A Scientometric Analysis of Robust Portfolio Optimization

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Abstract

During the past few years, there have been some turbulent events in the global economy that have significantly impacted the performance of financial markets. Therefore, there is an urgent need for a robust method to deal with the existing uncertainties related to the performance of financial entities. Robust portfolio optimization (RPO) refers to developing an investment strategy that performs well even in the worst-case scenario of the uncertain inputs, e.g., return and covariance. This research paper provides a systematic review of recent developments of this field and its extensions. The authors use bibliometric analysis and visual mapping techniques to examine the evolution and trends of 1085 articles published between 2000 and 2023. The analysis explores the evolution and trends within RPO, while also investigating the interconnectedness among articles, authors, sources, countries, and keywords. The insights gained from our analysis can inform future research directions in this field and help practitioners make better-informed investment decisions.

Keywords: Robust optimization, Portfolio selection, Risk measures, Scientometrics

Introduction

The capital market represents the country's international development and is a critical tool for determining its economy's main direction (Bagheriyan et al., 2023; Fooeik et al., 2022; Ghanbari et al., 2022). Individuals, brokers, and fund managers invest billions of dollars in the capital markets every year. 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 indeed crucial when it comes to allocating funds optimally among financial assets in order 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 & Korkie, 1981; Arreola Hernandez et al., 2017; Best & Grauer, 1991; Schubert, 2009)). To address the shortcomings of the early MV model, new constraints, objectives, and approaches were developed ((Sharpe, 1963; Konno & Yamazaki, 1991; Rockafellar & Uryasev, 1999; Skoruchi & 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 PO problem is to optimize the risk measure. In addition to using the variance of returns alone to define investment risk, there are several risk measures that 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 & 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. Measures of downside risk can be classified into two categories: semi-risk measures and quantile-based measures. Measures such as semi-variance (Rubinstein, 2002) and semi-standard deviation (Ledoit & 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 & Uryasev, 2002) belong to the group of quantile-based measures. In the context of volatility risk measures, which include mean-variance (Goldfarb & Iyengar, 2003), mean absolute deviation (Demiguel et al., 2007), lower partial moment (Fishburn & C, 1977), systematic risk (Sharpet, 1964), and factor-based portfolio models (Fama & French, 1992), Sharpe (1966) and Bernardo & 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 there are many uncertain factors that affect asset returns. In this case, several approaches have been proposed in the literature to reduce the parameter sensitivity of PO models (see (Goldfarb & Iyengar, 2003) for a comprehensive list of these approaches and relevant research). There are different approaches in the literature for handling uncertainty in mathematical program including stochastic programming and robust methodology. The stochastic programming methodology uses decision tree and considers all possible scenarios and this makes the approach hard to solve because the resulting program dimension increases exponentially as the size of the problem increases (Masmoudi & 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 where there is 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 & 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, and 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 even in the face of uncertainty in different input parameters. Bertsimas & 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, but it has the advantage

of being more accessible to practitioners who are accustomed to using regular optimization techniques. Bertsimas and Sim's approach has been shown to be 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 & Sturm, 2003). Given the rising interest in RPO, several reviews have identified key findings and trends in the field, including the development of new methods and their application to real-world problems, indicated in Table 1.

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.
2017	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.

Goldfarb & Iyengar (2003) introduced approaches for addressing RPO issues by utilizing uncertainty frameworks, reformulated 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 & 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.

This research aims at conducting 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 the identification of 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, containing a discussion on 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 a difficult task for the research community (Zabavnik & Verbič, 2021). Bibliometrics offers a solution to this problem by providing statistical measures for evaluating the literature on a particular research area (Aria & 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). In recent years, there has been a growing interest in bibliometric analysis, with its applications being widely adopted in various scientific fields (Motamedi, 2023; Reza Amiri et al., 2023; Wan et al., 2023). However, the application of bibliometric analysis in finance, particularly in the area of 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, as well as articles, journals, authors, countries, and institutions that have had a significant impact on 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 that they retrieve documents relevant to the research topic, while also being comprehensive enough to enable bibliometric analysis (Kilani & Kobziev, 2016; Xiang, 2014). In this study, a two-step methodology was adopted for determining 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).
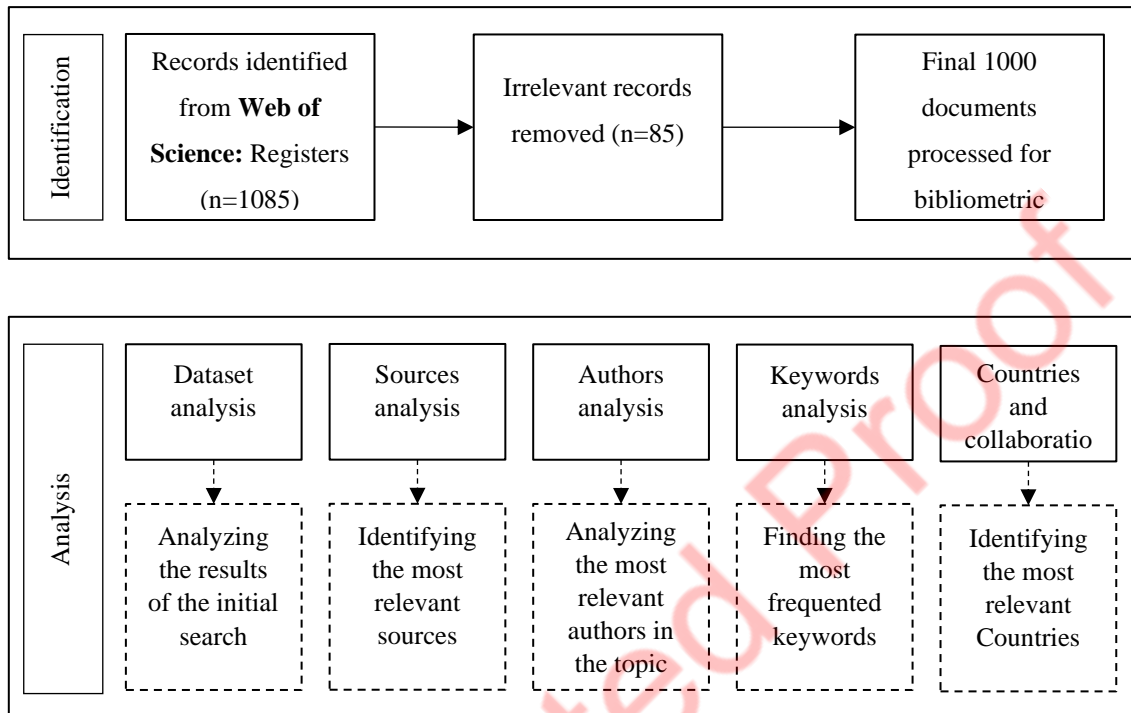

Figure 1: *Literature Search Strategy*

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	6.67
Average citations per doc	17.2
References	23118
Author's Keywords (DE)	2479
Authors	2056

Authors of single-authored docs	83
Co-Authors per Doc	2.83

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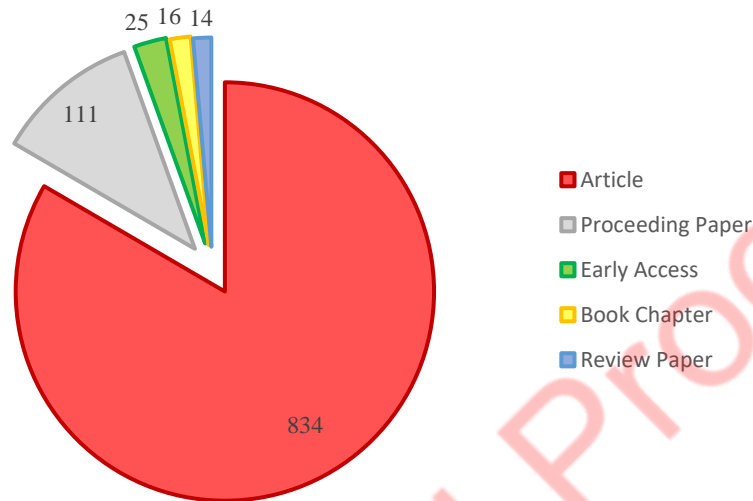

Figure 2: *An overview of the documents Type*

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.
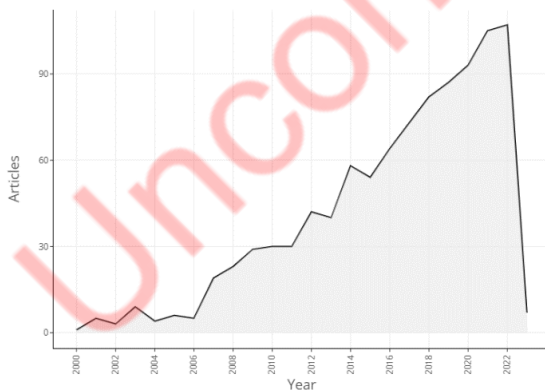
Figure 3: *Annual scientific production*
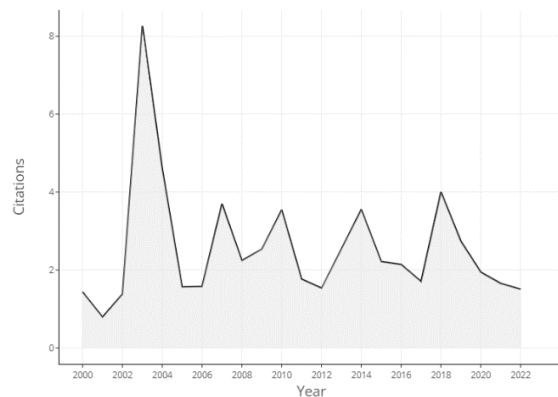
Figure 4: *Average article citation per year*

3.2. Sources analysis

Figure 5 presents a ranking of sources based on the number of articles published on the topic of RPO. The results indicate that this area has received significant attention, with a large number of articles being published in 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 Journal of Banking and Finance have the highest h-index among the analyzed sources, indicating their significant impact and influence in the field.

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 at the top with 1794 citations, followed closely by the Journal of Finance with 1552 citations.
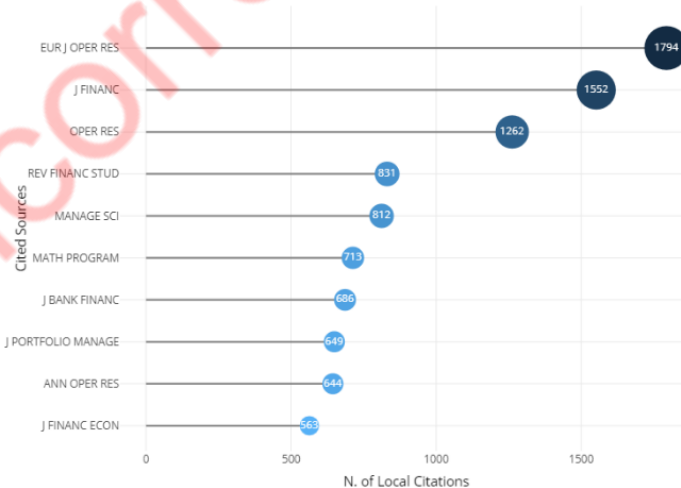

Figure 7: *Most local cited resources*

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.
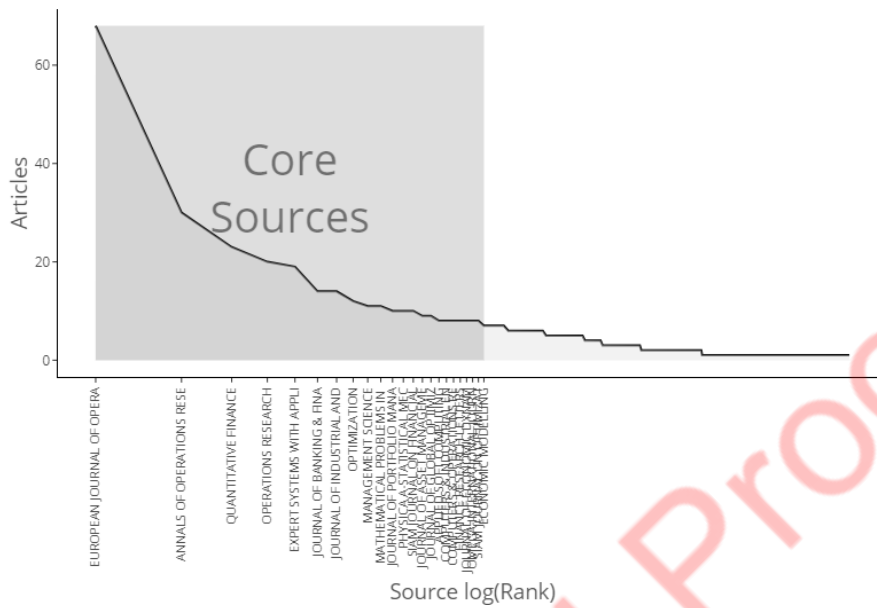

Figure 8: *Source clustering through Bradford's Law*

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.
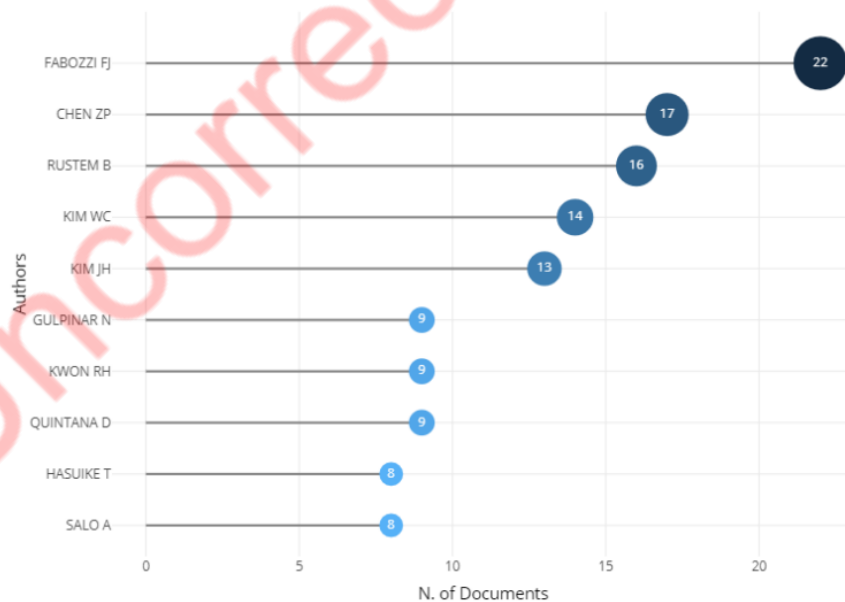

Figure 9: *Number of publications by authors*

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 size of the bubble 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. In the following year, he published two more papers, and another one in 2008.

Figure 10: *Top authors production over the time*

3.4. Keywords Analysis

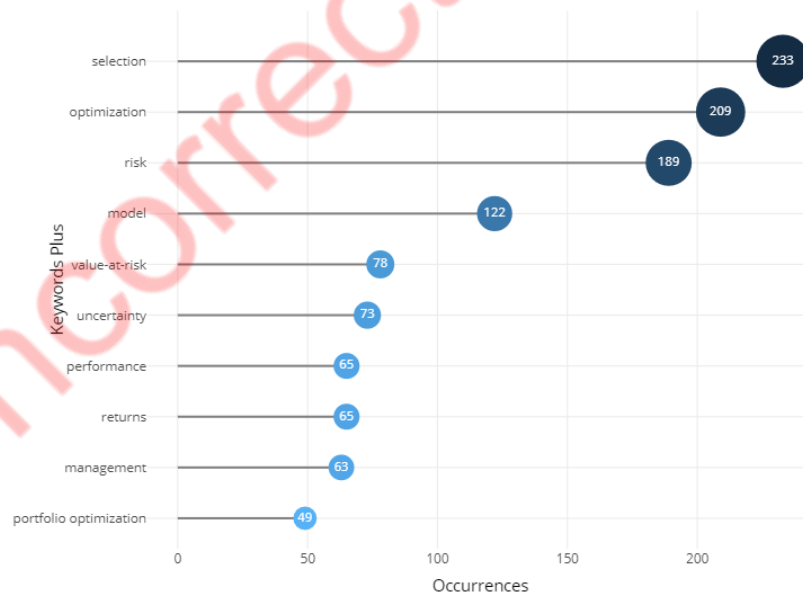The most frequent keywords in the 2000–2023 period is presented in Figure 11.

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.
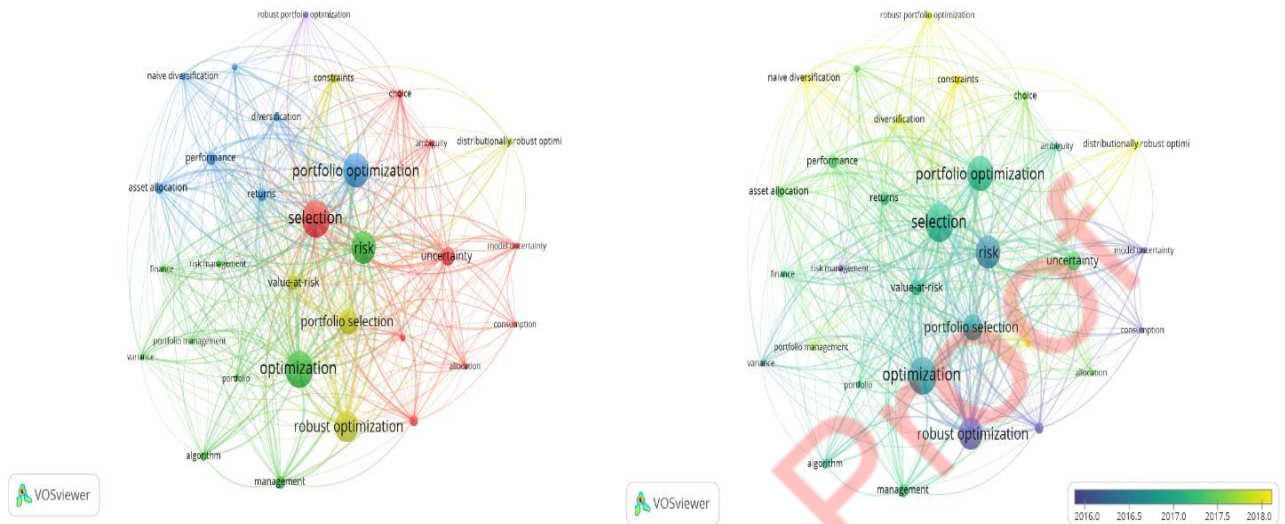

Figure 12: *Network of co-occurring keywords*

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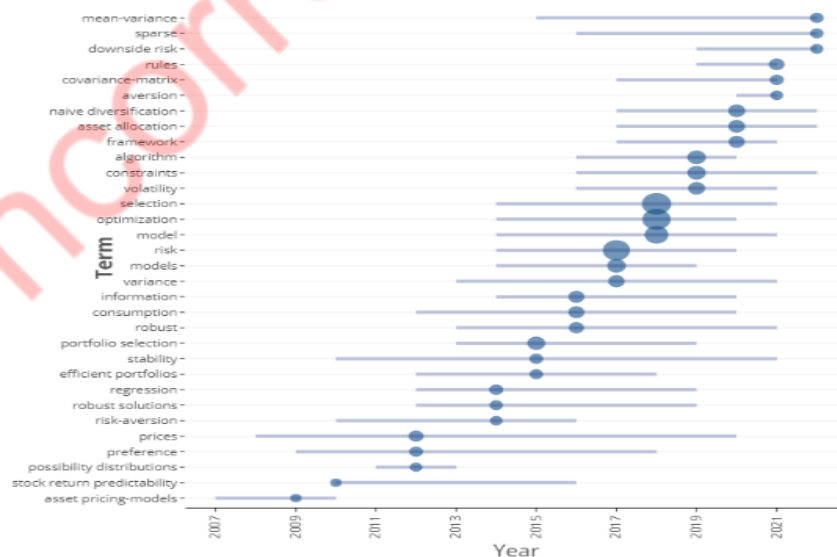

Figure 13: *Trend topic over the year*

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 a valuable insight into the field of study.
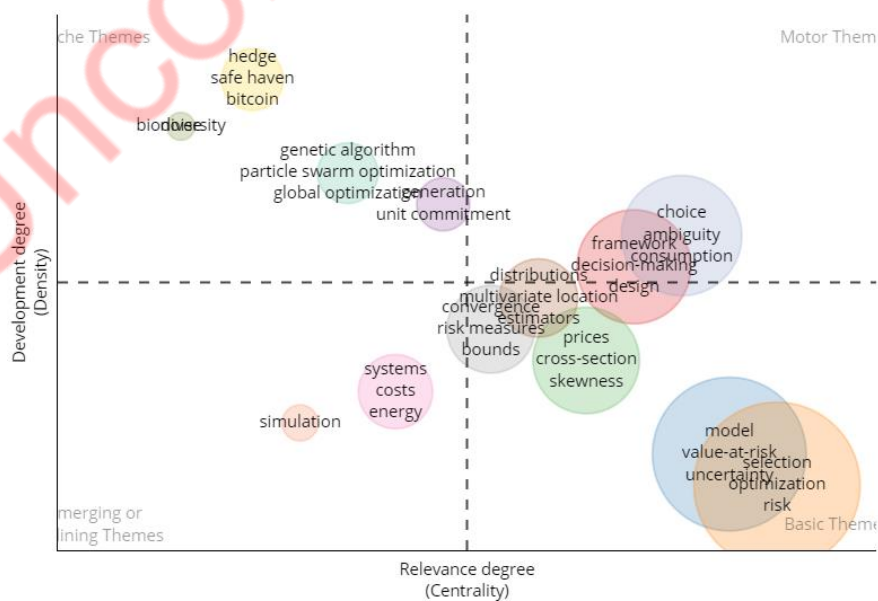

Figure 15: *Thematic map*

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.
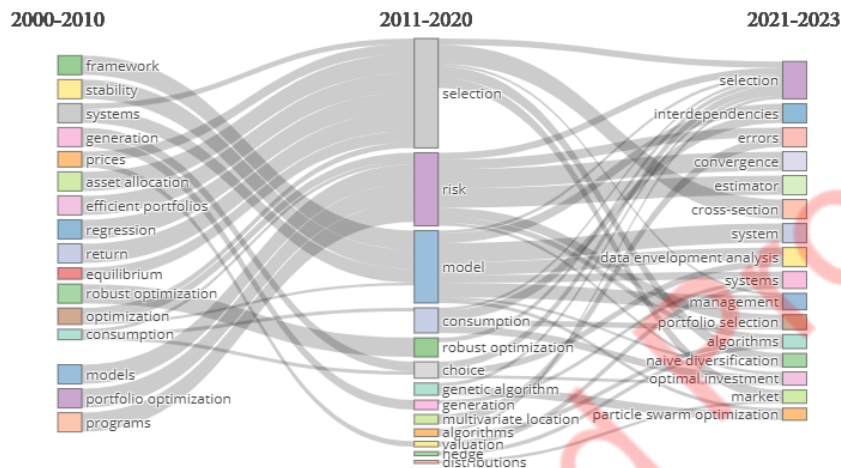

Figure 16: *Thematic evolution*

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.
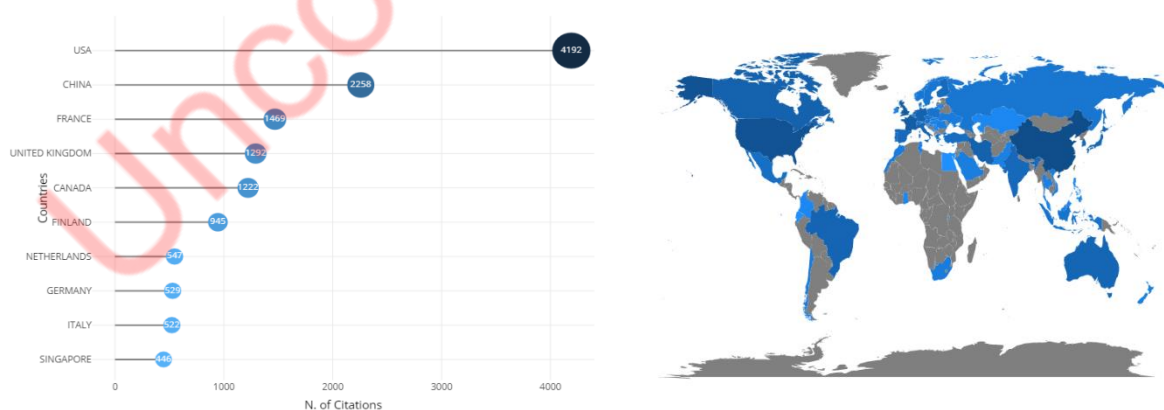

Figure 17: *Top Contributing Countries*

The production of these five top countries over the time is shown as follows:
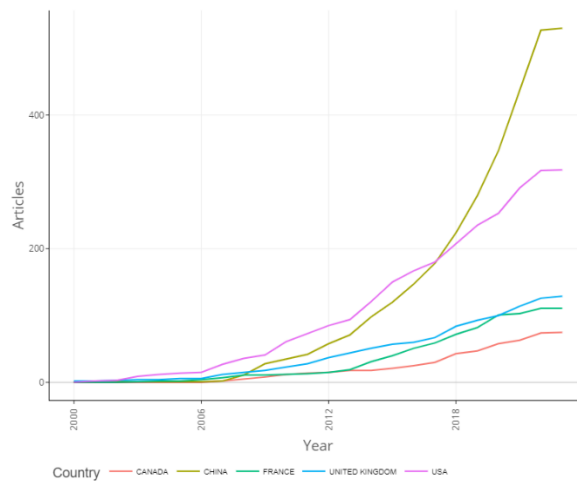
Figure 18. Countries Production over Time

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.
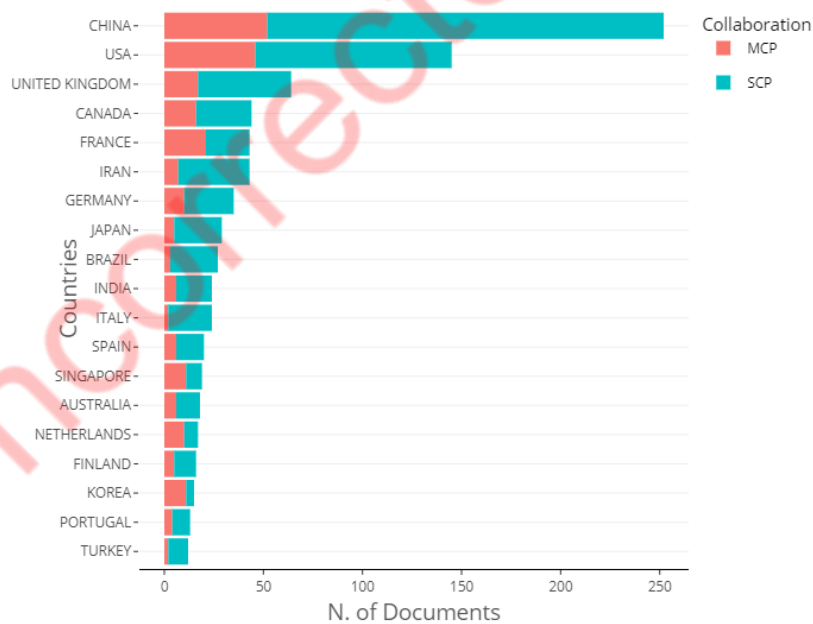

Figure 19. Corresponding Author's Country

4. Discussion

Numerous inferences and implications have been drawn from bibliometric and content analyses, which have been the subject of extensive discussion. 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 the structural and dynamic aspects of RPO research. The conceptual structures reveal key themes and intellectual contributions, aiding in the understanding of trends. This approach also allows for tracking the development of concepts over time. By highlighting prominent publications within theme clusters, researchers can efficiently focus their investigations. 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. These sources emerge as pivotal references for researchers exploring RPO, given their significant publication output. 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 is highlighted, demonstrating 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 indexed in the Web of Science database pertaining to RPO. 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 results of the analysis 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 the number of articles on RPO has steadily increased since 2006. Furthermore, regarding contributing countries and institutions, the United States, China, and Franch are the top three countries.

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 is about evaluating the uncertainty associated with estimating portfolio risk using the Value at Risk (VaR) model, which is 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 the process of 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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