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### **CONTENTS**

- |  |              |
|--|--------------|
| <b>The Future of Data Storage a Comparative Analysis of DNA Technology and HDD</b><br><i>Robertas Skliaustas, Saule Maciukaite-Zviniene</i>  | <b>01-14</b> |
| <b>Contribution of Psychological Motivations to Creating Customer Loyalty in Moroccan Luxury Restaurants</b><br><i>Khawla Mabrouk, Smail Ouiddad, Chaimaa Bendahou, Mounia Bennani</i> | <b>15-34</b> |
| <b>The Effect of Correlation in the CVaR Algorithm</b><br><i>Reza Habibi, Somayeh Maddapour</i>  | <b>35-45</b> |



# The Future of Data Storage: A Comparative Analysis of DNA Technology and HDD

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**Abstract:** The global data storage demand is predicted to grow. The costs of maintaining and transferring data, also demand advanced solutions. Despite substantial advancements in the field of DNA data storage technologies, commercial activity remains undeveloped. In this research the commercialization prospects of DNA storage technology are discussed. Through a comprehensive review of fundamental research, the most recent advances in DNA data storage technology in comparison to the leading hard disk drive data storage sector are revealed. The analysis encompasses companies developing the technology. The research shows that both scholarly and patenting activities within this domain are escalating, mirroring the evolutionary trends observed in existing commercialised technologies. Alternatively, there is an increasing magnetism for this technology in the data industry, with US dominance substantially outpacing the EU in terms of successful commercialisation initiatives. The exploration of a transdisciplinary bridge between industry, academia, and government attests to the critical influence of this collaboration for the streamlining of commercialisation process. Therefore, the research emphasises the profound impact of targeted state funding in bolstering commercialisation efforts. For DNA data storage technology to transition from a scientific possibility to a commercial reality, strategic enhancements in transdisciplinary cooperation, supportive regulatory frameworks, and dedicated funding are paramount.

**Keywords:** DNA data storage; commercialisation; innovation; triple helix.

## 1. Introduction

With modern advocacy for digitalisation [1] and digitalisation as a solution for sustainable and effective advancement in data management and storage [2], increasing digital data generation is predicted to reach 175 zettabytes by 2025. This will experience a 229% rise compared to the year 2021 (79 zettabytes). Technological advancement enhanced humanity moving from physical data storage to a digital form of storage, i.e. from simpler visible memory storage like floppy disks and CDs to more complicated hard drives and cloud storage. Every step later with every innovation the size of physical hardware has been decreasing and the density of information stored in the same space has increased. Currently, data storage relies on magnetic, optical, solid-state, and cloud-based technologies, allowing music, sounds, pictures, words, and movies to be stored in a binary form.

However, current data storage technologies are reaching both their technological and resource availability limits [3]. Expanding data centre areas offers only a short-term solution. This approach has a damaging environmental impact due to high energy requirements. Additionally, it is financially demanding, as current data storage technologies need replacement every 10-20 years [4]. Researchers, such as Mendell [5] advocate that digitalisation is a harmful phenomenon and suggest reducing data generation by slowing down the process itself. Nevertheless, there is a long-term technological solution that will enable data storage in much larger quantities than current capabilities allow, the 1953 discovery of the double helix gave rise to contemporary molecular biology, focusing mostly on understanding how genes regulate the chemical processes within cells [6]. The discovery yielded ground-breaking insights into the genetic code [7] and protein synthesis [8] that were crucial to the development of new and potent scientific techniques, including recombinant deoxyribonucleic acid (DNA) research [9], genetic engineering [10], rapid gene sequencing [11], and monoclonal antibodies [12], the techniques on which the current multibillion-dollar biotechnology industry is based [13]. Significant scientific developments, such as genetic fingerprinting

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and contemporary forensics [14], the mapping of the human genome [15], and ongoing gene therapy research [16], have become essential parts of the modern innovations market. And the fundamental function of DNA for storing immense amounts of data densely and compactly has not been exploited yet.

There has been a significant increase in research on commercially viable DNA data storage technology arguing the potential of future disruptiveness [4], [17-20] during the last twenty years. It was escorted by rapid patenting of technology-related findings and discoveries that could benefit further commercialisation and scalability of the technology [21], new cooperations between tech and biotech giants are being observed, resulting in the creation of new environments for transdisciplinary efforts between different industries, institutions, and societies, as well as emphasising industries' interest in further development of the technology. Furthermore, with increasing geopolitical instabilities and the fragility of supply chains even governments have shown interest in alternative storage solutions. Despite the mentioned governmental acknowledgment, there has been an observably significant difference between the popularity of the technology within the US and EU considering the financial and social involvement. As well as the number of existing and newly created companies dedicated to the technology's development.

There is a significant advancement in the understanding of the fundamental principles of the field of DNA digital data storage technologies, however, there has been comparatively little commercial activity in this field. This research aims to evaluate the prospects for commercialising DNA storage technology. It seeks to understand why existing efforts have not yet yielded a commercially viable product and explores ways to accelerate this process. As well as how far scientific research together with patenting of intellectual property has developed compared to already existing hard disk drive (HDD) data storage technology. It provides insights into whether the accumulated scientific knowledge suffices or if further development paths exist. This is followed by an analysis of commercialisation efforts within the EU and US by comparing the number of existing and newly created companies that are involved in developing DNA data storage technology and further investigation of transdisciplinary cooperation role and necessity for successful commercialisation of the technology.

## 2. Materials and Methods

Research has been conducted by triangulating literature review, statistical analysis and developed authors' insights to provide more accurate and detailed conclusions and recommendations. To analyse and evaluate the prospects for DNA data storage commercialisation, we conducted a statistical analysis of three main variables: scholarly activity, patenting activity, and commercial involvement. This approach is similar to Katherine E. Dunn [22] research on origami technology. Supplementing this research with additional insights into commercialisation activities within the US and EU, as well as, exploring potential transdisciplinary cooperation models within existing commercialisation effort. Katherine E. Dunn [22] has conducted analysis of patent applications and research activities as well as company case studies of DNA nanotechnologies, however, excluded DNA data storage technology from the sample.

In this research same approach of analysis has been chosen to analyse commercialisation efforts and additionally, a referent variable has been added. Referent variables have allowed to compare DNA data storage tendencies with already well-established technology tendencies. As a referent variable HDD technology has been chosen as it is currently used as a technology for archival data storage, as well as it is already broadly commercialised. Moreover, for the research "Lense" scholarly and patenting database has been chosen as it connects 422 million datasets of publications from "Microsoft Academic", "CrossRef", "PubMed", "And core", "OpenAlex" as well as, patenting datasets from major patenting offices. "Lense" database allows to application of extensive queries and filters to extract only relevant entries. All entries have been filtered for the timeframe of the last twenty years from 2000 to 2021 (Appendix A, Appendix B), taking a decade for the initial time frame. In such cases, DNA data storage-specific queries for scholarly activity and patenting activity have been created as part of the research to extract only valid scholarly and patenting activities related to DNA data storage. Using the same approach, a query, for scholarly activity and patenting activity of HDD storage has been created and extracted (Appendix C, Appendix D).

For commercial activity analysis, companies have been selected by analysing publicly available sources, such as webpages, LinkedIn profiles of the companies, annual reports, pages of official associations dedicated to DNA data storage technology development, research papers and articles. Additionally, using the Lens database, companies were identified based on the patents submitted and research papers published. Search of the companies has been segmented according to findings of literature review: *industry* (biotechnological (Biotech) industry, technological (Tech) industry); *region of operation* (United States (US), European Union (EU)); *Contribution towards development and commercialisation of DNA data storage technology* (Companies or start-ups that

are actively and directly developing DNA data storage technology, Companies or start-ups that are actively developing components or processes of DNA data storage technology and claim that their development can be used for DNA data storage: in the biotech sector (including enzymatic DNA synthesis, in vivo and in vitro data storage, improved DNA storage media, particle stabilization, and nanostructure) and tech sector (encompassing AI, decoding and encoding algorithms, and hardware/software development) and Companies or start-ups that are members of alliances and associations that are claiming to be a part of DNA data storage technologies but not directly involved in development).

Furthermore, data from Organisation for Economic Co-operation and Development (OECD) has been gathered regarding governmental funding in the science, technology and innovation sector, which includes OECD Research and Development Statistics (RDS), Eurostat, Statistics on Research and Development, UNESCO Institute for Statistics (UIS) data. All gathered data has been structured using Microsoft Excel, and statistical analysis and visualisations have been created using GraphPad Prism software.

An understanding of scholarly activity and patenting activity is necessary to determine the connection between these two variables as well as their connection and influence on commercial activity. Furthermore, a referential variable has been included to forge insight into where each variable of developing DNA data storage technology stands alone compared to already commercially active HDD technologies variables. For the statistical analysis linear regression and Spearman's correlation analysis have been conducted. For linear regression analysis significance value (P) and goodness of fit value (R<sup>2</sup>) have been extracted and analysed.

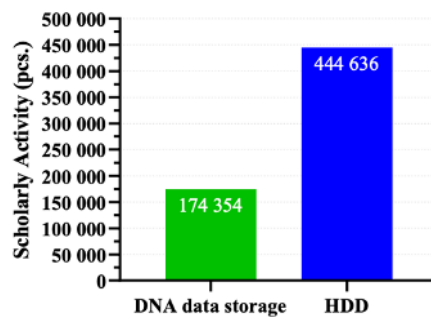
Scholarly activity and patenting activity between the EU and the US have been analysed and supported by the additional variables of governmental expenditure in the science, technology and innovation sector to evaluate the correlation between governmental impact on scholarly activity and patenting activity. The comparison analysis has been supported by linear regression analysis. Furthermore, the commercial activity variable has been expressed by the amount of commercially active companies related to DNA data storage. Commercial activity has been compared between the US and the EU. Upon developing a database of companies, it has been noticed that not all companies are equal contributors to commercialisation of DNA data storage, however, the involvement of each of them is of equal importance. Therefore, the company involvement scale has been developed by the authors to evaluate the distribution of companies between the involvement levels:

1. Biotech or tech companies or start-ups that are actively and directly developing DNA data storage technology;
2. Biotech or tech companies or start-ups that are actively developing components or processes parts of DNA data storage technology and claims that their development can be used for DNA data storage;
3. Biotech or tech companies or start-ups that are members of alliances and associations that are claiming to be a part of DNA data storage technologies but not directly involved in development, as well as, owning a patent related to DNA data storage technology or are involved in funding of DNA data storage technology.

### 3. Results

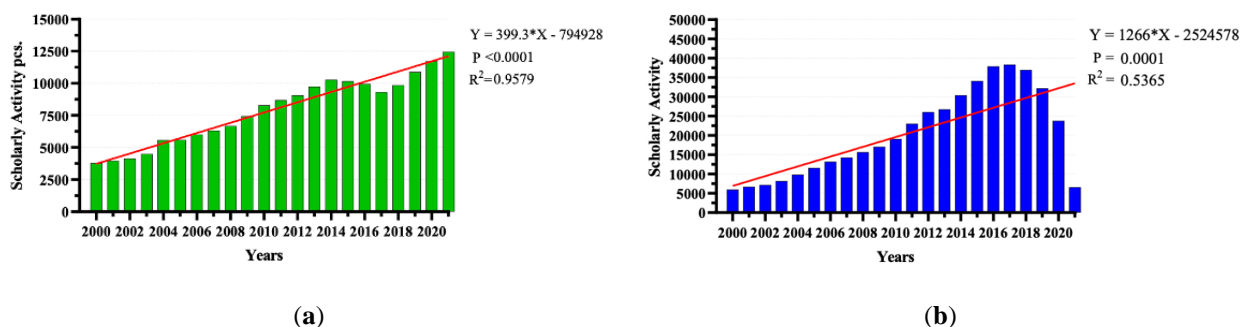
#### 3.1. Comparative analysis of DNA data storage and HDD technologies scholarly activity

One of the major challenges for DNA data storage technology is the passage of the valley of death that bridges the research part with the commercial part of the process. From the literature analysis the authors have established that DNA data storage still has some technological development ahead to successfully enter the market and serve as an attractive solution for archival data storage. Therefore, the success of research activities becomes an integral part of the commercialisation process. By analysing the general pattern of research activities, we can establish the potential interest that DNA data storage technology is generating among the research community. Figure 1 demonstrates that comparing well-established technologies like HDD scholarly activity with still-developing technologies of DNA data storage scholarly activity the total amount of publications released between 2000 and 2021 is significantly different. HDD-related scholarly activity is 2.55-fold higher than DNA data storage technology. However, the difference could be explained by the fact that HDD technology has been in commercial use since 1952 and research efforts have been catalysed by commercial companies both in funding and internal research as product development efforts.



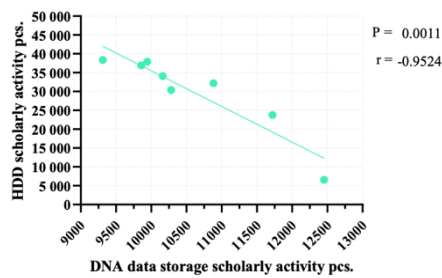
**Figure 1.** The total scholarly activity of DNA data storage and HDD technology between 2000 and 2021.

The general trend of DNA data storage technologies scholarly activities has been upwardly increasing ( $P < 0.0001$ ;  $R^2 = 0.957$ ) (figure 2a). Comparing years 2000 and 2021 research activity has increased by 3.29-fold. Indicating research communities' acknowledgment of the major potential that DNA data storage technology can bring to the market. Furthermore, increasing research activity indicates, that funding for DNA data storage research is also increasing. Figure 2b shows upwardly trending research activity of referential technologies, however, the confidence in further increase is lower than DNA data storage technologies ( $P = 0.0001$ ;  $R^2 = 0.5365$ ). The existing similarity between the two technologies can indicate that DNA data technology has the potential to be commercialised.



**Figure 2.** (a) Scholarly activity of DNA data storage technology from 2000 to 2021. (b) Scholarly activity of HDD technology from 2000 to 2021.

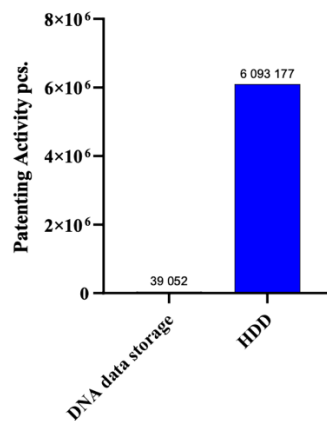
While comparing DNA data storage scholarly activity with HDD scholarly activity it was noticed that while DNA data storage research had a minor decrease in scholarly activity during period of 2014 – 2017, starting from 2017 it started rapidly increasing and exceeding previous years (Figure 2a). However, HDD scholarly activity has begun decreasing since 2017 (Figure 2b) and almost reaching the activity of the year 2000 (2000=5994, 2021= 6567). Therefore, Spearman's correlation was performed to understand if there is a connection between the increasing DNA data storage scholarly activity and the decreasing HDD scholarly activity. Spearman's correlation (Figure 3) showed that there is a strong negative correlation ( $r = -0.9524$ ,  $p = 0.0011$ ) between DNA data storage scholarly activity and HDD scholarly activity. Indicating, that increasing DNA data storage possibly affects HDD research. Combining theoretical research with correlation analysis it can be assumed that there is a relation between these two variables, however not a direct one. The authors have established that current data storage technologies are approaching their theoretical limitations, therefore researchers are focusing on finding alternative data storage technologies. Knowing that, it can also be assumed that science focus is shifting from HDD technologies research towards alternative ones, however not necessarily towards DNA data storage technology alone.



**Figure 3.** Correlation analysis of DNA data storage scholarly activity and HDD scholarly activity in the period of 2014-2021.

3.2. Comparative analysis of DNA data storage and HDD technologies patenting activities

The direct link towards commercialisation is patenting activities. Therefore, a comparative analysis of DNA data storage and HDD technologies patenting activities has been conducted. Figure 4 reveals a significant difference in patenting activities between DNA data storage and HDD technologies. HDD patenting activity is 156.027-fold higher from 2000 through 2021 than DNA data storage technologies. The results of the literature analysis and comparative analysis of this research suggest that HDD technology is indeed a well-established and commercially active technology. Furthermore, indicating approximations for DNA data storage patenting activities to be considered a well-established technology in the data storage market.



**Figure 4.** The total patenting activity of DNA data storage and HDD technology between 2000 and 2021.

Looking into the distribution of each technology patenting activity during the period of 2000-2021 in Figures 5a and 5b, a similar upwardly increasing trend is defined. DNA data storage patenting activity has increased 4.432-fold comparing year 2000 and year 2021, whereas HDD technologies patenting activity has increased 8.354-fold during the same timeframe. Suggesting that increasing patenting activity can potentially benefit commercialisation process of DNA data storage technology.

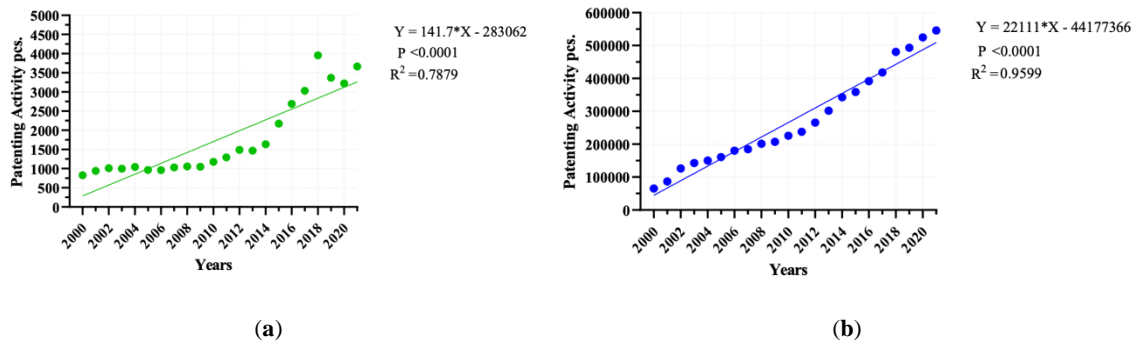


Figure 5. (a) The patenting activity of DNA data storage between 2000-2021. (b) The patenting activity of HDD technology between 2000-2021.

Upon further investigation of patent activities, the top 20 owners of patent activities have been analysed. Not surprisingly most of the top 20 HDD patent activity owners are global and well-known tech/IT companies with IBM having the most patent activities related to HDD technology (figure 6a). However, upon looking into the top 20 owners of patent activities related to DNA data storage technology (figure 6b) the authors encounter that 18 of 20 companies are also tech/IT corporations and only 2 companies represent the biotech industry (Life Technologies Corporation; Ion Torrent Systems Incorporated).

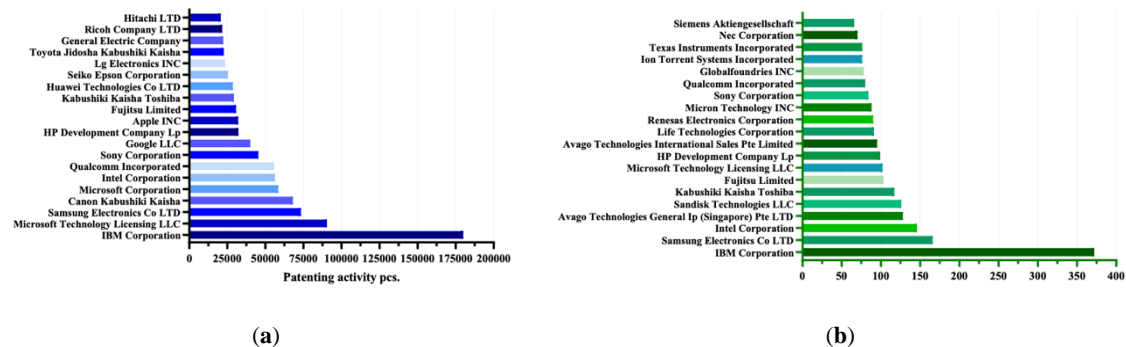


Figure 7. (a) Top 20 owners of HDD patenting activity. (b) Top 20 owners of DNA data storage patenting activity.

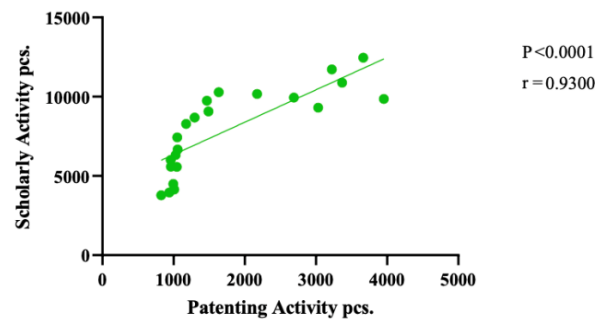
While further developing the research similarities between the top 20 HDD patenting activities owners and DNA data storage patenting activities owners (figure 8), the analysis showed that 9 out of 20 (45%) top HDD patenting activities owners are also 9 out of 20 (45%) DNA data storage patenting activities owners. This indicates the transdisciplinary interest and global companies' acknowledgment of DNA data storage technologies' potential for commercialisation and shifting focus from contemporary HDD storage towards DNA data storage is identified.



**Figure 8.** Relationship map between top 20 patent activity owners of HDD technology and DNA data storage technology.

*3.3. Comparative analysis of DNA data storage scholarly activity and patenting activity*

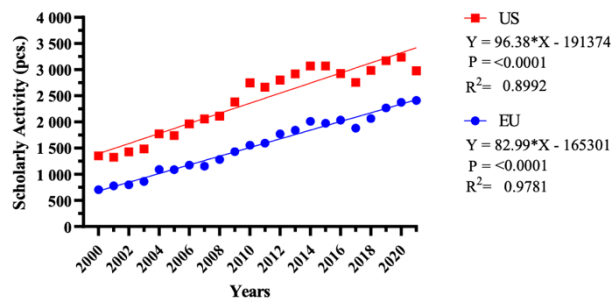
After establishing general similarities between DNA data storage and HDD technologies scholarly activities and patent activities the authors continued the analysis concentrating solely on DNA data storage. Theoretical analysis has indicated that the amount of patent activity should directly correlate with the amount of research activity. The authors' analysis has shown that, in the case of DNA data storage, this is indeed the case. Research activity shows a strong positive correlation with patenting activity ( $r=0.93, P<0.0001$ ) (Figure 9) meaning that with an increasing focus on DNA data storage research, patenting activity is likely to rise, fostering rapid commercialisation. As would be expected, the number of papers being published significantly exceeds the number of patents, as patent protection would be inappropriate for a large proportion of DNA nanotechnology research, including valuable studies on fundamental principles.



**Figure 9.** Correlation analysis of DNA data storage scholarly activity and patenting activity.

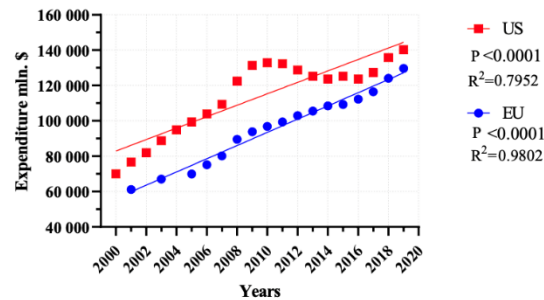
### 3.3. Comparative analysis of DNA data storage scholarly activity and patenting activity

Scholarly activity is an important part of DNA data storage commercialisation, and governmental funding is a crucial catalyst for biotech innovations such as DNA data storage technology during the Valley of Death stage. While comparing scholarly activity within the US and EU it was found that the US demonstrates higher levels of scholarly output, averaging 853.77 scholarly activities per year more compared to the EU (figure 10). Although, linear regression analysis showed an upward increase in scholarly activity both in the EU from 705 activities in the year 2000 to 2412 activities in the year 2021 ( $R^2 = 0.9781$ ,  $P < 0.0001$ ) and in the US from 1351 activities in the year 2000 to 2978 activities in the year 2021 ( $R^2 = 0.8992$ ,  $P = < 0.0001$ ). Further indicates a steady upward trend in both regions during the mentioned period, as well as the importance of both regions' participation in further development of DNA data storage technology since the US and EU are the top 2 global leaders in DNA data storage scholarly output.



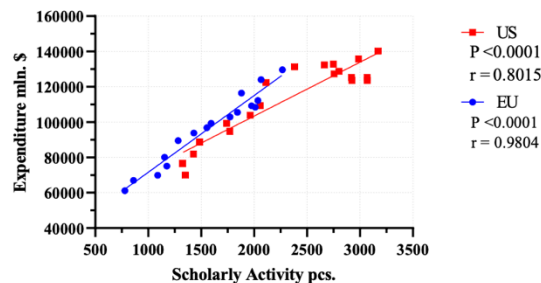
**Figure 10.** Linear regression analysis of DNA data storage scholarly activity within the US and EU.

However, to understand the difference in scholarly output between the US and EU it is important to investigate governmental financial support and contribution towards DNA data storage. Analysis of data from the OECD database for science, technology and innovation indicated an increase in overall governmental expenditure toward R&D activities between the years 2000 and 2019 (Figure 11). Nonetheless, the US demonstrates higher yearly expenditure toward science, technology and innovation compared to the EU. On an annual average, the US spends 22 645 million \$ more compared to the EU. With the biggest expenditure gap being in the year 2009 – 37 490 million \$. However, the EU has been steadily increasing its funding for Science, Technology and Innovation. From 93 840 million \$ in 2009 to 129 641 million \$ by the year 2019, thereby decreasing the gap between the US and the EU to 10 578 million \$.



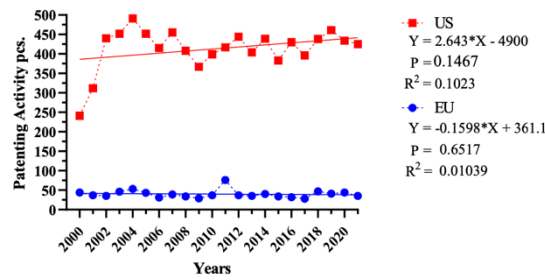
**Figure 11.** Linear regression analysis of governmental annual expenditure for science, technology and innovation within the US and EU.

Consequently, correlation analysis was conducted to identify if the increase in governmental funding had influenced the growth of scholarly activity in the US and EU. Both the EU and the US established a strong, positive correlation, indicating that an increase in governmental expenditure for science, technology and innovation has a positive increase in DNA data storage scholarly activity (Figure 12). Overall, the US has higher annual funding for developing technologies such as DNA data storage. However, the US has also developed a technology-specific funding programme: the Defence Advanced Research Projects Agency (DARPA), the Intelligence Advanced Research Projects Activity (IARPA), and the National Science Foundation (NSF) provide considerable financing opportunities. Fortunately, positive changes are seen in the EU research funding programs landscape. European Innovation Council has launched a new funding programme “Pathfinder Challenge: DNA- based digital data storage” in 2022, with a budget of 183 million euros.



**Figure 12.** Correlation analysis of governmental expenditure for Science, Technology and Innovation and scholarly activity of DNA data storage within the US and EU.

Further on, while analysing patenting activity in the US and EU (Figure 13) no significant increase between years 2000 and 2021 has been noticed in both regions. Suggesting that the increase in patenting activity observed between 2010 and 2021 happened in different regions like China where patenting activity rose from 19 activities in year 2000 to 2735 activities in 2021. However, upon further comparison of the US and EU it has been established that despite no significant rise in patenting activity, the US still demonstrates higher activity of patenting with an annual average of 373.909 patenting activities more than the EU.



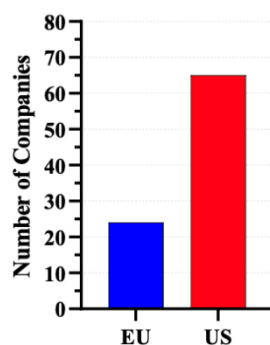
**Figure 13.** Linear regression analysis of patenting activity within the US and EU.

Lastly, data regarding commercially active companies contributing towards DNA data storage technology development has been analysed (n = 89) and there is a variety of involvement in the DNA data storage commercialisation process (Table 1). Just like in the earlier analysis, the US demonstrates the overall higher number of commercially active companies (n = 65) involved in DNA data storage commercialisation compared to the EU (n = 24). Furthermore, comparing the US to the EU on a level of involvement basis, US demonstrates a higher number of companies in level 1 (n = 18), level 2 (n = 21), and level 3 (n = 26), compared to EU level 1 (n = 9), level 2 (n = 12), level 3 (n = 3) (Figure 14). Indicating the US’s overall success in developing and attempting to commercialise DNA data storage technology compared to the EU. The analysis also demonstrates the involvement of both tech (n = 39) and biotech (n = 50) industries towards DNA data storage commercialisation.

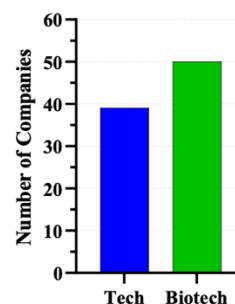
Since DNA data storage technology is primarily biotech industry innovation the higher number of biotech companies is understandable, compared to tech companies. It is observed, that biotech companies are more involved in the direct commercialisation of DNA data storage on level 1 (n = 21) and developing components or parts of DNA data storage process on involvement level 2 (n = 25) compared to tech companies on level 1 (n = 6) and level 2 (n = 8). However, tech companies demonstrate higher numbers on level 3 (n = 25) compared to biotech (n = 4). Indicating tech industries’ interest and support for the development of the technology through indirect measures like patenting, funding and consulting.

**Table 1.** Company classification according to region, industry and level of involvement in commercialisation of technology.

		Level of Involvement		
	Region	Level 1	Level 2	Level 3
Tech	EU	3	2	3
	US	3	6	22
Biotech	EU	6	10	0
	US	15	15	4



(a)



(b)

**Figure 14.** (a) Number of companies in EU and US. (b) Number of companies operating in Tech and Biotech industries.

#### 4. Conclusions

This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.

Even though overall research of DNA data storage technology is increasing globally with leading regions of the US and the EU, and proof of concepts are already developed showing practical possibilities of the technology, more research and development input is needed for DNA data storage to become a viable and scalable technology, capable of taking over magnetic storage media like HDD.

While comparing DNA data storage scholarly activity with HDD scholarly activity by decades it was established that HDD had a higher overall activity from the year 2000 up to the year 2020 with DNA data storage taking the lead in the year 2021. With correlation analysis it was concluded, that in the second decade from the year 2014 first steps in replacing HDD technology were already visible since scholarly activity on HDD has started its decrease, being replaced by alternative data storage innovations like DNA data storage technology research. Indicating a technological shift within the data storage market shortly.

Patenting activity analysis of DNA data storage and HDD showed absolute leadership of HDD technologies patenting activities for the two decades since 2000. However, research has also shown a constant increase in DNA data storage patenting activity and highlighted similarities to HDD technologies patenting activity pattern, meaning, that DNA data storage patenting activity demonstrates similar behaviour as already established technologies like HDD patenting activity.

Correlation analysis of DNA data storage scholarly activity and patenting activity showed a strong positive correlation proving, that increasing scholarly activity is directly increasing patenting activities resulting in increasing commercial activity of the technology. Moreover, discovering that 45% of the top patenting activity owners of HDD technology are also among the top 20 for DNA data storage technology – mostly big tech corporations – suggests that scientific activities will continue to increase. As the active interest and patent activity ownership indicate the increasing interest of the tech industry and further transdisciplinary partnership development between tech and biotech industries towards the successful commercialisation of DNA data storage technology.

The US output of scholarly and patenting activities has shown to be significantly higher than the EU same as governmental funding for the science, technology and innovation sector. Correlation analysis revealed that increased governmental funding for the science, technology, and innovation sector strongly correlates with DNA data storage scholarly activity. This explains the US's leadership in this field and underscores the importance of governmental support in developing DNA data storage technology. Furthermore, showing the necessity of technology-specific funding like IARPA's Molecular Information Storage Technology (MIST) initiative to further catalyse the development of DNA data storage technology and invite other countries to create similar initiatives according to good practices already established.

Biotech companies are primarily involved in the development of DNA data storage technologies, but there is an increasing interest from tech companies as well. Involvement of the tech industry with high monetary values and ability to provide funding for commercialisation of DNA data storage technology led to the creation of transdisciplinary organisations like “DNA data storage alliance”, connecting large companies from tech, biotech industries, universities, and venture capital companies striving towards the same commercialisation goals. This enabled companies like DNA Script and Illumina to be among the first to participate in governmental programs like IARPA's Molecular Information Storage Technology (MIST) initiative which intends to create systems that can write 1 TB and read 10 TB of data per day using DNA.

Therefore, transdisciplinary cooperation model should be considered for further DNA data storage development. This model facilitates the transfer of crucial insights and data from tech industry market experts to biotech companies focused on researching and developing DNA data storage. Incorporates universities, that have the freedom to conduct more risk-worthy research, but at the same time, together with industry experts, maintain focus on technologies commercial viability and scalability, develop market and consumer-oriented product.

However, more transdisciplinary alliances and ecosystems are required to minimise the chance of technological monopolisation and increase competitiveness within DNA data storage commercialisation allowing the technology to avoid the “valley of death”. Finally, it is also defined that increasing the number of transdisciplinary alliances will result in faster commercialisation and higher funding capabilities.





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# Contribution of psychological motivations to creating customer loyalty in Moroccan luxury restaurants

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**Abstract:** Maintaining loyalty is difficult for marketers, particularly in the luxury sector. This study aims to contribute to the corpus of marketing literature by investigating how psychological motives may contribute to customer loyalty in luxury restaurants in Morocco. As a result, a qualitative research study was conducted. In order to find and investigate the subject of study, we conducted interviews with customers of Moroccan luxury restaurants using a well-structured interview guide. Prior to presenting the findings, a theme analysis is offered. This study allowed us to develop restaurant quality criteria based on the responses of Moroccan consumers. In the Moroccan setting, personalizing the customer-brand relationship was later demonstrated to be a major component in establishing consumer loyalty to luxury restaurants. We then found the causes and consequences of customer satisfaction, as well as some new variables that drive customer loyalty. As a consequence, clients might be satisfied but not always loyal. This study has identified the barriers to loyalty and provided solutions for how to overcome them.

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## 1. Introduction

Brand loyalty has been referred to as a gauge of the strength of the customer-brand connection. Attitude and behavior are the two dimensions of loyalty. Behavioral brand loyalty concentrates on recurrent brand purchases and recommendation behaviors [1] whereas attitude brand loyalty encompasses the consumers' attachment, commitment, and intention to repurchase the brand [2]. Loyal customers are important for the brand's success in a variety of reasons, including recurring business, reduced price sensitivity, and cheaper service costs.

Consumer loyalty is obviously very crucial in the competitive environment of the luxury restaurant industry, because customer turnover costs far outweigh client retention costs [3]. Indeed, restaurant success is heavily dependent on their ability to meet the needs and expectations of its customers. Restaurants aim to build long-term relationships with their customers and gain their loyalty [3]. It was demonstrated that two major branding outcomes support luxury brand loyalty behavior: luxury brand attachment and luxury brand trust [4]. However, It has been revealed that brand personality congruence is a critical determinant of brand love and brand loyalty, suggesting congruence between the consumer's personality and the brand is essential to the luxury

branding sector [5]. As a result, it's critical for the restaurant industry to understand the factors that impact customers' decisions to return to the restaurant for another meal. By taking these factors into account, it is possible to meet the expectations of customers and prevent their defection, resulting in abundant earnings for the restaurant. Although, antecedents of loyalty are vastly discussed in diverse industries but the most significant predictor of loyalty is yet to be explored.

The need for prestige, which leads people towards the values and advantages connected with luxury goods, is one of the primary reasons for consumers' propensity to adopt luxury products [6]. Previous research suggest that people who visit upscale restaurants have particular needs, and that those needs, such as being distinctive, happy, or exposed to the public, must be met. These needs may elicit psychological pressures that push consumers toward high-end goods. Previous research has shown that customer behavior in the search for luxury is influenced by a variety of factors [7]. According to [8], five sorts of customers are distinguished by their motivational characteristics. These two researchers classified customer motives as observable, distinct, sociable, hedonists, and perfectionists. The visible and social elements might be thought of as aspects of materialism [9]. Consequently, four motivations such as materialism, unity, hedonism, and perfectionism may be used to justify the use of luxury good [10]. The services provided by luxury products and restaurants are non-tangible, non-essential, inseparable, and imperfect [8]. Future studies should include consumers' actual purchasing at luxury restaurants (spending data), and should consider consumers' intention of visiting the restaurant again [10].

Most of research done on customer loyalty in the luxury context are related to factors linked to brand; brand image [11], chatbots [12], brand equity, service quality, and product quality [13], multisensory marketing [14]. However, [15] suggested that consumers in the luxury store setting expressed stronger emotional attachment and brand loyalty than consumers in the nonluxury store environment). So, we know relatively little about the motivational factors linked to customer perspective that influence customer loyalty to luxury restaurants. Previous studies determine how personality traits (including the need for uniqueness and self-monitoring) and social traits (including self-expression and self- presentation) influence the importance of design and brand loyalty in the luxury context [16]. But no study shed light on customer psychological motivations (materialism, uniqueness, hedonism and perfectionism). Due to gaps in the literature, this study adds to the body of knowledge by examining psychological motivations and their role in building loyalty among Moroccan customers toward luxury restaurants. The interest of this research also stems from the fact of introducing satisfaction to understand the current relationship. We explore What are the psychological motivations that help to create the loyalty of customers at luxury restaurants in the Moroccan context? Which role play customer satisfaction in the current relationship? and How satisfied customers of luxury restaurants can become loyal?

The structure of this article is described below. We begin by proposing a conceptual framework for loyalty and psychological motives, then describe the research's theoretical framework before detailing the methodology and instruments employed in the current study. The findings of the

qualitative research are summarized, presented, and discussed. Finally, we present limitations as well as potential research directions.

## 2. Conceptual background

### 2.1 Psychological motivations

Five different consumer categories are distinguished based on the characteristics of their motives. They categorize consumer incentives as being conspicuous, unique, sociable, hedonistic, and perfectionist [8]. The research of [10] seeks to merge these two motives under the label "materialism" given that visible and social incentives are both based on interpersonal effects and are both materialist. Thus, they have identified four motives related to luxury: materialism, uniqueness, hedonism, and perfectionism.

#### 2.1.1 Materialism

Materialism, according to [17], is a "set of centrally held beliefs about the importance of possessions in one's life." People have always believed that having particular possessions will make them happier. The desire for wealth and status is what leads to materialism. [9]. The more materialistic consumers may believe that owning luxury brands will bring them happiness, and they may judge their own success and other people's success based on whether or not they own luxury brands [8].

#### 2.1.2 Uniqueness

Purchasing expensive goods may help people feel unique, and the rarity of the item will boost one's self-esteem by demonstrating individual taste, breaking the law, or avoiding identical existence [18]. This result combines selfish and altruistic goals. [1] first proposed this motivation, also known as the "snob" effect, and it can manifest in one of two ways: either when a product is launched and one wants to gain an advantage by belonging to the minority that owns it, or when one rejects a product because it is held by the masses [20].

When consumers feel the urge to step back from the consumption habits of others, this motivation is set off.

According to studies on uniqueness, three behavioral dimensions: creative choice counter conformity, unpopular choice counter conformity, and avoidance of similarity have been found.

- creative choice counter conformity: When people opt for social difference, their decisions might be influenced by others due to counter conformity.
- unpopular choice counter conformity: When people recognize how similar they are to others, they may breach norms or conventions or risk social rejection. This is known as counter conformity.

- avoidance of similarity: Consumers that have a high demand for uniqueness do not appreciate items or brands that they believe to be common.

### 2.1.3 Hedonism

Hedonistic consumption is defined by [21] as "consumer behavior that relates to the multi-sensory, fantasy, and emotive aspects of product use." A hedonic incentive is one that is focused on the consumer's pleasure, which includes visual pictures, fantasies, and physiological sensations including tastes, sounds, odors, tactile feelings, and perceptions of one's encounter with objects [21]. Affective consumption is a term used to characterize consuming that aims to produce a certain emotional state. This might involve purchasing something to improve feelings (sensation, fulfillment) or to recover from negative sensations (relief, recovery) [22].

### 2.1.4 Perfectionism

Perfectionism, which is sometimes referred to as the "functional" value of luxury but more broadly includes the superior design and customer services provided by luxury brands, is not limited to superior quality, usability, and/or performance [23]. The reason for perfectionism is the psychological propensity to do tasks completely. The pursuit of high human standards might be considered as a characteristic of perfectionism. The greatest quality is what consumers anticipate from premium brands. In the perspective of the majority, expensive goods and first-rate service may be equated with better pricing since they are perceived as reflecting excellent quality. Perfectionist clients place a higher value on quality and assurance, and in their eyes, luxury companies offer higher-quality products than non-luxury alternatives. Customers seeking perfection could be drawn to luxury items because, in their eyes, their high cost indicates superior quality [24-18].

## 2.2 *Personalization of customer-brand relationship*

It is one of the key components of a relational marketing strategy that works in tandem, according to [25]. It refers to the relationship between the customer and an organization as well as is carried out via a variety of activities, including recognition programs, product testing, business and customer meetings, preferential treatment, etc.

## 2.3 *Loyalty*

Loyalty is defined as "a firm and deep commitment to repurchase or purchase in the future a preferred product or service which, despite potential or actual environmental effects or competitors' marketing efforts to change the customer's purchasing behavior, is a repurchase of the same brand or series of brands. » [26].

Customer loyalty is viewed as the strength of the relationship between an individual's relative attitude and repatriation. Although customer satisfaction is a crucial part of a business, satisfaction alone cannot take a business to the next level. Customer satisfaction produces a positive bottom line, especially in regular purchases. Today's cutthroat market, where creating and retaining customers is more complex than ever before. This is due to the breakthrough in technology and the widespread use of the internet. Loyalty requires the company to concentrate the value of its products and services and to show that it is interested in fulfilling the desire or building the relationship with the customers [27]. A relationship with a customer is equally important in building customer loyalty and it requires the business to work in a larger context that extends beyond itself as no business can be world-class [28]. Customer loyalty was divided into three different categories which include behavioral loyalty, intentional loyalty and emotional loyalty. Behavioral loyalty is the repetition of the buying behavior while intentional loyalty is the possible buying intention. However, emotional loyalty is achieved when a customer feels a brand matches their value, ideas, and passion [29].

### 3. Materials and Methods

In order to carry out our study, we opted for a qualitative approach. Thus, it seemed to us that the semi-directive individual interview is the most appropriate to meet our objective of encouraging respondents to discuss freely their psychological motivations and their role in contributing to the formation of loyalty to luxury restaurants.

#### 3.1 Selected restaurants

The Moroccan restaurant industry is booming in 2023 thanks to trends including sustainable practices, creative menus, technological integration, emphasis on quality, and immersive culinary experiences that are shaping the nation's culinary landscape. Restaurants in Morocco try to adjust to these new trends in order to stay competitive and meet the evolving needs of their patrons.

Table 1 describes the evolution of restaurants and hotels in Morocco.

**Table 1.** Evolution of restaurants and hotels in Morocco from 2017 to 2023

Years	Restaurants, cafes and similar establishments	canteens	Accommodation services
2023	115,6	105,7	103,2
2022	109,3	105,3	98,4
2021	106	102,6	97
2020	104,7	100,5	97,6
2019	103	100,1	100,2
2018	101,2	100	100,9
2017	100	100	100

Source: Survey of industrial production, High Commission for Planning

Several researches have been carried out to explain the different dimensions of quality in the field of catering, table 2 identifies these dimensions, with the researchers concerned and the year of the study carried out.

**Table 2.** Quality dimensions related to restaurants industry

<b>Dimensions</b>	<b>Authors</b>	<b>Year</b>
Tangibility, responsiveness, empathy, reliability, assurance and quality of service perceived by the customer	[30]	2011
Restaurant image, accuracy, speed of service and price	[31]	2012
Food quality, tangibles, staff, convenience and advice	[32]	2013
Service, hygiene and atmosphere	[33]	2014
Quality of service, quality of food, quality of atmosphere and perceived value.	[34]	2015
Perceived value, emotional price, monetary price, behavioral price and reputation.	[35]	2016

In the Moroccan context, and in order to construct a list of luxury restaurants in Morocco, we based ourselves on the following criteria:

- a complete service
- a high quality environment
- and entrees that cost \$20 or more. [36–37-38]

The following table (table 3) lists the most luxurious restaurants in each Moroccan city.

**Table 3.** Luxury restaurants in Morocco by city

<b>Cities</b>	<b>Luxury restaurants</b>
<b>Casablanca</b>	Iloli La table de Rétro
<b>Marrakech</b>	l'italien de la mamounia, la cour des lions, , la table du royal mansour, la grande table marocaine, le jardin du royal mansour, sesamo, AL Aïn, Le Caravane, mes'lalla, Palais Jad Mahal, le selman, la villa des orangers, Le Jardin d'hiver, Malak Eme-raude,SINIMAN
<b>Agadir</b>	Au palais du jardin
<b>Essaouira</b>	Heure Bleue Palais
<b>El jadida</b>	Le Sel de Mer

### 3.2 Participants

One of the most important questions that the researcher asks when conducting this type of interview is to know how many interviews are necessary to obtain correct, relevant and meaningful results. Since our main objective is not to test a pre-established model, but more to understand the contribution of psychological motivations to the formation of loyalty to luxury restaurants in the Moroccan context, we will therefore have the possibility of limiting ourselves to a convenience sample.

Regarding the choice of the number and profile of people to interview, we chose to respect the criteria of saturation and diversification. Ten interviews were necessary to satisfy the theoretical and semantic saturation criteria. In terms of diversification, we interviewed different customers of luxury restaurants from different cities in Morocco (Casablanca, Marrakech, Agadir) in line with cities of luxury restaurants in Morocco, the customers questioned are of different ages from different social and economic levels, from different professional categories as it is shown in table 4. This is a very specific and inaccessible category of customers, we opted for the snowball effect in order to contact these people and have appointments with them, we started first with our entourage, and then we asked each respondent to recommend other contacts and so on.

**Table 4.** Characteristics of questioned individuals

<b>Name</b>	<b>Profession</b>	<b>Age</b>	<b>city</b>	<b>Duration</b>	<b>Date of interview</b>
<b>Mounia</b>	Professor of Higher Education	49	Casablanca	<b>56 min</b>	<b>20/08/2023</b>
<b>Said</b>	Entrepreneur	56	Casablanca	<b>1h20min</b>	<b>16/06/2023</b>
<b>Sami</b>	HR Director	36	Marrakech	<b>52 min</b>	<b>03/07/2023</b>
<b>Sanaa</b>	Doctor		Casablanca	<b>54min</b>	<b>01/06/2023</b>
<b>Asmaa</b>	decoration Architect	27	Agadir	<b>48min</b>	<b>28/06/2023</b>
<b>Dalal</b>	Entrepreneur	25	Marrakech	<b>50 min</b>	<b>13/06/2023</b>
<b>Rihab</b>	Haute couture brand owner	28	Agadir	<b>1h10 min</b>	<b>14/08/2023</b>
<b>Abderrahim</b>	Professor of Higher Education	59	Casablanca	<b>1h</b>	<b>07/06/2023</b>
<b>Laila</b>	Director of a bank branch	42	Agadir	<b>53 min</b>	<b>19/07/2023</b>
<b>Maha</b>	<b>Doctor</b>	<b>45</b>	<b>Marrakech</b>	<b>46 min</b>	<b>21/07/2023</b>

### 3.3 Data collection

All our respondents were interviewed individually, we carried out a face-to-face interview test before conducting the interviews in order to detect failures. We deduced from this test that the questions were a little badly formulated, this is what we tried to improve afterwards. We conducted ten face-to-face interviews with an average duration of fifty seven minutes per interview. The number and duration of interviews are respected and comply with the standards of qualitative exploratory studies [39]. Additionally, in order to guarantee that the interviews went well,

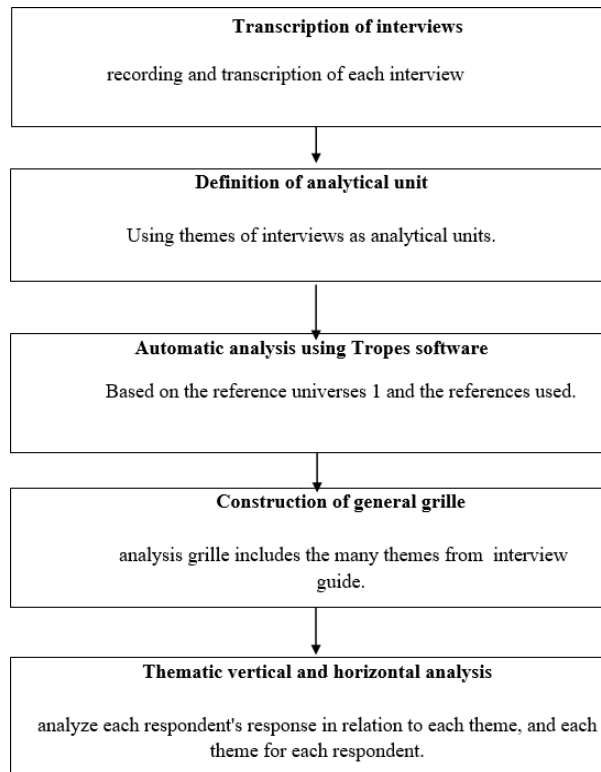
we employed an interview guide as an animated supplement that included a variety of topics related to the limitations of the literature review on the customer loyalty in luxury restaurants as well as the specific goals of the study. The themes were all addressed in their entirety, depending rather on the degree of proximity to the discourse of the interviewees than

“in a pre-established sequential order” [39], the interviewing guide was broken down into three parts. The first was to identify the respondent's psychological motivations for choosing a luxury restaurant and to categorize those motivating factors (materialism, hedonism, uniqueness, or perfectionism). Then, determine how these psychological motivations influence customer satisfaction with service, cost, quality, etc. and might result in a recommendation of the chosen restaurant and the dissemination of views. Finally, the frequency and regularity of respondents' visits to luxury restaurants, as well as their attachment to this kind of restaurants can help us determine their level of loyalty.

### **3.4 Data analysis**

We decided to perform a theme analysis of the interview guide's content in the context of our study by following these themes; theme 1: psychological motivations (under themes: materialism, uniqueness, hedonism, perfectionism), theme 2: satisfaction (under themes: affective satisfaction, cognitive satisfaction, Bidimensional satisfaction, relational satisfaction), theme 3: loyalty (under themes: behavioral loyalty, attitudinal loyalty). Given that the themes are already known, this analysis will be carried out a priori in order to interpret the content, connect each unit of meaning to a distinct theme, and discover how the various topics from the interview guide were covered during the interviews and what variations there were in approaches depending on each type of respondent. Every interview was really Dictaphone recorded so that transcription could be done later on. A thorough review of all the interviews was conducted after they had been taped and transcribed to acquire a broad overview and to spot any new topics that the participants had not previously brought up.

The following diagram (figure 1) illustrates the procedure for interview analysis and describes each phase.

**Figure 1.** Interview analysis process

**Source: Authors**

According to thematic analysis by Tropes Software, we include the five main universes of reference 1 in table 5 together with the references they contain, classifying each area according to relevance.

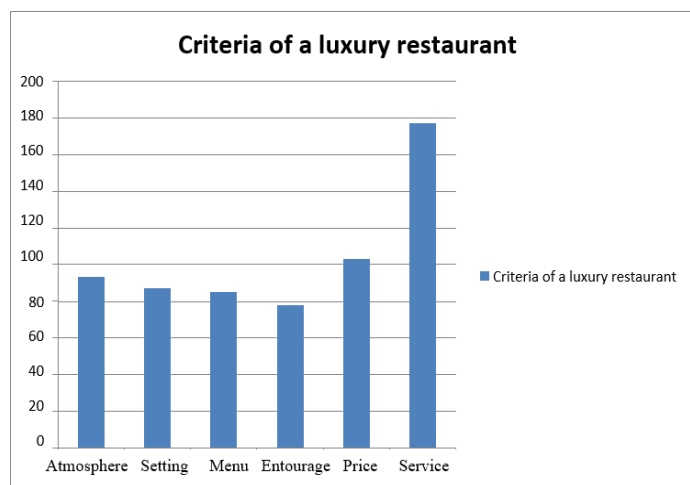
**Table 5.** Reference universes and their explanations (Tropes Software)

Reference Universe 1	References
<b>Restauration</b>	restaurant, gastronomy, menu, waiter, diner, lunch, food, "cuisine"
<b>Richness</b>	richness, luxury, rich people
<b>Trade</b>	Price, cost, customer, business, bar summer, February 14, birthday, new year, in addition to the terms; day, period, month, week.
<b>Time</b>	This universe presents the different opportunities to visit restaurants
<b>People</b>	everyone, no one, someone, physical person. These references present the terms customers use when they talk about staff, the restaurant environment or others.

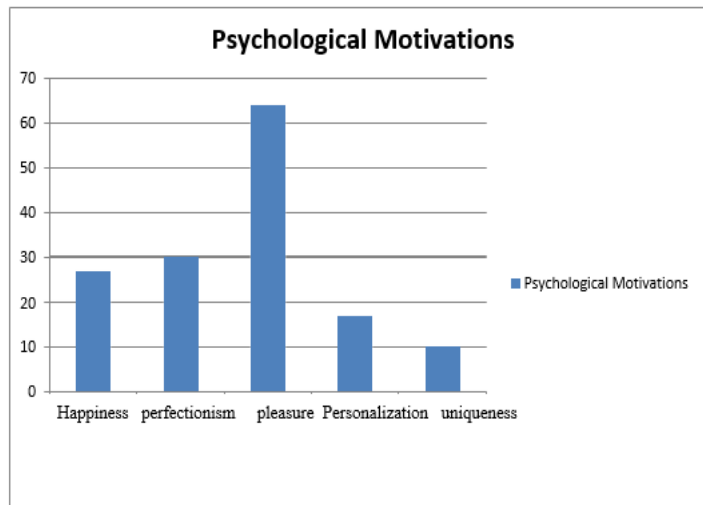
#### 4. Results

In order to properly assess our study, we first decided to make advantage of the automatic analysis offered by the program Tropes, which creates classifications, graphs, and correlations between terms automatically. By selecting from a variety of scenarios constructed from the conducted interviews and by establishing links between the numerous references utilized, we will be able to identify our problem in a different approach and provide graphs and tables at the conclusion of the study. After building the general grille, we went onto the vertical analysis (analyzing each answer in terms of its corresponding theme) and horizontal analysis (analyzing each topic in terms of its corresponding responding theme).

**Figure 2.** Criteria of a luxury restaurant



From interviews, it has been determined that the main criteria for a luxury restaurant is service, which means perfect service including waiter, welcome... Next, the price must be appropriate and not excessively expensive to qualify as a "luxury restaurant," followed by a beautiful setting that meets the criteria for a "luxury restaurant," a great personal or professional atmosphere, a good ambiance that complements this setting, a varied and well-planned menu, and finally entourage, the clientele that frequents this kind of establishment.

**Figure 3.** Psychological motivations of luxury restaurants' customers

The customers of luxurious restaurants have various psychological motivations, such as the desire for happiness through the ambiance, the surroundings, and the setting; on the other hand, the pleasure is found in the staff's welcome and service; next, the need for perfection is found in the details, such as the plate, the cutlery, and the service; and finally, the desire for personalization, which emerged as a fresh motivation in the interviews. Finally, uniqueness can be found in recognition or personalized service.

**Figure 4.** Obstacles to customer loyalty in luxury restaurants

The interviews also revealed the barriers to customer loyalty. For example, high prices make it difficult for customers to return to a restaurant; instead, they need to be at a fair price. Additionally, customers may not be loyal because they like to try new restaurants to find the perfect fit for their needs. And then if they do not always find the same quality of service and dishes, they will not return and then change the restaurant.

## 5. Discussion

Our study's findings will be discussed in three parts, each of which is based on existing research sub-questions.

### **What are the psychological motivations that help to create the loyalty of customers at luxury restaurants according to Moroccan context?**

Through the results obtained, we can see that the psychological motivations that contribute to the formation of loyalty is first of all happiness which results in a good atmosphere, lively music, *"If I will be happy, I will be loyal"*, *"where I can find a show...spectacle with different music, different styles, there I can tell you that I will be attached to this restaurant"* or a change of mood, *"I need my Mood to change completely"*. Then the personalization of customer-brand relationship has emerged in theme 1 (psychological motivations) as a new theme, it is a dominant motivation for our respondents to go and visit luxury restaurants, indeed this motivation is explained first of all by the fact of being called by the client's own name "customer recognition", *"he calls me by Miss X"*, *"it's Mr, it's Mrs and who takes me to my table"*, *"he calls me by my name, it's important for me"*, *"let me be recognized"*, *"let me be called by my name"*, all these expressions show that this point is interesting for them, then the manager's presence and his personal accompaniment contribute also to the personalization of customer-brand relationship. *"welcomed by the manager"*, *"the manager accompanies me in and out"* which plays an important role in loyalty, then the perceived value in the restaurant is crucial as well, they want to feel important in the restaurant. *"I feel like an important customer"*, *"I'm already part of their database, it's important"* in addition to the personalized service that meets the personal expectations of the customer *"the staff is very caring"*, *"I had a personalized welcome"*, *"to be well served, to have a personalized welcome, then I will be really loyal to the restaurant"*. On the other hand, findings revealed that the pleasure motivation is reflected in many elements; the warm welcome *"they welcomed us with applause"*, the varied menu, *"their menu is really varied"*, *"the menu is really gastronomic"*, *"a very nice varied menu"*, the atmosphere *"it's a nocturnal atmosphere"*, *"special friendly atmosphere"*, the place *"a very chic place"* *"I really liked the place"* *"the place was just beautiful"*, the staff service *"the staff was courteous"* *"the waiter was always present"* *"they were attentive"*, the classy people nearby *"we were well surrounded"* *"respectful, classy people"* or in general the promise displayed by the word luxury *"everything must show luxury"*. However, perfectionism's motivation is found in the details; the plate, the cutlery *"crystal glasses, plates, high quality silverware"*, the service *"a professional service"* *"zero fault"*, the presentation of the dish *"...even how he puts the dish"* *"the presentation is done carefully"*, the luxury items, the decoration, the view, the special place, the cleanliness *"the glasses, the dishes, the cutlery everything must be clean otherwise it's dead"*...and finally the uniqueness that can be found in the welcome *"if you are well received you feel unique"* and the fact of taking care of your dress before going there *"I will not go with blue jeans, it won't work but I'll take care of my clothes very well by putting on a suit and tie"*, *"I'll be really well-coiffed."*, *"I choose what I'm going to wear carefully"* are among the psychological motivations cited for visiting luxury restaurants.

### Which role play customer satisfaction in the current relationship?

From an affective side, positive and negative emotions have a direct effect on overall satisfaction, the feelings felt by customers during their consumption experience have an impact on its evaluation [40]. So, they are satisfied with the experiences *"the unique experience of being at Royal Mansour"* *"an environmental culinary experience"* however they prefer to do it better by comparing Moroccan restaurants with restaurants abroad *"but we can do best"* *"for restaurants in Spain it has nothing to do with Morocco"* *"thus, there are certain luxurious restaurants but which do not manage to perpetuate the luxury label"* *"it is difficult to always be on top..."* *"sometimes we are disappointed"*. On the other hand, sometimes luxury can be exaggerated *"I feel it's overrated"*, *"it may lack naturalness"* *"it doesn't look like me"* and then for them there are no real luxury criteria in Morocco, especially in Casablanca unlike in Marrakech *"for me there is no real luxury in Casablanca"* *"in Marrakech maybe..."* *"there is always some randomness compared to other countries"* *"...The staff is not always at the highest level"*. So, they suggest, for instance, that the hostess at the reception dress appropriately, have extremely well-coiffed hair, and be very attractive. *"she must be very well dressed, every thing on point..."* They also demand that the waiter be able to communicate in many languages, be well dressed, and be knowledgeable about the food. Therefore, the main criteria for a luxurious restaurant that is convenient for them is first and foremost the service, which refers to excellent service from the server to the host to the staff. Then the price must be appropriate and not excessively expensive to qualify as a "luxury restaurant," followed by a beautiful setting to be considered as a luxury restaurant, a pleasant personal or professional environment, good atmosphere that complements this setting, a varied and well-developed menu, and finally the restaurant's entourage or the customers who frequent this type of restaurants and surround it. *"so, the selection is made naturally, there are only the people of a certain level"* *"we are well surrounded"*.

In terms of cognitive satisfaction, satisfaction is related to customer expectations regarding the product [41-42]. Customers are satisfied with a variety of elements, including the decoration, some ones said *"a very beautiful Moroccan-Berber decoration"*, *"pure Spanish decoration"*, the good service: *"professional service"* *"particularly the server's courtesies"*, the good price/quality ratio: *"if I am very satisfied, I will pay with my eyes closed"*. However, there are complaints, such as the inconsistent service in comparison to foreign standards, *"the poor server is completely wet"* *"it has nothing to do with foreign countries,"* so there is always this comparison between international standards and Moroccan setting. In addition, the price is also seen as being high in Morocco *"The prices remain high, without alcohol, one cannot eat for less than 600 to 700 DH per person."* Thus, occasionally it is luxurious in price but less in others elements *"It lacks atmosphere or other services for paying 1950dh."*

The bidimensional aspect of satisfaction is strongly present. For example, customers of luxurious Moroccan restaurants frequently recommend their favorite restaurants to others, which is approved by Trope's software. Among the determinants of satisfaction *"I recommend it frequently"* *"My friends loved it when I recommended it"* *"I recommend it to my family"* Whether

in a personal or professional setting, *"I frequently recommend it to my coworkers" "It's a beautiful professional setting that I recommend"*. Therefore, according to Trope's software "work" is an indicator of satisfaction that describes a work environment, it is far more satisfying than a personal setting by opting for positive word of mouth *"I only choose positive word of mouth," "I leave my comment which is always positive on the internet"*.

Next, the relational satisfaction, which is an assessment of the current experience as well as past and future experiences [43]. In response, it is explained by a strong desire to return *"...from next weekend" "...why not the following week if it's a nice weather,"* which is motivated by the personalization of customer-brand relationship and particularly the personal accompaniment of manager; *"he accompanied me until the valet" "he takes me to my table"*. Then, they insisted on consistency of food and service quality *"I always want to find the same thing, otherwise I'll change the restaurant"*, same thing for the special setting, customers said *"a beautiful setting" "it's the setting that attracts me"* in addition to the warm welcome for example *"being well received by the restaurant staff"* which makes customers feel important and never disappointed. By using the acts revealed by Trope's software, the satisfaction will then generate a feeling of happiness for the customer, take a picture of themselves under the word "photography" some customers are therefore attached to the social networks Instagram, Facebook, and Snapchat...consequently they take a lot of pictures in these luxurious places in which they are satisfied, then the satisfaction made clear the cities of the most visited restaurants namely Marrakech, Casablanca, Agadir. The respondents' verbatim accounts of their encounters with friends and family in luxury restaurants reflect their satisfaction with these relationships.

#### **How satisfied customers of luxury restaurants can become loyal?**

Loyalty is the result of satisfaction [44]. Satisfaction can lead Moroccan customers of luxury restaurants to loyalty through several elements; personalization of customer-brand relationship *"he calls me by my name" "everyone recognizes me"*, happiness *"if I'm happy I'll go back"*, valuation and personalization *"when I go to this restaurant, I feel important" "I can have everything I want, I'm spoiled"*, Service *"to be well served, to have a personalized welcome, then I will be really loyal to the restaurant"*. On the other hand, loyalty is explained by maintaining the high quality of dishes and service. *"I will come back to eat my favorite dish" "if it is a special dish it will attract me to come back and be loyal"*, by the decoration as well *"I am attached to Instagram, Facebook and Snapchat, so the decoration attracts me a lot to be loyal"* it's especially for people attached to social networks, Loyalty is also attached to the experience lived *"in fact it's a whole experience that I want to relive" "it's a special experience including the service, the dishes, the atmosphere..." "even if it's expensive but I want to relive it"*. Gifts can explain loyalty as well *"we had free desserts at the end, it was special. They don't do it for everyone", "...they gave us free wine glasses and we spent an extra hour"*.

Consumer satisfaction affects loyalty by influencing both purchase intentions and repeat purchase behavior [45]. Thus, even if the respondents have a strong desire to return, they only frequently dine at luxury restaurants once a month or once every two to three months or once every holiday depending on the city, which is mostly due to the expensive price. Contrarily, a

customer may have a good attitude and purchase a brand's products or services for one or two years before simply changing their behavior, which explains the unstable nature of loyalty. The luxury customers questioned may also not be truly loyal to a luxury restaurant brand since they want to switch restaurants based on their needs *"there is not really a loyalty toward a precise restaurant"*. So, they're interested in discovering the newest openings, *"I change it depending on the atmosphere I look for"*, *"That doesn't stop me from going out and finding a new restaurant"*. Loyalty is important, but discovery is equally enriching. *"Whenever there is a new opening, I am curious to go discover."* In light of this, we can identify the barriers to loyalty. For example, the high price, as previously said, creates a requirement to return to the restaurant. Since the price must be reasonable, it acts as a barrier to doing so. Then, customers may not be loyal because they like to switch restaurants based on their preferences; as a result, there isn't really a loyalty to a specific luxury brand. Instead, they want to discover new openings because it's enriching for them, and if the food and service aren't consistently of the same high quality, they won't return and will instead choose another restaurant. Thus, suggestions were made by the respondents to be loyal, they want to have a loyalty card *"...to be loyal, you get me the card, for example tell me if I go 5 times the sixth time I will be invited... for me it's an advantage, it will motivate me to go there 5 times in a row to get the gift"* then, to have privileged places at events *"...to invite me to events, like say we organize an evening with such an artist and therefore we invite you to come. that doesn't mean that I won't pay for my meal, but the fact that the information is communicated, means a lot for me..."*, customers proposed the restaurant's creativity and surprises as well *"I want the restaurant to impress me every time"*, *"I expect surprises on Valentine's day, the new year..."*. Finally practicing a correct price is recommended by the most of customers *"If the price is too high, I won't go back," "a high price won't make me feel attached"*.

## 6. Conclusions

According to this study, it has been discovered that a side the psychological motivations for visiting this type of restaurant, others factors such as loyalty card, preferred seating for events, restaurant's creativity and surprises, offering the right price may contribute as well to the loyalty of its customers, it is like a package of several aspects. In fact, personalization of customer-brand relationship has emerged as a fresh theme in the Moroccan context; it is also seen as a psychological driver that may be explained by the personalized service, the perceived value, the use of customer's name while being addressed, and the manager's accompaniment. Although customers may be satisfied, loyalty is hindered by the recent openings of rival restaurants, high prices, and irregularities in the service and the food. Thus, it appears that Moroccan consumers have their own standards for luxury; the entourage; who frequents these places, where the price must be reasonable, a beautiful setting, a welcoming atmosphere, high-quality service, and a well-constructed menu.

From a theoretical perspective, contributions are clearly seen in the answers given to the sub-questions as well as in the newly developed themes. First and foremost, we identified the standards for a high-end restaurant as determined by Moroccan customers. Then, we discovered a

new psychological motivation to visit a high-end restaurant in a Moroccan setting, which is personalization of customer-brand relationship. Later, our research allows us to better understand the formation of loyalty in the luxury restaurants field from the point of view of the consumers who are concerned. This concludes previous research on the topic carried out in other industrial sectors as a result of being able to identify the factors that influence and restrain consumer loyalty. From a methodological standpoint, we chose a qualitative methodology, which allowed us to understand the subject in detail in contrast to a quantitative study while also bringing up new themes that were not covered in the interview guide. Then, we carefully selected the respondents, as this is a real sample (customers of luxury restaurants). Finally, from a managerial point of view, the results of our study made a double contribution. First, help luxury restaurants managers learn about the obstacles to loyalty. Why are satisfied customers not always loyal customers? Which role play psychological motivations? Second, identify the possibilities for acting on these obstacles. What variables should be acted upon in order for the customer to be loyal? given that we presented the respondents' suggestions to be loyal, namely loyalty card, privileged places at events...

## 7. Limitations and future research

Given the particular characteristics of this class, we initially concentrated on a limited sample size. We interviewed 10 customers of luxury restaurants, which may convince more researchers to choose a bigger sample size in the future. Additionally, because our study focused on how consumers interpret their experiences, we neglected to include the viewpoint of experts in the luxury restaurant sector. In order to better grasp these themes, the current research has chosen to concentrate on a variety of factors at once, including satisfaction with its four dimensions; cognitive, emotional, bidimensional, and relational; and loyalty with its two dimensions; behavioral and attitudinal. Finally, during the data analysis phase, we chose the software Tropes. However, we didn't use the NVIVO software to code the data before breaking it down into proposals.

On the other hand, the present paper has suggested several research directions. First, how do psychological motivations influence how loyal people are to luxury goods? Is there a difference in relation to luxury services? Future studies may decide to do a comparison of luxury goods and services in terms of loyalty. Second, what are the criteria of a Moroccan consumer of a luxury restaurant? what role does the socio-professional criterion play? So far, we've discussed many criteria of a luxury restaurant that the consumer has mentioned. However, we now need to know how this consumer who frequents these restaurants might be distinguished. Then, what we learned from the interviews is that everyone has their own definition of luxury in terms of restaurants, so it will be beneficial to conduct a quantitative study in the future in order to identify the standards of luxury restaurants in Morocco. This will allow to generalize the standards of a luxury restaurant to the Moroccan context. However, further confirmation is needed concerning more culturally diverse nations in order to distinguish between different luxury restaurants standards based on the context studied. Finally, it was concluded from the study that gifts,

invitations to events, and loyalty cards are all considered to be signs of loyalty by Moroccan consumers. However, what do marketing experts think of suitable loyalty programs in the luxury restaurant sector?

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# The Effect of Correlation in the CVaR Algorithm

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**Abstract:** According to existing literature, the CVaR (conditional value at risk) method outperforms, therefore in this study CVaR is applied as a constraint to transform portfolio optimization problem into a linear one. Linearization of portfolio optimization plays a central role in financial studies, since linear problem allows for performing sensitivity analysis. Sensitivity analysis makes it possible to measure the variation of parameters due to the variation of one parameter in a linear problem, without solving the problem from the scratch. The objective function coefficient of mentioned method for a portfolio includes average of asset returns, which are highly correlated. Therefore, principal component analysis is employed to tackle the correlation of the functional relations. An example of stock market is employed to validate method. Finally, it is shown that the result of the presented method is closer to the ideal result.

**Keywords:** Correlated parameters, Sensitivity analysis, Linear portfolio optimization, Principal component analysis

## 1. Introduction

Studies about portfolio optimization could be categorized based on its risk measurement. The initial model uses variance as a risk measurement, thus considered as a quadratic programming problem. Regarding its compact covariance matrix there is computational difficulty associated with. Many scholars had attempted toward linearization of portfolio because linear problem have some advantages over the non-linear one. The related software and solution for a linear problem are effortless. Moreover, it makes the sensitivity analysis possible. As an alternative, the mean absolute deviation (MAD) that was first initiated by sharp (1971) was introduced to alleviate the shortcoming of initial model and plus takes its advantage. This method allows that large-scale optimization problem being solved on a real time. However, the assumption of dies-utility, which prevents detecting of risk from larger losses, reduces the popularity of this method.

CVaR method presented by Uryasev (2002) was highly populated due to the following advantages. It has been shown that CVaR is a convex risk measurement (Uryasev, 2002). The minimization of CVaR on the other hand leads to a portfolio with a small VaR. Moreover, CVaR could be involved either as a subjective function or as a constraint (Uryasev, 2002).

After proposition of linear portfolio optimization, the question raised that which algorithm has to be applied in order that the answers become more reliable. The simplex method finds an optimal solution for the LP problem, which has entered the algorithm. After the simple method, interior point methods (IPMs) were introduced to solve large-scale problems. This method solves problems in polynomial time. Simplex algorithm outperformed interior point methods (Potra, 2018). Therefore, this method has been widely used in portfolio optimization problems (Lim, 2020).

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Later, the importance of measuring the perturbation of other parameters because of change in one parameter was considered. Such questions are addressed through sensitivity analysis (Bazaraa, 2009). However, the following sensitivity analysis techniques do not consider the correlation among parameters.

The ordinary sensitivity analysis proposed by Koltai and Terlaky (2019) is only solvable by simplex method and no simultaneous changes of OFC or RHS is allowed. The problem is tackled through two distinctively different methods. Each of these methods has some drawbacks. The 100% rule does not assure whether the optimal solution remain unchanged if this rule does not satisfy or not, and the tolerance approach could not be applied to large-scale problems due to the small range. The shortcoming of these methods intrigued. This method considered individual percentage change for every RHS parameters or OFC. However, small tolerance and no simultaneous perturbation among parameters are among weak points of this method. It is attempted to combine different sensitivity analysis through a parametric system. The Parametric programming method is useful when RHS parameters or OFC depend only on one parameter. The weak point of this study is that it is only applicable for diverse sensitivity analysis (Shahin, 2016). After that, Hladík (2021) presented another method, which was computationally attractive and applicable to broader cases. However, this method ignores the correlation among parameters. To eliminate the shortcomings of ordinary sensitivity analysis Hladík (2021) represented a noble method that addresses the correlation among parameters. The method then followed by Shahin 2016. In this study Shahin used Principal component analysis (PCA) to account for correlation among parameters.

PCA method in some research is applied as a creator of factors (Victor, 2021; Heij, 2021). This is also a useful method in portfolio optimization. They used the forenamed method for portfolio optimization problem and showed the superiority of using PCA method in portfolio optimization to portfolio optimization without using PCA. PCA method diversifies portfolio; thus, the risk decreases because stocks are chosen from those with lower risks.

In addition, sensitivity analysis in portfolio optimization has been concerned in a number of studies (Arbaiy, 2019). Nonetheless, neither of them has considered correlation among stock's price.

In this paper we aim at performing sensitivity analysis for a linear portfolio optimization problem under CVaR method and simplex algorithm. CVaR method objective function consists of the average returns of the stocks and these parameters are highly correlated. To the best of authors' knowledge, among the previous studies there is no study to deal with this problem. We will use the PCA method to tackle the problem and then the sensitivity analyses based on the related formulas are computed.

The paper is organized as follows. In section 2 the methodology of sensitivity analysis in the presence of correlation among parameters is introduced. Section 3 illustrates the details of sensitivity analysis details while considering correlation among OFC. Section 4 presents portfolio optimization using CVaR as a constraint. In Section 5, the sensitivity analysis of real example of portfolio optimization is examined. Finally, the conclusion is presented in sections 6.

## 2. Materials and Methods

In this paper, to construct a linear portfolio under CVaR method, first, the historical data of four stocks (MNST, MAR, FISV, SON.SG) are derived from the related websites and then the logarithmic returns are calculated. Next, the returns divided into two parts the latest (newest) data,

which is regarded as future data, and the historical data. For solving portfolio optimization with CVaR method some scenarios are needed. We use Mina & Yi Xiao method to generate scenarios, which is a historical data simulation. The historical monthly prices are used to derive monthly returns. The problem is solved without the latest data.

Next, we use the covariance matrix as the input of a multivariate statistical method called principal component analysis (PCA) in order to convert correlated parameters (OFC) into independent ones, introduced by some functional relations. Because the objective function constructs of average of returns; thus, the PCA should be applied over average of data. The historical returns for each stock in each 3 months put into one group -season data- and the average of each group is computed. Then the difference between historical return of one stock with and without the latest data is calculated. For the rest of the stocks, the deviation is calculated by the help of the equation 5.

Then the 100% rule should be applied to see whether the basic variables remain unchanged. If the 100% rule is satisfied, we know that the current optimal solution still remains optimal even though all the RHS parameters or OFC have changed. Then to evaluate the volatility and the prediction capability of this method, the result is compared with two other problems. The first one as we call the ideal result includes the whole data. Second, we consider a case in which instead of latest price, the historical price average is implied except for one stock which takes its latest data because we assume we know one stock price and not the rest of the stock price. To obtain it, the historical price of data without the latest data is considered and then average of each stock is calculated. Next, the result of linear portfolio optimization as before is derived. Finally, these three results are compared. The following flowchart shows the conceptual framework of this paper.

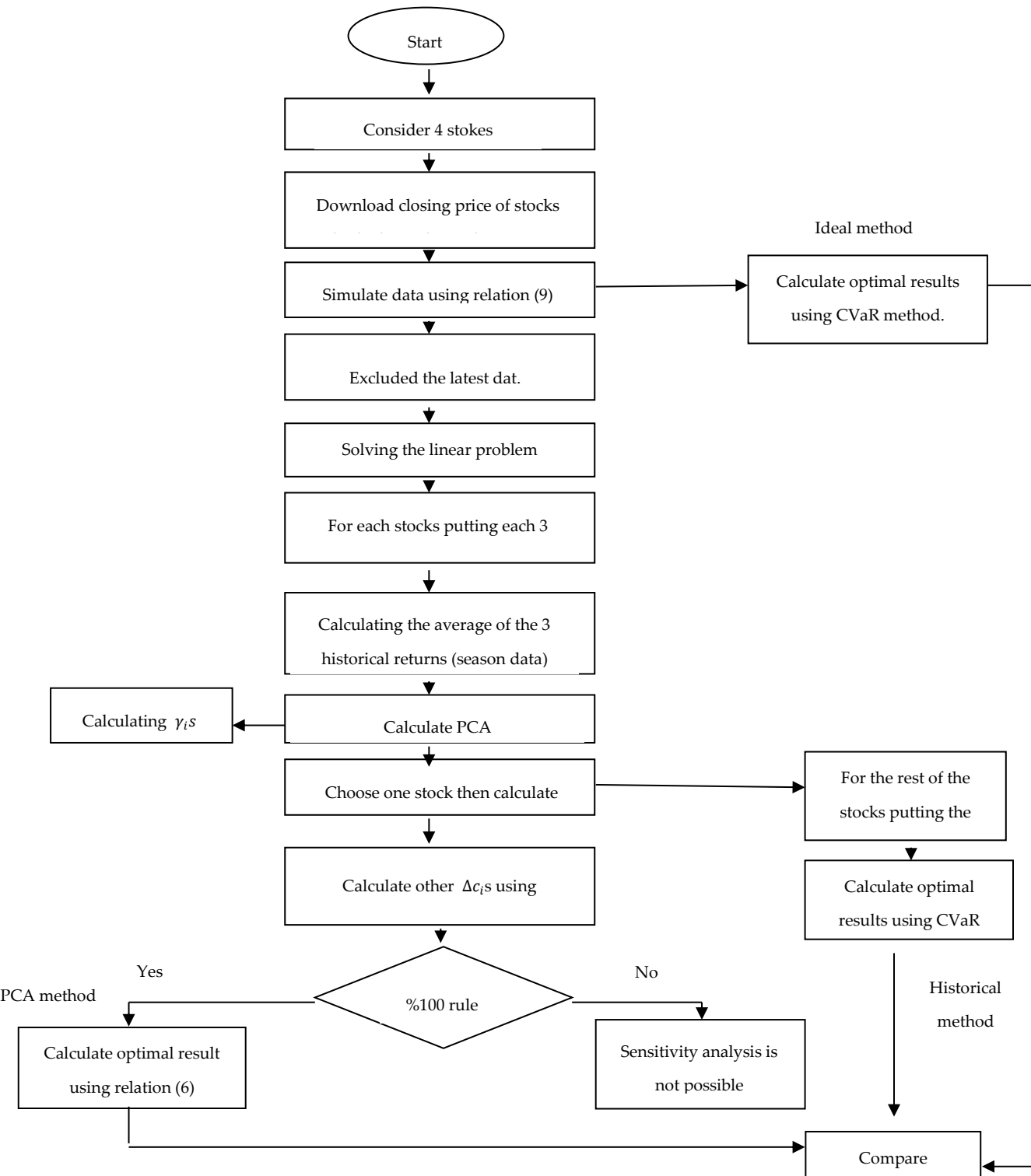


Fig. 1. The flowchart of sensitivity analysis in the presence of correlation

Source: Author’s research

### 3. Sensitivity analysis:

In this section, we briefly discuss the formulas of sensitivity analysis of LP problem in the presence of correlation among OFC by Shahin (2016). It should be noted that these formulas rely upon a series of assumptions. First, they are valid for local perturbation, that is, the acceptable range for parameters change should be small and within  $\varepsilon$ -neighborhood of the estimated parameters. Second, formulas are only applicable when a basic optimal non-degenerate solution is available. The following LP program is considered as a basis on which other formulas are derived.

$$\begin{aligned} \text{Min } & \mathbf{c}^T \mathbf{x} \\ \text{s.t. } & \mathbf{Ax} = \mathbf{b}, \\ & \mathbf{x} \geq \mathbf{0}, \end{aligned} \quad (1)$$

where  $\mathbf{x}$  is a vector with  $n$  variables,  $\mathbf{A}$  is an  $m \times n$  matrix,  $\mathbf{c}$  is the OFC vector with  $n$  variables, and  $\mathbf{b}$  is the right hand side (RHS) vector with  $m$  parameters.

If equation (1) is solved, then the optimal value and the optimal solution are calculated as the following:

$$\begin{aligned} z^* &= \mathbf{c}_B^T \mathbf{B}^{-1} \mathbf{b}, \\ \mathbf{x}_B^* &= \mathbf{B}^{-1} \mathbf{b}, \end{aligned} \quad (2)$$

where  $z^*$  is the optimal value of the objective function,  $\mathbf{c}_B$  is the OFC of basic variable and variable  $\mathbf{x}_B^*$  is the optimal solution. The subscript  $\mathbf{B}$  denotes basic variables and the superscript  $*$  indicates the optimal value. In addition,  $\mathbf{B}$  is the constraint matrices of basic and  $\mathbf{N}$  is the constraint matrix of non-basic variables.

If there is not a correlation between the components of vector  $\mathbf{c}$ , we will have:

$$\frac{dz^*}{dc_k} = \begin{cases} x_{B_i}^*, & \text{if } c_k = c_{B_i} \\ 0, & \text{if } c_k \text{ corresponds to nonbasic variables} \end{cases} \quad (3)$$

In the presence of functional relation between OFC parameters, Shahin (2014) extended the following formulas based on the PCA method in order to change dependent parameters into the independents parameters:

$$\Delta \bar{c}_j = \left[ \frac{y_{11}}{y_{1j}} + \frac{y_{21}}{y_{2j}} + \dots + \frac{y_{n1}}{y_{nj}} \right] \quad (5)$$

$$\Delta z^* = \left[ \frac{\partial z^*}{\partial c_1} + \frac{\partial z^*}{\partial c_2} \left( \frac{y_{11}}{y_{12}} + \frac{y_{21}}{y_{22}} + \dots + \frac{y_{n1}}{y_{n2}} \right) + \dots + \frac{\partial z^*}{\partial c_n} \left( \frac{y_{11}}{y_{1n}} + \frac{y_{21}}{y_{2n}} + \dots + \frac{y_{n1}}{y_{nn}} \right) \right] \Delta \bar{c}_1 \quad (6)$$

Here  $\gamma_{ij}$ 's are the entries of the  $j$ -th eigenvector, which is calculated through PCA method.

### 4. CVaR Algorithm:

In this section, the CVaR algorithm is discussed. The portfolio optimization under CVaR method is solved by using scenario generation method. The optimal weights of stocks and optimal value of portfolio could be derived afterwards. Then by using the formulas which are presented in section 3, the portfolio sensitivity analysis based on the small changes in OFC which are mean return of stock's price will be performed and portfolio sensitivity analysis based on the a small changes of each stocks return is determined.

The first step of the CVaR calculation is to find the matrix of historical returns from the matrix of historical prices. Mina and Yi Xiao (2021) historical simulation method is applied, which considers logarithmic returns are applied. Logarithmic returns is the preferred method for return

calculations in finance and it will make calculations simpler in later stages of the thesis. The general formula for logarithmic returns is as the following:

$$r_{it} = \ln\left(\frac{p_{it}}{p_{it-1}}\right) \quad (8)$$

where  $r_{it}$  is the return of stock  $i$  in day  $t$  and  $p_i$  indicates the initial price of the security, whereas  $P_{i+1}$  is the price in the next period.

Then by using formula (9), the scenarios of the next period of stock's price will be calculated based on the historical monthly returns i.e.  $r_{it-1}, r_{it-2}, \dots$ .

$$y_{ij} = q_i * \exp(r_{it-j} * \sqrt{t}) \quad j = 1, 2, \dots, J \quad (9)$$

Here  $y_{ij}$  is the  $t+1$  or the next-month price of stock  $i$  in the scenario  $j$  also is a random variable and  $q_i$  is price of stock  $i$  in month  $t$ .

The expected end-of-period ( $t + 1$ ) stock  $i$  is derived from the following equation:

$$E[y_i] = \sum_{j=1}^J \pi_j y_{ij} = \frac{1}{J} \sum_{j=1}^J y_{ij} \quad (10)$$

We assume that all scenarios have equal probability.

In an optimization problem, CVaR can be considered as an either objective or constraint. If CVaR is considered as the objective, the risk of the portfolio measured by CVaR will be minimized based on the given required expected return. If CVaR is considered as a constraint, the expected return of the portfolio will be maximizing based on the given level of risk.

In this research, CVaR will be treated as the constraint of the portfolio optimization. Therefore, the objective of the optimization problem is to maximize the portfolio expected return. In other words, we could change the objective function into minimization by adding minus and minimize the portfolio expected loss based on the certain level of risk of the risk.

In this case, the portfolio optimization problem would be:

$$\min_{x, \zeta} \sum_{i=1}^n -E[y_i]x_i \quad (11)$$

subject to.

$$\zeta + (1 - \alpha)^{-1} \sum_{j=1}^J \pi_j e_j \leq w \sum_{i=1}^n q_i x_i^0 \quad (12)$$

$$e_j \geq \sum_{i=1}^n (-y_{ij} x_i + q_i x_i^0) - \zeta, \quad e_j \geq 0, \quad j = 1, \dots, J \quad (13)$$

$$q_i x_i \leq v_i \sum_{k=1}^n q_k x_k, \quad i = 1, \dots, n \quad (14)$$

where  $i$  is the number of stocks,  $E[y_{ij}]$  is the average of stock's return in all scenarios,  $x_i$  is the number of stock  $i$  in portfolio,  $w$  is the coefficient of risk tolerance,  $x_i^0$  is the number of stock  $i$  in the initial portfolio,  $e_j$  is the coefficient for changing CVaR into the linear variable,  $q_i$  is the price of stock  $i$  at the end of month in scenario  $j$  and  $\zeta$  is VaR.

## 5. Numerical examples:

In order to exemplify and mixed two proposed methods, a real example of stock market is solved in this section. Then, the results are compared with the results of two other problems where correlations among parameters have not been considered.

The data-sets used in this paper are historical monthly close prices of 4 stocks (SON.SG, FISV, MAR, MNST) from February 1, 2014 to September 1, 2015. The latest prices are excluded and the

problem is solved by using CVaR method. For solving portfolio optimization with CVaR method, some scenarios are required. Thus, Mina & Yi Xiao method is used to generate scenarios. First, the historical monthly prices are used to derive monthly returns. Twenty scenarios are derived from according to equation (9) for each stock. We assume that all scenarios have equal likelihood. Then based on the CVaR algorithm, the portfolio optimization problem is solved with lingo software. The basic variables are shown in the following table:

**Table 1:** The basic value

$\zeta$	e(20)	X(MNST)	X(FISV)	X(MAR)
692.33	28.53	13.87	22.53	13.59

**Source:** Author's research

Because objective function includes mean  $y$ , each of three monthly scenarios is put in one group, then the average of each group is computed. We regard these data as season data which are to generate PCA. To do so, first covariance matrix between season data is calculated and then eigenvalue and eigenvector are derived.

**Table 2:** Eigen-values of season data

Component	Eigen-value
1	0.031548103
2	6.064279805
3	24.62035181
4	1187.936196

**Source:** Author's research

It turns out; the Eigen-value of the fourth element is notably bigger than other elements. Therefore, based on the equation (15) it can be concluded that 0.97 percent of data are explained by the fourth element.

$$s_1^2 + s_2^2 + \dots + s_p^2 = l_1 + l_2 + \dots + l_p \quad (15)$$

where  $s$  represents variance and  $l$  is the eigenvalue.

**Table 3:** Eigenvectors of season data

Eigenvectors				
Variable	1	2	3	4
SON1.SG	-0.85846	0.287165	0.380537	0.189148
MNST	0.184078	-0.32384	0.210371	0.903872
FISV	0.311176	0.898522	-0.11826	0.286081
MAR	-0.36378	-0.07294	-0.89272	0.255728

**Source:** Author's research

To derive PCA, eigenvectors should be arranged in descending order based on the Eigen-value.

**Table 4:** PCA of data

$\gamma_{ij}$	j=1	j=2	j=3	j=4
i=1	0.189148	-0.38054	0.287165	0.858458
i=2	0.903872	-0.21037	-0.32384	-0.18408
i=3	0.286081	0.118264	0.898522	-0.31118
i=4	0.255728	0.89272	-0.07294	0.363778

**Source:** Author's research

Then for a selected stock, for the selected stock the difference between  $\bar{y}$  with or without latest data is calculated, it is notable that this value should be in acceptable range, then the variation of other stock is calculated based on formula 5. These data should also be in acceptable range. We consider stock 4, the variation between two  $\bar{y}$  is -0.242 and variation of other stocks are calculated using equation 5. The result is shown in table 6:

**Table 5:** Objective Coefficient Range (from lingo output)

Variable	Allowable Increase	Allowable Decrease
X_SON1.SG	INFINITY	58.96188
X_MNST	37.53784	INFINITY
X_FISV	2.339523	INFINITY
X_MAR	115.8636	2.22285

**Source:** Author's research

**Table 6:** The variation of correlated parameters

Stock (i)	$\Delta c_i$
i=1	0.199453733
i=2	1.382213411
i=3	-1.74051599

**Source:** Author’s research

All of the above changes are in the accepted range for which the basis is unchanged. Now 100% rule should be examined. If it is satisfied, we can calculate the new  $z^*$ .

$$\sum_{i=1}^4 \frac{\Delta \bar{c}_j}{\Delta \bar{c}_j^{max}} \leq 1 \tag{16}$$

By replacing the value of  $\Delta \bar{c}_j$  in the above equation, it can be observed that the 100% rule is satisfied. Therefore, the current optimal basis remains optimal.

In addition, by calculating  $\frac{dz^*}{d\bar{c}_k}$  and replacing those into equation 6 new  $z^*$  can be calculated.

$$\Delta z^* = -23.3258$$

$$new\ z^* = oldz^* + \Delta z^* = -4073.013 + (-23.3258) = -4096.3388$$

For Comparison, two steps are taken. First, we include the latest data that has been excluded first time and the portfolio optimization with whole data is solved. We regard this case as the ideal result because we assume that the future can be predicted 100%. Second, which is regarded a historical method the forth stock variation considered as the first case (-0.242) while for the other stocks the average of historical return without the latest data is applied. The purpose of this case is that how the result would be different from the ideal results, if the correlation among parameters is ignored and instead the historical data replaced. Finally, we want to know the derivation of which case is considerable (considering correlation among parameters or using historical data) based on the ideal result. The summary results are presented in table 7.

**Table7: The summary of results**

	$\zeta$	Non-zero e	x (SON1.SG)	x (MNST)	x (FISV)	x (MAR)	VaR	CVaR	Z*
PCA method	692.33	e(20)=28.53	0	13.87	22.53	13.59	0.16	0.17	-4096.33
Ideal method	468.69	e(21)=127.54	0	14.8018	21.96	13.95	0.11	0.25	-4110.35
Historical method	460.11	105.06	0	15.55135	22.83	11.61	0.111	0.23	-4133.02

**Source:** Author’s research

As can show in table (7) the variation of PCA method and ideal method is 14.02 and the variation of historical method and the ideal method is 22.26, which can be realized that the PCA method has explained the correlation and has resulted in the closer result to the ideal result. The results of three different cases are depicted in Fig.2 and Fig 3.

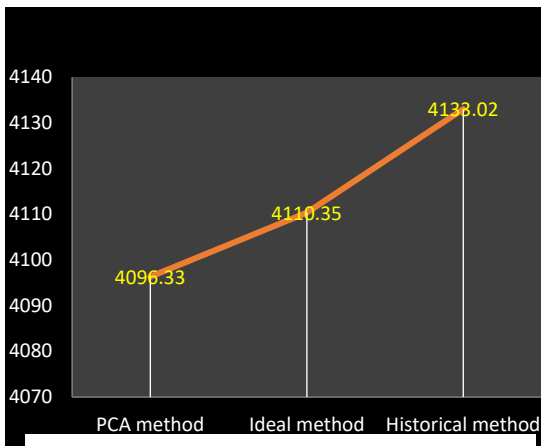


Fig. 2. The amount of Z\* of three cases

Source: Author’s research

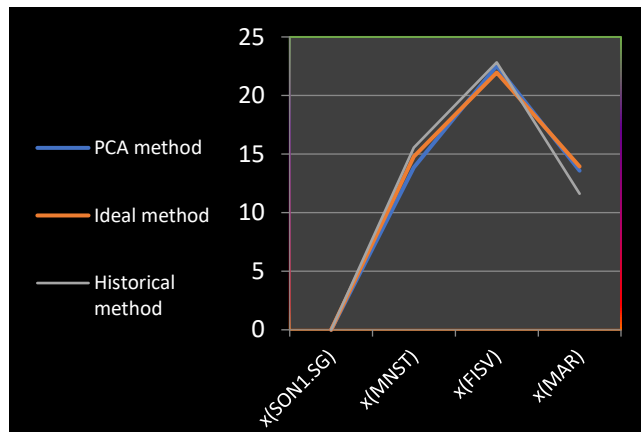


Fig. 3. The amount of x\*s in optimal portfolio

The amount of Z\* of three cases are compared by

$$\frac{\text{Historical}}{\text{Ideal}} = 1.005; \frac{\text{Ideal}}{\text{PCA}} = 1.003; \frac{\text{Historical}}{\text{PCA}} = 1.009$$

Clearly, PCA has better performance, In this way. By comparing the amount of x\*s in optimal portfolio in four cases SON1.SG, MNST, FIVS, and MAR again the PCA is relatively better.

6. Conclusions:

In this study, we discussed a linear portfolio optimization regarding correlation among the average returns of four stocks. In case of presence of correlation among prices, the variation of one variable contributes to the variation of correlated variables. Current sensitivity analysis had failed to predict the exact changes in other variables. Here, we calculated the changes in correlated variables and compared the result of new method with two other cases.

Historical data set divided into two parts. The first part includes the latest historical returns and the rest of the data put into the second part. For performing portfolio optimization, the CVaR method is employed and PCA method is applied to account for the correlation among OFC. Then, sensitivity analysis of linear portfolio optimization has performed to calculate changes in parameters as a result of change in one parameter without solving problem from the beginning.

In order to evaluate the result, we considered two different cases. First case is called ideal result and obtained by considering the whole data (including latest data). We try to be as much as close to this result. Second case, this obtained through historical data. The results then indicate that the result of new sensitivity analysis is closer to the ideal result whereas the historical method.

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