assets is one of the most common investment strategies in this regard. The problem of portfolio optimization (PO) is crucial when allocating funds optimally among financial assets to maximize return and minimize risk. A key study in PO was Markowitz's Mean-Variance (MV) model, which established the modern era of portfolio theory. In addition to considering the return on investment, in 1952, Markowitz suggested that the covariance between securities as a risk measure should also be considered when selecting assets to invest in. Yet, according to the academic literature, modern portfolio management has several shortcomings and offers mixed results, particularly in light of the 2007-2009 financial crisis shocks (see (Jobson and Korkie, 1981; Arreola Hernandez et al., 2017; Best and Grauer, 1991; Schubert, 2009)). To address the shortcomings of the early MV model, new constraints, objectives, and approaches were developed ((Sharpe, 1963; Konno and Yamazaki, 1991; Rockafellar and Uryasev, 1999; Skoruchi and Mohammadi, 2022)). As a result, the literature on PO problems has grown significantly in both volume and variety, allowing a diversity of classification systems to be used.

An obvious classification of the PO problem is to optimize the risk measure. In addition to using the variance of returns alone to define investment risk, several risk measures can provide a more accurate picture of risk in investments (Ortobelli et al., 2005; Buehler et al., 2019). In this case, researchers proposed a number of criteria for risk assessment, each of which addressed an aspect of the uncertainty debate and in some cases complemented each other (Ghanbari et al., 2023). In general, two main categories of risk measures have been proposed: volatility-based and downside-based (Catania and Luati, 2021; Mensi et al., 2019). While volatility risk measures refer to the fluctuation of a variable around a mean or other random parameter, downside risk measures examine only the destructive part of the risk, focusing on harmful fluctuations. Downside risk measures can be classified into two categories: semi-risk and quantile-based. Measures such as semi-variance (Rubinstein, 2002) and semi-standard deviation (Ledoit and Wolf, 2003) belong to the group of semi-risk measures, and measures such as Value-at-Risk (VaR) (Jorion, 2007) and Conditional-Value-at-Risk (CVaR) or expected shortfall (Rockafellar and Uryasev, 2002) belong to the group of quantile-based measures. In the context of volatility risk measures, which include mean-variance (Goldfarb and Iyengar, 2003), mean absolute deviation (Demiguel et al., 2007), lower partial moment (Fishburn, 1977), systematic risk (Sharpet, 1964), and factor-based portfolio models (Fama and French, 1992), Sharpe (1966) and Bernardo and Ledoit (2000) introduced the Sharpe Ratio and Omega Ratio, respectively, to evaluate portfolio performance simultaneously based on risk and return.

The literature on the mean-variance PO problems usually assumes that the problem parameters are known with certainty ignoring estimation errors. However, this framework requires the estimation of both the mean and the covariance matrices of the asset returns. These parameters are virtually unknown, and the resulting optimal solution heavily depends on the quality of the estimated parameters, which are based on some assumptions that may or may not hold (Eskorouchi et al., 2022). In other words, we live in an uncertain world where many uncertain factors affect asset returns. In this case, several approaches have been proposed in the literature to reduce the parameter sensitivity of PO models (see (Goldfarb and Iyengar, 2003) for a comprehensive list of these approaches and relevant research). Different approaches in the literature for handling uncertainty in mathematical programs include stochastic programming and robust methodology. The stochastic programming

methodology uses a decision tree and considers all possible scenarios. This makes the approach hard to solve because the resulting program dimension increases exponentially as the problem size increases (Masmoudi and Abdelaziz, 2018). Recent advances in robust Optimization have focused on developing methods to handle uncertainty in optimization problems by explicitly accounting for parameter uncertainty and optimizing worst-case performance over a set of plausible scenarios (Lu et al., 2022).

Robust Optimization has become an increasingly popular area of research over the past two decades, especially for problems with significant uncertainty in the input parameters (Dauod et al., 2019). One of the first approaches to robust Optimization was presented by Soyster (Soyster, 1973), but his method was criticized for being overly pessimistic and conservative. In response, Ben-Tal and Nemirovski (1999) developed a new robust method that was more optimistic and allowed for a wider range of possible outcomes. Their method uses an interior point-based algorithm to find the robust solution on a counterpart of the initial model. It includes a parameter Ω that controls the probability of deviation from the nominal constraints. While the implementation of Ben-Tal and Nemirovski's method changes an ordinary linear programming problem into a convex nonlinear problem, it has been shown to be effective in many PO problems, where the final optimal solution remains feasible despite uncertainty in different input parameters. Bertsimas and Sim (2003) developed a robust optimization approach aiming to preserve as much of the original problem structure as possible. Their method involves reformulating the robust optimization problem as a second-order cone program, which can be solved efficiently using standard optimization software. This approach has the advantage of maintaining the same problem structure as the original problem, which can be important for some applications. Additionally, their method may not provide solutions that are as optimistic as other robust optimization methods. Still, it has the advantage of being more accessible to practitioners accustomed to regular optimization techniques. Bertsimas and Sim's approach is effective in a wide range of applications, including PO, supply chain management, and transportation planning.

Robust portfolio optimization (RPO) aims to combat the sensitivity of optimal portfolios to errors in input estimates by imposing the model's constraints over a set of plausible parameter values rather than a single most likely value (Sadjadi et al., 2012). The new robust optimization problem is then solved, assuming the worst-case behavior within the plausible set of the parameter values (Lutgens and Sturm, 2003). Given the rising interest in RPO, several reviews have identified key findings and trends in the field, including developing new methods and their application to real-world problems, as indicated in Table 1.

Goldfarb and Iyengar (2003) introduced approaches for addressing RPO issues by reforming uncertainty frameworks into second-order cone programs. Zhang et al. (2017) presented an overview of enhanced iterations of the mean-variance portfolio selection model, incorporating robust Optimization. Milhomem and Dantas (2020) provided a comprehensive overview of exact and heuristic methods, software/programming languages, constraints, and types of analysis to solve the PO problem, emphasizing the importance of robust optimization techniques, fuzzy logic, and forecasting to mitigate estimation errors, with implications for both researchers and investors, along with identified trends and gaps for future exploration. Xidonas et al. (2020) compiled a categorized bibliography focused on applying robust mathematical programming to address issues in portfolio selection. Ghahtarani et al. (2022) provided an organized bibliography on robust mathematical programming for portfolio selection, providing a convenient resource for accessing relevant research and exploring future avenues.

Table 1. A selection of previous reviews on RPO

Year	Authors	Key Contribution
2003	Goldfarb and Iyengar	Presented methods to solve robust portfolio selection problems using uncertainty structures, reformulated as second-order cone programs.
2018	Zhang et al.	Provided a review of improved versions of the mean-variance portfolio selection model, including robust Optimization.
2020	Milhomem and Dantas	Explored methods of PO, focusing on robust techniques and forecasting to reduce estimation error, with implications for researchers and investors, highlighting trends and future research opportunities.
2020	Xidonas et al.	Provided a categorized bibliography on the application of robust mathematical programming to the portfolio selection problem.
2022	Ghahtarani et al.	Presented a categorized bibliography on robust mathematical programming for portfolio selection, offering quick access to related research and future directions.

This research aims to conduct a comprehensive Scientometric study in the area of RPO and provides an overview of the recent and current developments in this area.

In summary, the contributions of this research are highlighted as follows: 1) This study pioneers the incorporation of Scientometric analysis into the research topic by employing VOSviewer and Bibliometric tools, offering an effective framework for shaping and comprehending RPO. 2) This research categorizes a diverse array of documents related to the investigation of RPO. 3) Opportunities for further research can be revealed by applying maps of networks and conducting reviews of topic clusters, allowing for identifying emerging themes from both empirical and theoretical literature.

The structure of this paper is organized as follows: In Section 2, we demonstrate the data and methodology used in this review. Subsequently, we present the results of a bibliometric analysis that highlights recent trends in the research area under investigation. This analysis also provides an overview of the most influential authors, journals, affiliations, and documents. Section 4 contains a discussion of the strengths and limitations of the study. Finally, Section 5 concludes the paper and discusses future research directions.

2. Materials and methods

In the era of "Big Science" keeping up with all contributions and reviewing all scientific publications has become difficult for the research community (Zabavnik and Verbič, 2021). Bibliometrics solves this problem by providing statistical measures for evaluating the literature on a particular research area (Aria and Cuccurullo, 2017). Bibliometric analysis is a useful way to measure the influence of publications in the scientific community by statistically evaluating published articles, books, or book chapters (Broadus, 1987). There has been a growing interest in bibliometric analysis recently, with its applications being widely adopted in various scientific fields (Motamedi, 2023; Amiri et al., 2023; Wan et al., 2023). However, the application of bibliometric analysis in finance, particularly in the PO, is relatively new, and only a few researchers have focused on this subject in recent years. This paper focuses primarily on conducting a bibliometric analysis to identify emerging trends, outstanding publications, articles, journals, authors, countries, and institutions that have significantly impacted the development of the research area under investigation.

Bibliometric analysis requires the collection of relevant documents to create a database. To achieve this, it is crucial to define appropriate search terms in databases such as Web of Science and Scopus. The search terms must be carefully selected to ensure they retrieve documents relevant to the research

topic and are comprehensive enough to enable bibliometric analysis (Kilani and Kobziev, 2016; Xiang, 2014). This study adopted a two-step methodology to determine the final search terms. Firstly, we reviewed the literature to identify relevant keywords, see Table 1. Subsequently, we consulted subject matter experts and brainstormed amongst ourselves to finalize the search terms. The resulting list of keywords included "Portfolio Optimization", "Portfolio Selection", "Robust", and "Robustness".

Table 2. The main keyword combination structure

Level	Search Terms
1	Portfolio
	AND
2	Optimization OR Selection
	AND
3	Robust*

Based on the list of keywords extracted from Table 2, a search query was constructed using the "AND" and "OR" operators to obtain relevant documents from the Web of Science database. A total of 1,085 documents published between 2000 and 2023 were retrieved. After reviewing document titles and abstracts, 85 articles were excluded as irrelevant, leaving 1,000 articles for further analysis using Scientometrics. The bibliometric data collected included article titles, abstracts, keywords, full-text publications, and references. Figure 1 provides an overview of the bibliometric analysis procedure. It's worth noting that the collected data was cleansed of duplicates and erroneous entries before conducting the bibliometric analysis. The Web of Science is a vast bibliographic database containing scholarly literature from a wide range of fields (Dzikowski, 2018).

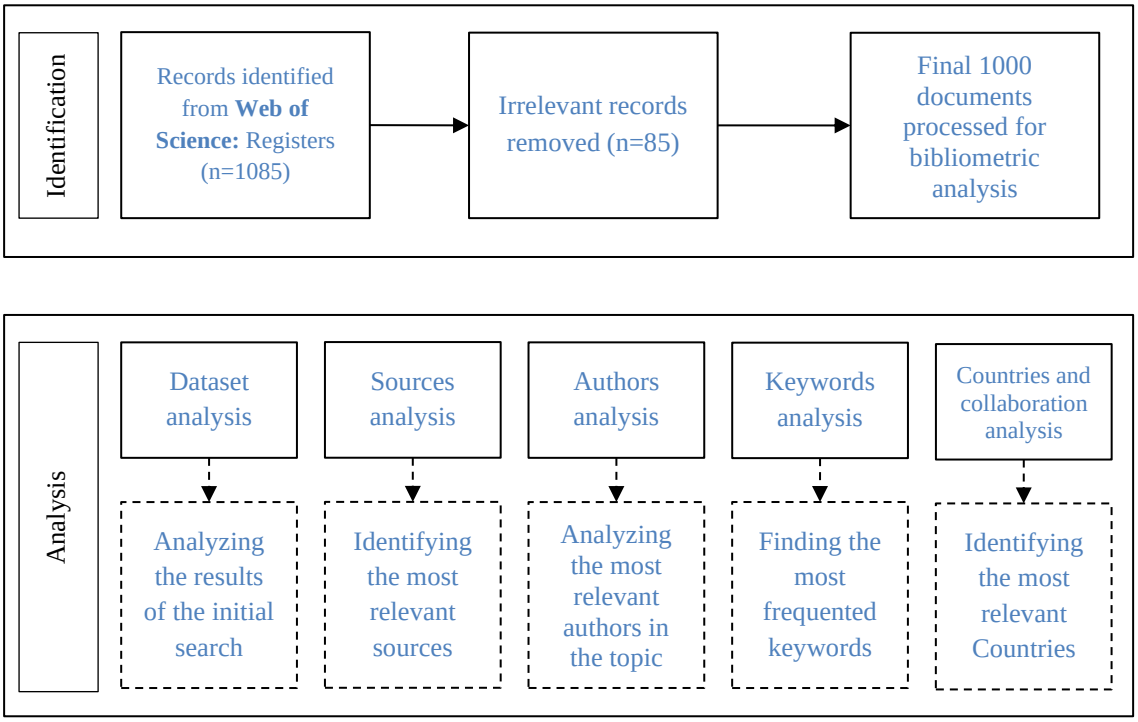

Figure 1. Literature Search Strategy

3. Bibliometrics analysis

The findings of this study have been categorized into five distinct subsections, including dataset analysis, source analysis, keywords analysis, authors analysis, and countries and collaboration analysis. Each subsection provides a comprehensive overview of the bibliometric data collected and analyzed.

3.1 Dataset analysis

Out of the 1000 documents selected for this study, a total of 440 sources and 2056 authors were identified. Table 3 provides a summary of the general information related to the papers analyzed in this study.

Table 3. An overview of the descriptive information

Description	Results
Timespan	2000:2023
Sources (Journals, Books, etc.)	440
Documents	1000
Annual Growth Rate %	8.83%
Document Average Age	6.670
Average citations per doc	17.200
References	23118
Author's Keywords (DE)	2479
Authors	2056
Authors of single-authored docs	83
Co-Authors per Doc	2.830

The document types are summarized in Figure 2, and as shown, the majority of the documents are articles.

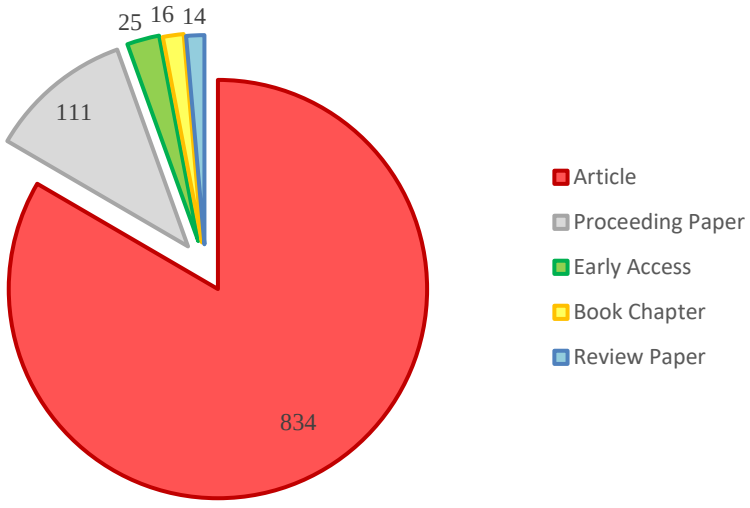

Figure 2. An overview of the type of the document

Figure 3 demonstrates a significant increase in the number of studies published in recent years, indicating a growing interest from the academic community. The annual growth rate has risen from one document in 2000 to over 100 documents in 2022. Figure 4 depicts the average annual citation

count, with 2003 exhibiting the highest value.

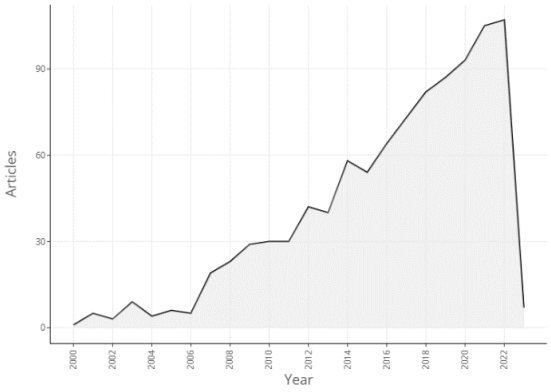

Figure 3. Annual scientific production

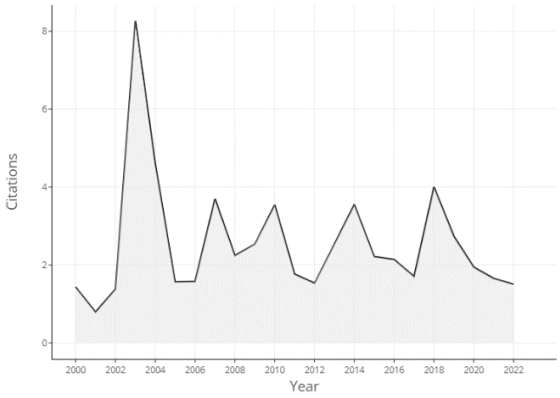

Figure 4. Average article citation per year

3.2 Sources analysis

Figure 5 presents a ranking of sources based on the number of articles published on RPO. The results indicate that this area has received significant attention, with a large number of articles being published in the European Journal of Operation Research (68), followed by Annals of Operation Research (30) and Quantitative Finance (23), respectively. These findings suggest that these sources are important references for researchers interested in this field. In Figure 6, the top 10 sources are ranked based on their h-index. The h-index is a quantitative measure that assesses the overall impact of researchers, journals, countries, and institutions and has been widely used since its introduction in 2005 (Hirsch, 2010). The European Journal of Operation Research and the Journal of Banking and Finance have the highest h-index among the analyzed sources, indicating their significant impact and influence.

Figure 5. Distribution of documents across sources

Figure 6. Top sources by H-index

This section analyzes the most impactful sources in the field of RPO. Figure 7 depicts the distribution of the most cited sources. The European Journal of Operation Research is ranked top with 1794 citations, followed closely by the Journal of Finance with 1552 citations.

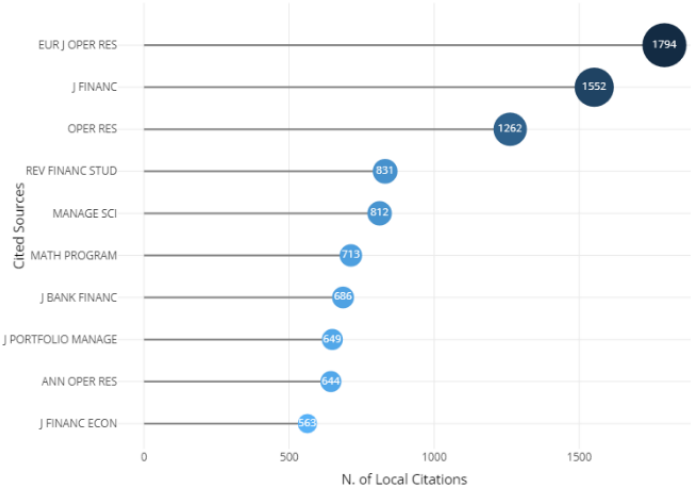

Figure 7. Most local cited resources

Bradford's Law is a bibliometric principle that states that the most frequently cited sources in a field tend to be concentrated in a small number of core journals or sources, followed by a larger number of less-cited sources. In the case of RPO, Figure 8 shows that only ten journals are included in zone 1 or the core area, which are the most frequently cited in the literature on this subject.

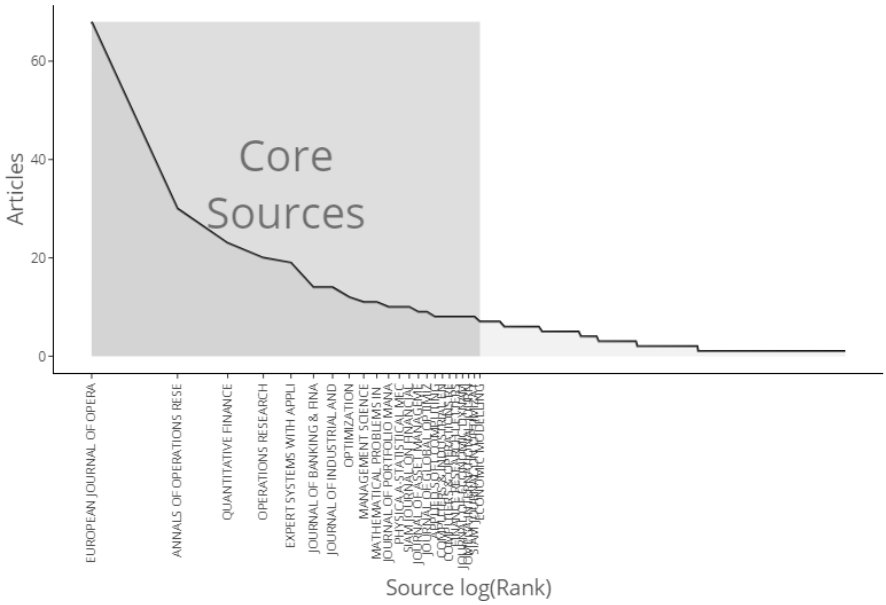

Figure 8. Source clustering through Bradford's Law

3.3 Authors Analysis

Figure 9 displays the top ten most influential authors based on the number of published articles in the field of RPO.

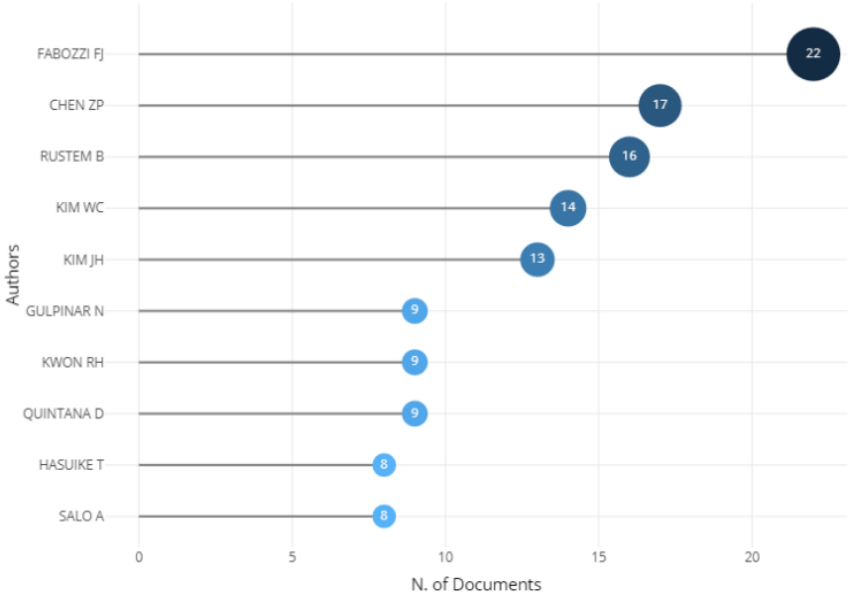

Figure 9. Number of publications by authors

Figure 10 presents the top authors and their publications on RPO analysis over the years. The intensity of color in the graph corresponds to the citation year, while the bubble size represents the number of articles published by each author in a given year. For instance, Fabozzi published his first article on this topic in 2006. The following year, he published two more papers and another one in 2008.

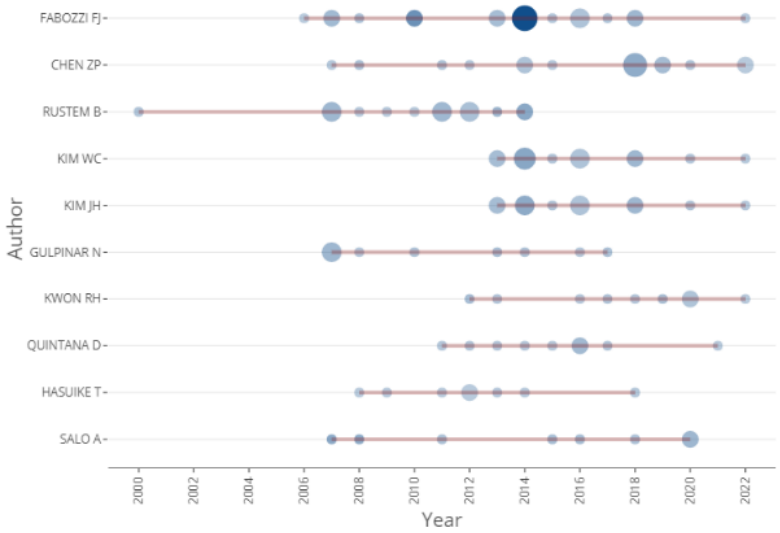

Figure 10. Top authors' production over time

3.4 Keywords Analysis

The most frequent keywords in the 2000–2023 period are presented in Figure 11.

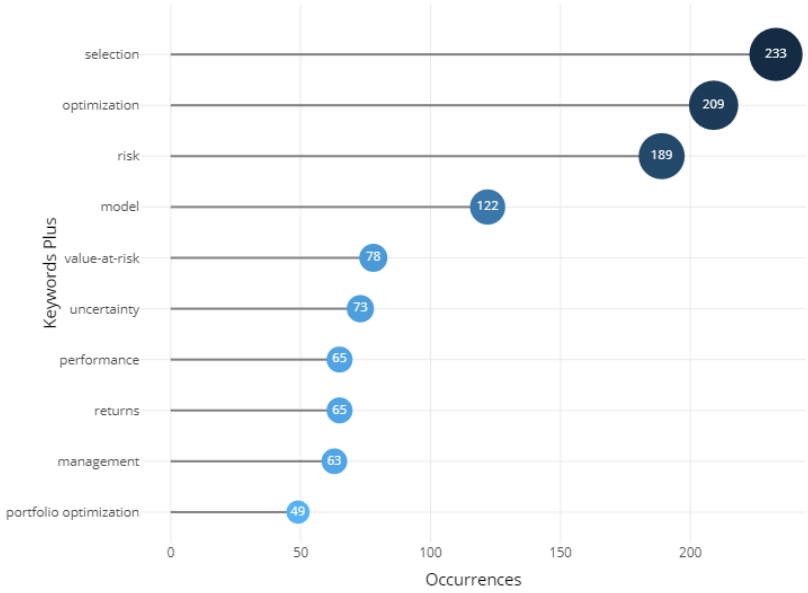

Figure 11. The most frequent keywords

In addition to identifying research topics, keyword analysis enables the study of their evolution over time. Figure 12 presents an overlay visualization of the keyword network.

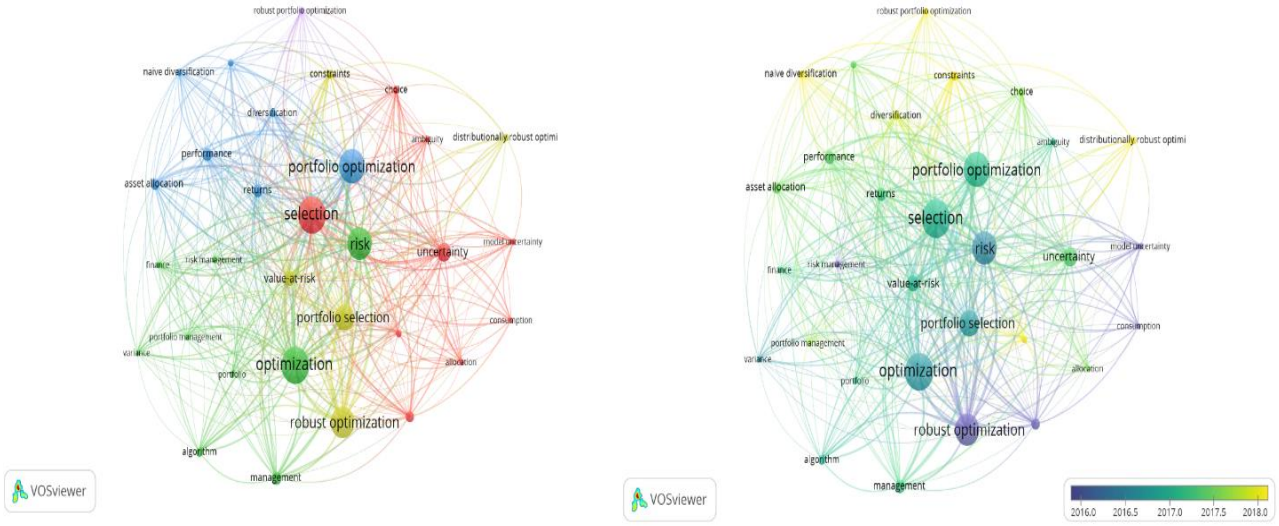

Figure 12. Network of co-occurring keywords

A trending topic analysis is an essential mapping tool that helps demonstrate the evolution of literature. Figure 13 illustrates the topics identified by examining the author's keywords.

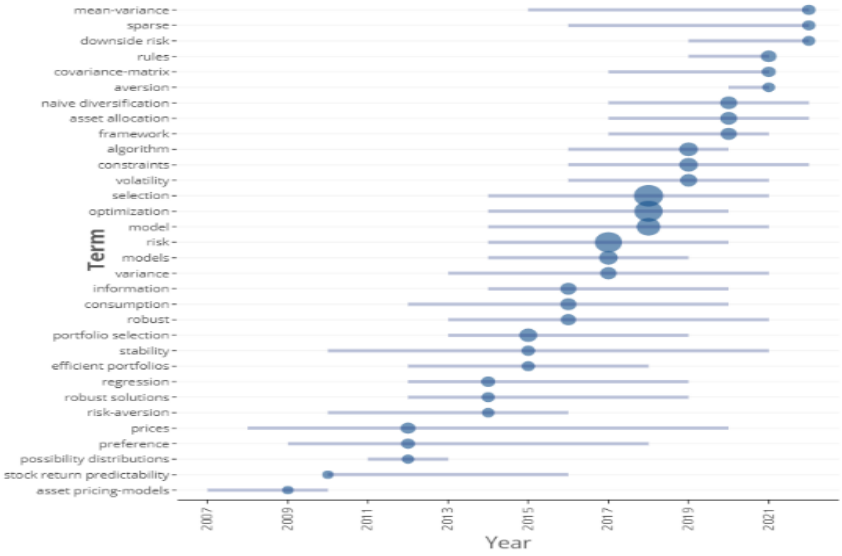

Figure 13. Trend topic over the year

The co-word or co-occurring keywords analysis identifies the most significant keywords in the analyzed bibliographic records. It helps determine which categories of analysis are most relevant in the field of study, with a larger size indicating a higher frequency. Figure 14 illustrates the co-occurring keyword analysis.

Figure 14. Word Cloud

The thematic map produced through this analysis presents a segmentation into four topic quadrants based on the density and centrality of the issues depicted in Figure 15. The upper-right quadrant, characterized by high density and centrality, features themes that require more profound scrutiny and examination. The analysis identified 13 major clusters of keywords, which can provide valuable insight into the field of study.

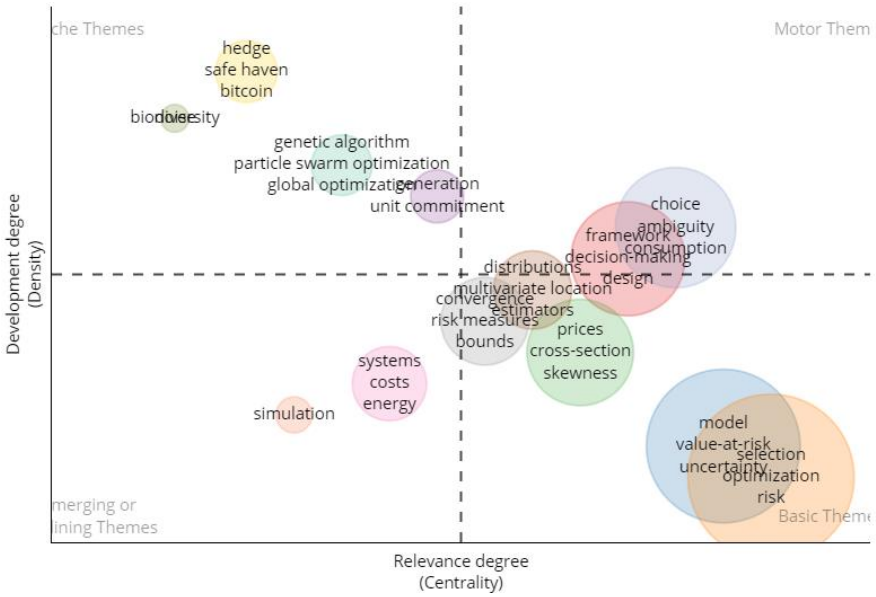

Figure 15. Thematic map

Thematic evolution is a bibliometric technique that provides a historical perspective on research and contributes to a science-based paradigm for directing further research themes. It emphasizes the most significant research themes of evolution across time, providing insights into the area's future direction (Moral-Munoz et al., 2018). Figure 16 illustrates the progression of the most frequently used terms in the study of RPO based on the co-occurrence network from 2000 to 2023. Two periods were selected as cut-off points: 2010 and 2020.

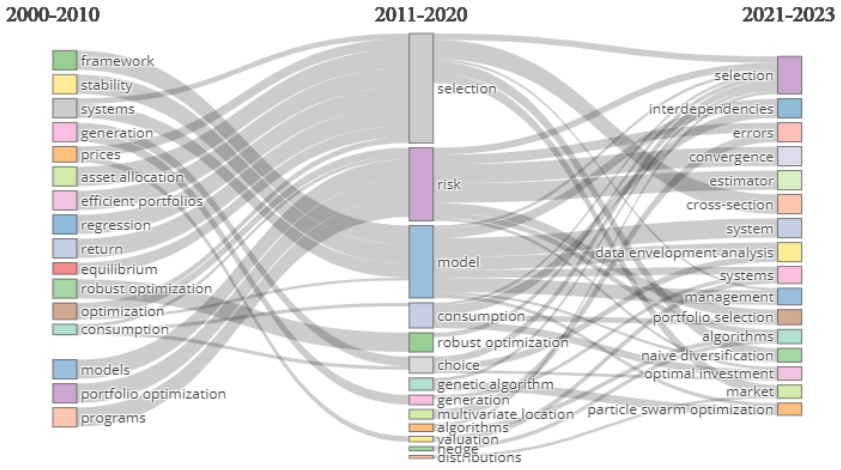

Figure 16. Thematic evolution

3.5 Countries and Collaboration Analysis

According to the bibliometric analysis conducted, the top countries contributing to research in the field of RPO, based on the number of citations, are the United States, China, France, the United Kingdom, and Canada, with 4192, 2258, 1469, 1292, and 1222 citations respectively. Figure 17 illustrates this distribution of citations among countries.

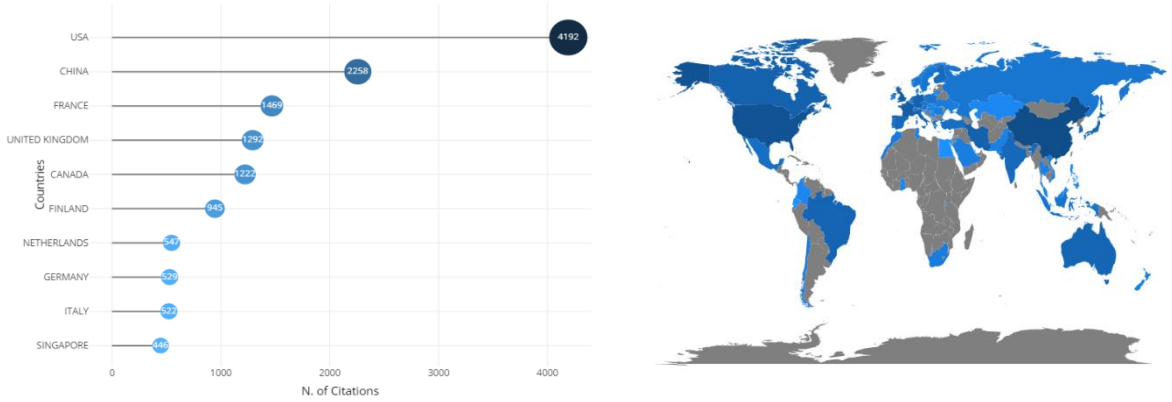

Figure 17. Top Contributing Countries

The production of these five top countries over time is shown as follows:

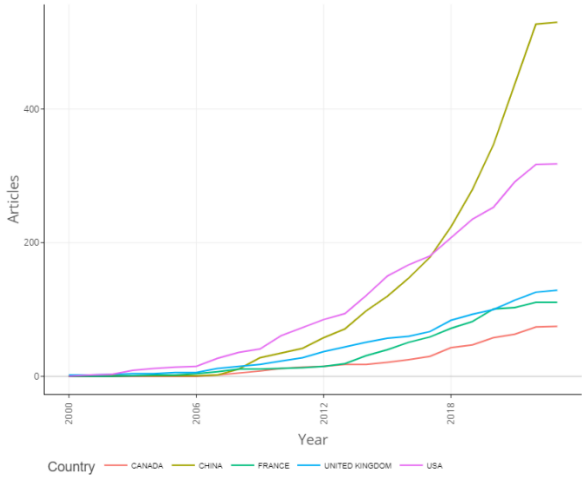

Figure 18. Countries' Production over Time

Multi Collaboration Production (MCP) involves multiple countries collaborating in production, while Single Collaboration Production (SCP) involves a single country handling the production process. For instance, Figure 19 demonstrates that approximately half of France's total productions were done in collaboration with other countries.

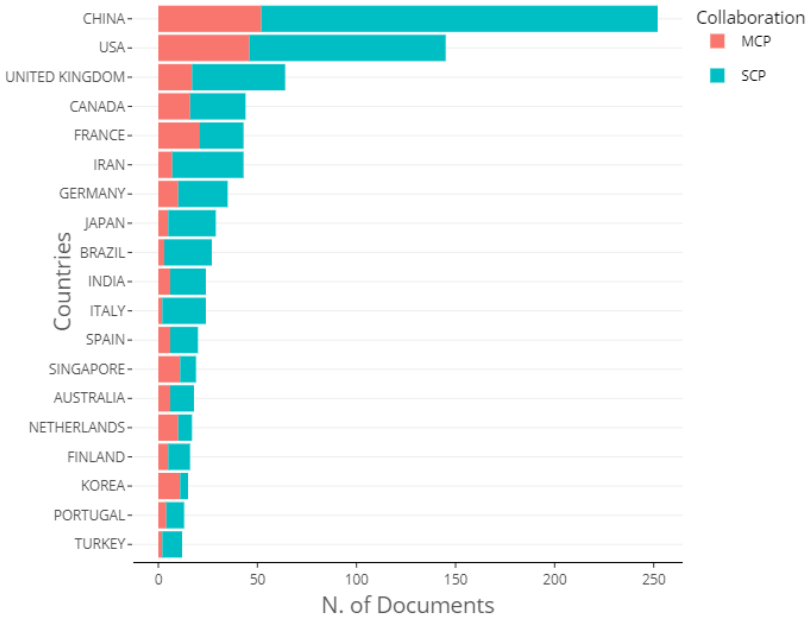

Figure 19. Corresponding Author's Country

4. Discussion

Numerous inferences and implications have been drawn from bibliometric and content analyses, which have been extensively discussed. The surge in scholarly works within the realm of RPO has been remarkable in recent years, reflecting an escalating curiosity within the academic community and, notably, experiencing a dramatic increase in the number of publications in 2022. Nevertheless, there has been a scarcity of studies specifically analyzing bibliometric data on RPO despite the significance of bibliometric studies as a tool for examining research quantity, directions, and interactions within the academic community. This study utilizes scientific mapping to analyze RPO research's structural and dynamic aspects. The conceptual structures reveal key themes and intellectual contributions, aiding in understanding trends. This approach also allows for tracking the development of concepts over time. Researchers can efficiently focus their investigations by highlighting prominent publications within theme clusters. The resulting thematic map provides insights into topic significance, aiding predictions of future theme expansion in the field.

This study delves into the expansive landscape of publications on RPO through a rigorous bibliometric analysis using the Web of Science database. The results illuminate key facets, starting with the substantial attention this field has garnered, notably in sources such as the European Journal of Operation Research, Annals of Operation Research, and Quantitative Finance. Given their significant publication output, these sources emerge as pivotal references for researchers exploring RPO. The study further refines our understanding by ranking the top sources based on their h-index, providing insights into their overall impact. Examining the most cited sources underscores the dominance of the European Journal of Operation Research, holding the highest citation count at 1794, closely followed by the Journal of Finance with 1552 citations. In addition to source analysis, the study identifies influential authors in the RPO domain, such as Fabozzi Fj, Chen Zp, and Rustem B. The geographical dimension is explored through a comprehensive bibliometric analysis, revealing the leading countries contributing to RPO research, including the United States, China, France, the

United Kingdom, and Canada. Furthermore, the study delves into collaboration patterns, distinguishing between MCP and SCP. An intriguing finding demonstrates that about half of France's RPO productions involve collaboration with other countries, shedding light on the dynamics of international research partnerships in this field.

This study focused solely on publications pertaining to RPO indexed in the Web of Science database. While the investigation did not extend to comparing datasets across different databases, it is important to note that such comparisons may yield varying sets of entries, and the analysis results can differ accordingly.

5. Conclusions

This paper has provided a comprehensive review of RPO using bibliometric analysis to identify articles, journals, authors, countries, and institutions that have contributed significantly to the field. Results indicate that articles on RPO have steadily increased since 2006. Furthermore, the United States, China, and France are the top three countries regarding contributing countries and institutions.

To further expand the current understanding of RPO, there are several potential avenues for future research. One promising area is to explore the uncertainty of Model Value at Risk. This topic evaluates the uncertainty associated with estimating portfolio risk using the Value at Risk (VaR) model, a widely used risk measurement tool. Studying the sources and effects of uncertainty in VaR models can improve the accuracy and reliability of risk management strategies in PO. Another area that deserves attention is selection optimization risk. This involves examining the risks associated with selecting assets for inclusion in a portfolio. Traditional PO techniques often assume that historical data accurately represent future market behavior. However, this assumption can lead to selection biases and miss critical risk factors. Addressing selection optimization risk can involve exploring alternative approaches that account for the uncertainties and biases inherent in the asset selection process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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