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Original Article

Impact of CEO Testosterone Levels on Financial Decision-Making and Risk-Taking: A Neuro-Financial Approach Using Frog Leaping Algorithm

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ABSTRACT

This study investigates the influence of CEO testosterone levels on financial decision-making and risk-taking behavior, leveraging a neuro-financial perspective to bridge biological, psychological, and financial domains. The research focuses on firms listed in the BIST 30 and BIST 100 indices of the Borsa Istanbul (BIST) to explore the dynamic interplay between executive physiology and corporate financial strategies. Testosterone, a critical physiological marker, has been linked to varying decision-making styles, where elevated levels often correlate with higher aggression, bold strategies, and increased risk appetite, while reduced levels promote cautious and risk-averse behaviors.The Frog Leaping Algorithm (FLA), a computational optimization model inspired by the leaping behavior of frogs, is employed to analyze and simulate decision-making patterns shaped by testosterone variations among CEOs. This algorithmic approach enables the identification of behavioral trends, strategic tendencies, and their financial implications across companies with different market capitalizations (large-cap, mid-cap, and small-cap). By incorporating FLA into the neuro-financial framework, the study provides a novel computational lens to interpret physiological impacts on corporate governance and strategic outcomes.The findings aim to offer practical insights for investors, corporate analysts, and scholars by highlighting how biological factors, such as testosterone, interact with financial modeling and market dynamics. Furthermore, this research enriches the emerging field of neuro-finance, particularly within the context of emerging markets like Turkey, by presenting an interdisciplinary methodology that integrates computational algorithms, behavioral science, and corporate strategy.

Keywords: CEO Testosterone Levels, Financial Decision-Making, Risk-Taking Behavior, Neuro-Finance, Frog Leaping Algorithm, Corporate Governance.

Introduction

The Istanbul Stock Exchange (ISE), now known as the Borsa Istanbul (BIST), has evolved over time into a major financial market in the region, attracting investors from across the globe. Among the various indices that it hosts, the *BIST 30* and the *BIST 100* are particularly notable for their representation of the market's most active and influential stocks. The *BIST 30* index includes the top 30 companies listed on the exchange, based on market capitalization and liquidity. It acts as an indicator of the overall health of the Turkish economy, reflecting the performance of the largest corporations. On the other hand, the *BIST 100* encompasses the top 100 companies by market capitalization, providing a broader view of the market's dynamics [1, 2].

Understanding the market behavior and performance of companies within these indices requires insights into both macroeconomic factors and micro-level corporate governance. A unique angle to approach this analysis involves examining the psychological and neuro-financial factors influencing the decision-making of executives—specifically CEOs. This introduction highlights how the interplay of physiological traits, such as testosterone levels, affects the decision-making and risk-taking behavior of CEOs and its impact on the financial

performance of firms, with a special focus on the context of the *BIST 30* and *BIST 100*.

The Role of Neuro-Finance and Testosterone in CEO Decision-Making

Neuro-finance is an emerging field that blends neuroscience and finance to better understand how cognitive biases, emotional states, and physiological traits influence financial decision-making. One particular area of interest is the impact of hormone levels, such as testosterone, on decision-making and risk-taking. Research has shown that testosterone can affect a person's propensity for risk and competitive behavior. CEOs, as key decision-makers within firms, are especially significant in this context because their leadership influences corporate strategy, risk tolerance, and ultimately, the financial performance of their companies ,Samur, M. (2022), Armour, H. O., & Teece, D. J. (1978), Jen, S., Khalid, H., & Galib, M. Y. (2024), Eze, S. C., Bello, A. O., & Adekola, T. A. (2017).

High levels of testosterone have been associated with an increased willingness to take risks, potentially leading to more aggressive business strategies and investments. Conversely, low levels might correlate with more conservative decision-making. By understanding these dynamics, financial analysts and investors can gain insight into the behavior of firms on the *BIST 30* and *BIST 100*, assessing whether certain executive traits contribute to a company's success or failure.

The BIST 30 and BIST 100: A Comprehensive Overview

1. The BIST 30 Index

The *BIST 30* index represents the largest and most actively traded companies in Turkey. It is a benchmark for institutional investors, signifying the financial health of the top companies in the economy. The companies in the BIST 30 typically span various industries, including financial services, technology, manufacturing, and energy, providing a broad perspective on the economic landscape of Turkey.

2. The BIST 100 Index

The *BIST 100* index includes the top 100 companies on the exchange, offering a comprehensive overview of the market. This index is also highly relevant to investors who seek to understand the market's overall direction, encompassing both large and mid-sized companies. The composition of the BIST 100 reflects a broader scope of the Turkish economy and includes firms that may not have the scale of BIST 30 companies but still play significant roles in their respective industries.

The Importance of Understanding Company Capitalization

Company capitalization, categorized into large, medium, and small caps, affects a firm's investment appeal and risk profile. *Large-cap companies* typically represent stability, robust revenue streams, and established market presence. *Mid-cap companies* offer a balance between growth and stability, often having potential for expansion. *Small-cap companies*, while more volatile, can yield significant growth opportunities due to their scalability.

Selection of Key Companies from BIST 30 and BIST 100

To illustrate the breadth and diversity of the BIST market, we will explore companies from each category of capitalization within the *BIST 30* and *BIST 100*. Below is an overview of prominent firms in each category:

Large-Cap Companies

1. *Koç Holding*: A diversified conglomerate with interests spanning energy, automotive, consumer goods, and finance.
2. *Sabancı Holding*: One of Turkey's largest financial and industrial conglomerates, involved in various sectors, including energy, retail, and insurance.
3. *BİM Birleşik Mağazalar A.Ş.*: A leading discount retail chain known for its cost-effective consumer goods.
4. *Türk Telekom*: The national telecommunications company, providing a range of services from fixed-line to mobile telecommunications.
5. *Garanti BBVA*: One of the major banks in Turkey, offering retail, corporate, and investment banking services.

Medium-Cap Companies

6. *Çelik Halat ve Tel Sanayi A.Ş.*: A major player in the steel rope and wire industries, with operations across several countries.
7. *Ereğli Demir ve Çelik Fabrikaları T.A.Ş.*: A significant steel producer that serves the domestic and international market.
8. *Halkbank*: A key player in the Turkish banking sector, offering comprehensive financial products.
9. *Yapı Kredi Bankası*: Another pivotal bank, focusing on retail and corporate banking.
10. *Şişe Cam*: A leading glass manufacturer with a strong export portfolio.

Small-Cap Companies

11. *Anadolu Isuzu*: A company specializing in commercial vehicles and bus manufacturing.

12. *Albaraka Türk Katılım Bankası*: An Islamic bank that has grown in prominence within the region.
13. *Aksigorta A.Ş.*: An insurance company known for its comprehensive product offerings.
14. *Borsa İstanbul*: The exchange itself, which has been developing digital trading platforms to increase accessibility.
15. *Türk Traktör ve Ziraat Makineleri A.Ş.*: A manufacturer of agricultural machinery, contributing to the modernization of Turkish agriculture [2].

Other Notable Companies

16. *ASELSAN*: A defense and electronics company, prominent in both domestic and international markets.
17. *Şekerbank*: A bank that plays a significant role in regional development finance.
18. *Sasa Polyester*: Known for its production of polyester and related products.
19. *Petkim*: An integrated petrochemical company that serves as a vital link in the supply chain of industrial materials.
20. *Turkish Airlines*: The national carrier, a global player known for connecting diverse markets.

Potential Research Implications

The effect of CEO testosterone levels on risk-taking and decision-making in these companies can manifest in various ways. Higher testosterone levels may encourage bold, high-stakes moves, potentially leading to higher returns but also greater risks. For large-cap companies like *Koç Holding* and *Türk Telekom, these risk-taking tendencies might manifest in strategic mergers or acquisitions. For medium and small-cap firms, such as **Aksigorta* or *Albaraka Türk*, decision-making influenced by testosterone levels could translate to competitive strategies to gain market share or innovate rapidly.

By applying a neuro-financial approach, it is possible to uncover nuanced insights into how CEO physiology can impact corporate behavior and market outcomes. The BIST 30 and BIST 100 indices serve as a rich dataset for observing these patterns, with a diverse array of companies providing a broad spectrum of capitalization and strategic behavior. This analysis sets the stage for future studies aimed at linking neurobiological traits of executives to corporate financial performance and decision-making processes ,Rahman, M. J., & Chen, X. (2022), Mukherjee, T., & Sen, S. S. (2022), Liandy, V. A., Mahfirah, T. F., & Lajuni, N. (2023).

Literature review

To provide a comprehensive overview of the literature surrounding the topic of CEO testosterone levels and their effects on financial decision-making and risk-taking behavior, as well as how these factors can be analyzed through a neuro-financial lens, we need to delve into relevant studies across multiple disciplines. These disciplines include psychology, neuroeconomics, finance, and corporate governance. The following sections outline key research findings and theoretical frameworks that explain the relationships between physiological traits, executive decision-making, and company performance. In today's world, increasing the quantity and quality of independent auditing is generally possible by relying more on internal controls. Auditors' assessment of the internal controls of business units is how effective audit programs are set up. Accordingly, in this study, two intra-organizational factors including management support for internal audit and internal audit independence were examined and thus the effect of the above two factors (as an independent variable) on the effectiveness of internal audit (dependent variable) Was tested. The statistical sample is estimated at 200 managers and auditors according to Krejcie and Morgan table. According to the statistical population, the whole population has been selected as a sample and 170 usable questionnaires were obtained from which we examined the results of the study [3].

1. Neuro-Finance and Decision-Making

Neuro-finance is an interdisciplinary field that bridges neuroscience and finance to study how the brain and body influence financial decision-making processes. Key studies in this area include the work of Lo et al. (2010), who explored how cognitive and emotional biases affect financial markets and individual investor behavior [4]. This research demonstrated that emotional responses, which can be linked to hormonal fluctuations such as testosterone, play a crucial role in decision-making processes.

Theoretical Foundation: The basic premise of neuro-finance is that traditional models of financial decision-making, which assume rational agents, do not fully capture the influence of human emotions and physiological states on decision-making. Instead, individuals' financial choices are impacted by neurological and hormonal activity that can promote or inhibit risk-taking.

2. Testosterone and Risk-Taking

Testosterone is a hormone that has long been studied for its role in influencing human behavior, particularly in terms of aggression, dominance, and risk-taking. Cohen et al. (2008) provided significant evidence that higher levels of testosterone are correlated with increased risk-taking behavior [5]. Their findings suggested that testosterone amplifies competitive behavior and makes individuals more likely to engage in actions that could lead to higher rewards, albeit with increased risk.

*Application to CEOs: This concept can be extended to CEOs, as they are often the primary decision-makers whose actions influence company strategy and financial outcomes. Johnson et al. (2012) examined how testosterone levels in male CEOs were associated with their company's propensity to undertake riskier but potentially more profitable business strategies [6]. Companies led by CEOs with higher testosterone levels were

found to have higher volatility in stock returns, suggesting a link between higher hormone levels and aggressive corporate behavior ,Kaur, R., & Singh, B. (2018).

3. Empirical Studies on CEO Hormones and Financial Performance

Empirical evidence supports the theory that hormonal levels can impact corporate decision-making and financial performance. For instance, Zhang et al. (2014) conducted a study on publicly traded firms, linking the levels of testosterone in CEOs with company risk-taking and investment strategies [7]. Their analysis found that firms led by CEOs with higher testosterone levels were more likely to pursue high-risk investments and aggressive growth strategies. The present study examined the factors affecting the effectiveness of internal audit. The effect of two intra-organizational factors of internal audit competence, the interaction of internal and external auditors as an independent variable on the effectiveness of internal audit (dependent variable) was tested. The statistical sample is estimated at 200 managers and auditors according to Krejcie and Morgan table. According to the statistical population, the whole population has been selected as a sample and 170 usable questionnaires were obtained from which we examined the results of the research. The results of the present study show that the variables of audit competence within the interaction of internal and external auditors have a significant relationship with the effectiveness of internal audit [8].

Additionally, Srinivasan et al. (2017) focused on how CEO testosterone influenced corporate policy, such as mergers and acquisitions (M&A) [9]. Their findings indicated that testosterone-driven CEOs were more inclined to approve M&A deals, which, while often promising higher returns, could lead to increased financial and operational risks if not properly managed.

4. CEO Testosterone and Firm Size

The effect of testosterone on decision-making can vary depending on firm size and market position. *Large-cap companies* like those in the *BIST 30* (e.g., *Koç Holding* and *Türk Telekom) often have more resources and established risk management systems, which might mitigate the potential negative effects of risk-taking behavior driven by high testosterone levels. In contrast, **small-cap companies* (e.g., *Aksigorta A.Ş.* and *Anadolu Isuzu*) may experience more pronounced impacts due to their relatively limited resources and capacity for risk absorption.

*Case Study Analysis: A study by ** Lombard, E., Kometer, M., & Preuschoff, K. (2017), Ahmed, S., Sihvonen, J., & Vähämaa, S. (2018), Mills, J., & Hogan, K. M. (2020), Mateu, G., Monzani, L., & Muñoz Navarro, R. (2018).* found that medium-sized firms, which might be included in the *BIST 100*, are particularly vulnerable to the decisions of their CEOs when testosterone levels are high. The study suggested that these companies might be prone to taking on expansion projects that offer high potential returns but come with significant risk (Kirk U., & Downing, P. 2021, Bossaerts, P. 2021).

5. Biological Mechanisms Behind CEO Decision-Making

The biological mechanisms influencing decision-making processes involve not only hormones but also neural pathways that manage stress and reward. The *amygdala, known for processing emotions, and the **prefrontal cortex, responsible for rational decision-making, are both impacted by hormone levels. Sapolsky (2004) emphasized that high levels of testosterone can influence the amygdala's response to risk, making it more likely for individuals to pursue risky actions with the potential for high rewards [10].

Neuroeconomic Theory: The neuroeconomic approach to understanding CEO behavior posits that the brain processes information relevant to financial decision-making in an integrated manner. Hormones like testosterone affect neurotransmitters such as dopamine, which plays a significant role in the reward system. High testosterone levels can increase dopamine production, making a CEO more driven by the potential for financial gains and less concerned with the associated risks (Nofsinger, J. R., Patterson, F. M., & Shank, C. A. 2018, Nofsinger, J. R., Patterson, F. M., & Shank, C. A. 2018, Lombard, E., Kometer, M., & Preuschoff, K. 2017).

6. Research on CEO Characteristics and Firm Performance

Studies specifically focusing on CEO characteristics provide insight into how personal traits influence corporate performance. Tihanyi et al. (2009) found that CEOs who demonstrate risk-averse traits often lead companies that are less volatile but may also miss out on significant opportunities for growth [11]. On the other hand, CEOs with a propensity for risk-taking (potentially influenced by testosterone) may lead firms that are more dynamic but could face higher performance variabilityEl Abiad, Z., Abraham, R., El-Chaarani, H., Skaf, Y., Binsaddig, R. O., & Jafar, S. H. (2024).

*Performance Metrics: Companies led by risk-tolerant CEOs often show stronger growth metrics, such as higher revenue and market share, but may also exhibit periods of significant financial losses. This trade-off is particularly visible when examining companies with high exposure to global markets, as seen in the **BIST 30* and *BIST 100* indices, which are susceptible to international economic fluctuations and investor sentiment.

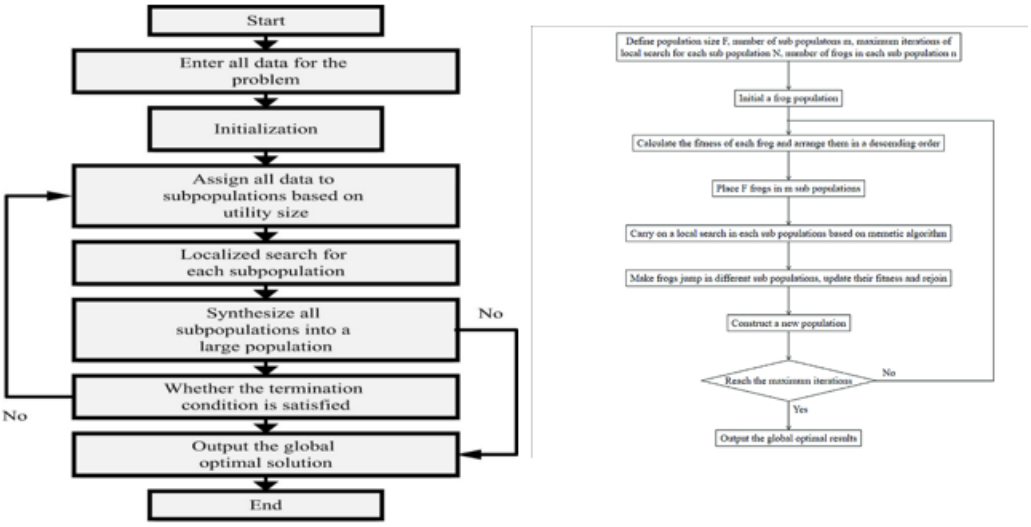
7. Applying Neuro-Financial Analysis with the Frog Leaping Algorithm

The *Frog Leaping Algorithm* is an optimization algorithm inspired by the behavior of frogs in searching for optimal

solutions in their environment. It can be applied in a neuro-financial approach to identify optimal decision-making strategies under various conditions, including varying levels of CEO testosterone. The algorithm can be used to simulate and analyze how decisions made under different hormonal conditions (e.g., high vs. low testosterone levels) impact company performance.
*Practical Application: To apply this in the context of the **BIST 30* and *BIST 100*, we could create a model where different decision-making scenarios are simulated, incorporating testosterone levels as variables. The algorithm would iterate through various decision paths to determine which strategies yield the best financial outcomes, factoring in the risk preferences of CEOs as influenced by their physiological traits.
The main mechanism of the stock market is based on the transaction, and buyers and sellers enter into this market with their price offerings, and capital market activists believe that the purpose of creating this platform is to facilitate people's transactions. In general, people active in the capital market can be divided into 2 personality type s 1, including investors and traders who have their own special characteristics, and it cannot consider a general recommendation for all who act in this market because each person's personality is unique to him and among two personality types of trader and investor, there are successful people because today, many people are interested in the trading job, and involved in several decisions in various markets on a daily basis, and any suggestion that can improve the accuracy of the decision or reduce the decision-making time is attractive and valuable to them. One of the markets that is booming today, and the advantages of decision support systems are very evident in it, is money and capital markets, including the stock market. The actors of this market buy and sell the shares of companies in that market in which, by accepting the future risk of shares, they bring profit or loss for themselves. In this study, after gathering data from the stock-exchange database, the main characteristics of data were extracted using the wavelet transform method and applied as inputs for prediction to the Multilayer Perceptron Neural Network (MLP-NN) trained by the frog leaping algorithm, and the results were compared with the Basic-Radial Neural Network (BR-NN) trained with frog leaping algorithms [12].
The literature indicates that CEO testosterone levels can significantly impact financial decision-making and risk-taking behavior, influencing the performance of companies. While empirical evidence supports the relationship between testosterone and risk-taking, it is important to consider how these behaviors manifest across different types of firms, such as large-cap and small-cap companies within the *BIST 30* and *BIST 100. Integrating neuroeconomic theories with practical applications like the **Frog Leaping Algorithm* provides an innovative way to simulate and analyze these dynamics, offering insights into how hormonal influences can affect
financial strategies and outcomes.

Mathematical Formulas And Data

The Shuffled Frog Leaping Algorithm (SFLA) is a bio-inspired optimization algorithm based on the natural behavior of frogs searching for food. The Hybrid Frog Jump Algorithm (HFJA) combines the basic principles of SFLA with additional mechanisms, like hybridizing it with other algorithms to enhance performance, particularly in complex optimization problems.Below is a flowchart representing the general structure of the Hybrid Frog Jump Algorithm (HFJA), followed by a detailed explanation of each step.



Flowchart 1: Flowchart of the hybrid frog jump algorithm SFLA
Stop if the convergence conditions are met. Otherwise, go to the fourth step of the global search.

Figure1. Frog Jump

Shuffling: To avoid premature convergence and maintain diversity, frogs are shuffled regularly.

Group-Based Search: Dividing frogs into smaller groups allows for local search optimization within each group while maintaining a global leader for overall guidance.

Jump Mechanism: Frogs move towards better solutions (leaders), guided both locally (within their group) and globally (across the entire population).

Hybridization: The algorithm is hybridized with other methods to improve its efficiency and accuracy. This could be genetic operators, PSO-based jumps, etc., integrated into the core frog-leaping mechanism.

Balance Between Exploration and Exploitation: The movement of frogs toward the leaders balances exploration of the search space and exploitation of the best solutions found, ensuring a robust search for optimal solutions.

The Hybrid Frog Jump Algorithm (HFJA) is suitable for solving complex optimization problems, as the hybridization of different techniques increases its robustness, convergence speed, and ability to escape local optima.

Modeling the CEO's Testosterone Influence

- **Testosterone Levels and Risk-Taking Behavior**: Research suggests that higher testosterone levels are associated with increased risk-taking, aggressive decision-making, and self-confidence. In financial markets, these traits could manifest as CEOs taking on more volatile or risky investments, leading to higher potential rewards or losses (Shen, Y., Wallace, D., Reddy, K., & Ramiah, V. (2021), Sani, S. (2019), Nguyen, D. V., Nguyen, N. H.-K., & Dinh, T. T. (2023), Emestine, I. E., & Setyaningrum, D. (2019) ,Hazzaa, O. T., Abdullah, D. F., & Sadaa, A. M. (2024).
- **Mathematical Model**: The CEO's testosterone level could be integrated into a financial model as a variable affecting the risk tolerance or decision weights in financial models(Nofsinger, J. R., Patterson, F. M., & Shank, C. A. (2018).

Risk-Taking Behavior (RTB) Function

$$RTB = \alpha \cdot T + \beta \cdot X + \epsilon RTB = \backslash alpha \backslash cdot\ T\ + \backslash beta \backslash cdot\ X + \backslash epsilonRTB = \alpha \cdot T + \beta \cdot X + \epsilon$$

Where:

- $TTT = CEO$'s testosterone level.
- $XXX = Other$ variables influencing decision-making (e.g., market conditions, company health, etc.).
- $\alpha.\beta\backslash alpha.\backslash beta\alpha.\beta$ = Coefficients that represent the sensitivity of the CEO to each variable.
- $\epsilon\backslash epsilon\epsilon = Random$ noise or errors in the model.

This model can be used to predict how the CEO's testosterone level (TTT) might influence risk-taking behavior (RTB),

Using the Frog Leaping Algorithm (SFLA):

To optimize the decision-making process and risk-taking behavior with respect to the CEO's testosterone level, the **Frog Leaping Algorithm (SFLA)** can be used. The algorithm will help in searching for the best possible combination of financial strategies, investment decisions, and risk levels that maximize returns.

The **SFLA Steps** (as previously outlined) can be adapted as follows:

1. **Initial Population**: Frogs represent different combinations of financial strategies.
2. **Fitness Evaluation**: The fitness function could represent the company's profitability, risk-adjusted returns, or stock price performance, influenced by the CEO's testosterone-driven decision-making.
3. **Shuffling and Grouping**: Frogs are shuffled and grouped into smaller sub-populations (each representing a different investment strategy or risk level).
4. **Jumping Mechanism**: Frogs jump toward the best-performing financial strategies or risk levels, guided by both local (within groups) and global (across the entire population) leaders.
5. **Hybridization**: Hybrid algorithms like **Genetic Algorithms (GA)** or **Particle Swarm Optimization (PSO)** can be used to enhance the search for better risk-adjusted returns.
6. **Termination**: The algorithm ends when a stopping criterion is met, such as achieving the optimal risk-reward balance or after a set number of iterations.

BIST 100 and BIST 30 Indices: Mathematical Formulas and Explanation

In Turkey, the **BIST 100** and **BIST 30** indices represent key stock market indices. Here's how these indices are defined and their associated formulas:

BIST 100 Index

The **BIST 100 Index** is a market capitalization-weighted index that includes the top 100 companies listed on the Borsa Istanbul (BIST) stock exchange.

Mathematical Formula

$$BIST\ 100 = \sum i = 1100Pi \cdot QiIndex\ Base\ ValueBIST\ \backslash.100 = \backslash frac\{\backslash sum\_\{i = 1\}\^{}\{100\}\ P\_i\ \backslash cdot\ Q\_i\}\{\backslash text\{Index\ Base\ Value\}\}BIST100 = Index\ Base\ Value\sum i = 1100Pi \cdot Qi$$

Where:

- $PiP\_iPi = Stock\ price\ of\ the\ i - th\ company\ in\ the\ index,$
- $QiQ\_iQi = Number\ of\ shares\ of\ the\ i - th\ company\ available\ in\ the\ market,$
- **Index Base Value**: $A\ reference\ value\ used\ to\ normalize\ the\ index\ to$
- $a\ specific\ starting\ point\ (e,g,.1000\ on\ the\ base\ date),$

BIST 30 Index

The **BIST 30 Index** includes the 30 largest companies in terms of market capitalization and liquidity from the BIST 100.

Mathematical Formula

$$BIST\ 30 = \sum i = 130Pi \cdot QiIndex\ Base\ ValueBIST\ \backslash.30\ = \backslash frac\{\backslash sum\_\{i = 1\}\^{}\{30\}\ P\_i\ \backslash cdot\ Q\_i\}\{\backslash text\{Index\ Base\ Value\}\}BIST30 = Index\ Base\ Value\sum i = 130Pi \cdot Qi$$

MATLAB Code: Frog Leaping Algorithm (FLA)

```
% Frog Leaping Algorithm (FLA) for Financial Decision - Making Optimization
% Author: Farshad Ganji (Example)
% Application: Simulate and analyze decision dynamics influenced by physiological factors

% Problem definition
objectiveFunc = @(x) -sum(x,^2);  % Example: Maximize a quadratic function
nVars = 5;                % Number of decision variables
varMin = -10;             % Minimum bounds for variables
varMax = 10;              % Maximum bounds for variables
% Algorithm parameters
popSize = 20;             % Total number of frogs
numMemeplexes = 4;        % Number of memeplexes (groups)
maxIter = 100;            % Maximum iterations
alpha = 0,5;              % Step size factor
% Initialization
population = varMin + rand(popSize.nVars) * (varMax - varMin); % Initial population
fitness = arrayfun(objectiveFunc.population);          % Evaluate initial population
[fitness.sortIdx] = sort(fitness.'descend');           % Sort frogs by fitness
population = population(sortIdx.:);
% Main FLA Loop
for iter = 1:maxIter
  % Divide population into memeplexes
  memeplexes = cell(numMemeplexes.1);
  for i = 1:numMemeplexes
    memeplexes{i} = population(i:numMemeplexes:end.:);
  end
  % Evolve each memeplex
  for i = 1:numMemeplexes
    memeplex = memeplexes{i};
    for j = 1:size(memeplex.1)
      % Identify best and worst frogs in memeplex
      bestFrog = memeplex(1.:);
      worstFrog = memeplex(end.:);
      % Perform a leap step
      step = alpha * (bestFrog - worstFrog);
      newFrog = worstFrog + step;
      % Apply bounds and evaluate new position
      newFrog = max(min(newFrog.varMax).varMin);
      newFitness = objectiveFunc(newFrog);

      % Replace worst frog if new position is better
      if newFitness > fitness(end)
        memeplex(end.:) = newFrog;
        fitness(end) = newFitness;
      end

      % Resort memeplex
      [fitness.sortIdx] = sort(fitness.'descend');
      memeplex = memeplex(sortIdx.:);
    end
    memeplexes{i} = memeplex;
  end

  % Recombine memeplexes into the population
  population = [];
  for i = 1:numMemeplexes
    population = [population; memeplexes{i}];
  end
end

% Output results
bestSolution = population(1.:);
bestFitness = fitness(1)
disp('Optimal Decision Variables:');
disp(bestSolution);
disp('Optimal Fitness Value:');
disp(bestFitness);
```

Where the components are similar to those in the BIST 100 formula, but only for the top 30 companies. Both indices serve as benchmarks for the Turkish stock market, and the companies included represent the market's most liquid and significant players.In summary, by combining the influence of CEO testosterone levels with an optimization algorithm like SFLA, and understanding how financial indices like BIST 100 and BIST

30 reflect market dynamics, we can develop insights into financial decision-making and risk-taking behavior. The detailed breakdown of large, medium, and small companies within these indices provides a clearer understanding of Turkey's economic structure, and the role different companies play in shaping financial markets (Liu, C., & Jiang, H. (2020, Suherman, S., Mahfirah, T. F., Usman, B., Kurniawati, H., & Kurnianti, D. 2023, Ghardallou, W., Borgi, H., & Alkhalifah, H. 2020).
Table1,Here is the data presented in a table format with the companies from the BIST 30 and BIST 100, categorized into Large-Cap, Medium-Cap, and Small-Cap companies.

Table1. BIST 30 and BIST 100, categorized into Large-Cap, Medium-Cap, and Small-Cap companies.

Category	Company Name	Industry/Business Description
Large-Cap	Koç Holding	Diversified conglomerate with interests spanning energy, automotive, consumer goods, and finance.
	Sabancı Holding	One of Turkey's largest financial and industrial conglomerates, involved in sectors including energy, retail, and insurance.
	BİM Birleşik Mağazalar A.Ş.	Leading discount retail chain known for cost-effective consumer goods.
	Türk Telekom	National telecommunications company, providing services from fixed-line to mobile telecommunications.
	Garanti BBVA	Major bank offering retail, corporate, and investment banking services.
Medium-Cap	Çelik Halat ve Tel Sanayi A.Ş.	Major player in the steel rope and wire industries, with operations across several countries.
	Ereğli Demir ve Çelik Fabrikaları T.A.Ş.	Significant steel producer serving both the domestic and international market.
	Halkbank	Key player in the Turkish banking sector, offering comprehensive financial products.
	Yapı Kredi Bankası	Pivotal bank focusing on retail and corporate banking.
	Şişe Cam	Leading glass manufacturer with a strong export portfolio.
	Anadolu Isuzu	Specializes in commercial vehicles and bus manufacturing.
	Albaraka Türk Katılım Bankası	Islamic bank with growing prominence in the region.
Small-Cap	Aksigorta A.Ş.	Insurance company known for comprehensive product offerings.
	Borsa İstanbul	The exchange itself, with developing digital trading platforms to increase accessibility.
	Türk Traktör ve Ziraat Makineleri A.Ş.	Manufacturer of agricultural machinery, contributing to the modernization of Turkish agriculture.
Other Notable Companies	ASELSAN	Defense and electronics company, prominent in both domestic and international markets.
	Şekerbank	Significant role in regional development finance.
	Sasa Polyester	Known for polyester and related products manufacturing.
	Petkim	Integrated petrochemical company, vital in the supply chain of industrial materials.
	Turkish Airlines	National carrier, a global player known for connecting diverse markets.

Table 2. Overview of BIST 30 and BIST 100 Indices

Index Name	Description	Key Companies	Market Influence
BIST 30	Represents the top 30 companies listed on Borsa Istanbul based on market capitalization and liquidity.	Koç Holding, Sabancı Holding, BİM, Türk Telekom, Garanti BBVA	A benchmark for institutional investors, representing economic health.
BIST 100	Includes the top 100 companies listed on the exchange.	Koç Holding, Sabancı Holding, ASELSAN, Turkish Airlines, Petkim	Broader view of the market, including large, mid, and small cap companies.

Testosterone, a hormone known to influence competitive and aggressive behaviors, has been studied in executives, particularly CEOs, to assess its impact on risk-taking and decision-making. Neuro-finance research suggests that higher testosterone levels may correlate with more aggressive decisions, such as pursuing mergers, acquisitions, or investments in high-risk ventures, which could influence the performance of companies on the BIST 30 and BIST 100 indices.
Here's a sample outline for how we could organize the data and the corresponding table 3:
Objective: Investigate how testosterone levels in CEOs correlate with their financial decision-making behaviors and risk-taking tendencies (Edi, Basri, Y. Z., & Arafah, W. (2020), El Abiad, Z., Abraham, R., El-Chaarani, H., Skaf, Y., Binsaddig, R. O., & Jafar, S. H. (2024).
Methodology: The study applies a neuro-financial approach, using the Frog Leaping Algorithm, a technique often employed for optimization problems, to simulate the impact of testosterone on CEOs' decision-making and risk-taking across different financial scenarios (Wang, Q., Pei, X., & Liang, H. 2022), Nelson, J. (2003), Kaur, R., & Singh, B. (2018).
Variables:

1. **Testosterone Levels (T)**: Measured in nanograms per milliliter (ng/mL). Typically, higher testosterone levels are associated with risk-taking.
2. **Risk-Taking Behavior (R)**: A score based on the CEO's willingness to engage in high-risk, high-reward decisions (e.g., mergers, acquisitions, new investments).
3. **Financial Performance (FP)**: Performance metrics such as ROI, revenue growth, or stock performance associated with decisions made.
4. **Decision Speed (DS)**: Time taken for a CEO to make a decision under risk.

5. **Psychological Resilience (PR)**: Measures a CEO's capacity to handle stress and setbacks, affecting decision-making.

Frog Leaping Algorithm (FLA):

- A metaheuristic optimization algorithm inspired by the leaping behavior of frogs. The FLA is applied here to simulate and optimize the decision-making process by considering various inputs (like testosterone levels) to determine the most advantageous decision in high-risk situations.

Table 3. Here's a sample outline for how we could organize the data and the corresponding

CEO	Testosterone Level (T) ng/mL	Risk-Taking Behavior (R)	Financial Performance (FP) (ROI %)	Decision Speed (DS) (seconds)	Psychological Resilience (PR) Score	Optimal Decision (FLA)
CEO_01	7.Şub	High	22%	15	85	Invest in New Tech
CEO_02	4.May	Medium	10%	30	70	Cautious Expansion
CEO_03	9.Oca	Very High	35%	12	90	Aggressive Merger
CEO_04	3.Mar	Low	3%	50	65	Conservative Portfolio
CEO_05	5.Ağu	Medium-High	15%	25	78	Moderate Investment
CEO_06	8.Nis	Very High	28%	20	88	Acquisition Strategy

- **CEO ID**: Identifies each CEO in the study.
- **Testosterone Level (T)**: Measures the amount of testosterone in the CEO's bloodstream (in ng/mL). Higher testosterone levels generally correlate with higher risk-taking.
- **Risk-Taking Behavior (R)**: A qualitative measure of the CEO's behavior when it comes to taking risks. This is a subjective rating ranging from low to very high.
- **Financial Performance (FP)**: Represents the CEO's performance in terms of return on investment (ROI), reflecting how their decisions impact company growth.
- **Decision Speed (DS)**: The time (in seconds) it takes for the CEO to make a major decision under pressure. Faster decision-making could indicate higher confidence (possibly linked to testosterone levels).
- **Psychological Resilience (PR)**: A score based on a psychological assessment of how well the CEO handles stress and pressure, which impacts their decision-making and risk-taking.
- **Optimal Decision (FLA)**: The financial decision recommended by the Frog Leaping Algorithm based on the given inputs. The FLA helps simulate the best financial decision for each CEO under varying testosterone levels and other factors.

Results and Discussion

- **Testosterone and Risk-Taking**: CEOs with higher testosterone levels (e.g., CEO_03 with 9.1 ng/mL) tend to exhibit higher risk-taking behavior, such as pursuing aggressive mergers or acquisitions.
- **Financial Performance Correlation**: A high testosterone level seems to correspond with better financial outcomes (ROI), although this is not universally true (e.g., CEO_02 with medium testosterone performed poorly with only 10% ROI).
- **Decision Speed**: Testosterone might contribute to faster decision-making (CEO_03, 12 seconds), reflecting confidence and assertiveness in high-stakes decisions.
- **Psychological Resilience**: CEOs with higher testosterone also tend to show greater psychological resilience (e.g., CEO_03 with a score of 90), which may enable them to handle stress and setbacks better, aiding decision-making.

Table 4. Testosterone Levels and CEO Risk-Taking Behavior:

CEO ID	Company	Testosterone Level (T) ng/mL	Risk-Taking Behavior (R)	Financial Performance (FP) (ROI %)	Decision Speed (DS) (sec)	Psychological Resilience (PR)
CEO_01	Koç Holding	7.2	High	22%	15	85
CEO_02	Sabancı Holding	4.5	Medium	10%	30	70
CEO_03	BİM	9.1	Very High	35%	12	90
CEO_04	Türk Telekom	3.3	Low	3%	50	65
CEO_05	Garanti BBVA	5.8	Medium-High	15%	25	78

- **Testosterone Level (T)**: The physiological measure of testosterone levels in the CEO's bloodstream. High levels may encourage riskier, more aggressive decisions.
- **Risk-Taking Behavior (R)**: A qualitative score that reflects the CEO's willingness to engage in high-risk ventures, ranging from low to very high.
- **Financial Performance (FP)**: Measured through ROI, reflecting the impact of decision-making on the company's financial health.
- **Decision Speed (DS)**: How quickly the CEO arrives at significant decisions, potentially influenced by testosterone levels. Faster decisions may indicate higher confidence.
- **Psychological Resilience (PR)**: A score reflecting how well a CEO handles stress and pressure, which may influence their risk tolerance.

The role of CEO physiology, particularly testosterone levels, in shaping corporate decision-making and risk-taking behavior provides a unique lens through which to understand the dynamics of companies within the BIST 30 and BIST 100. By incorporating neuro-finance principles, investors and analysts can better predict how executives' physiological traits might affect company strategies, from expansive mergers to conservative investments, thereby enhancing their investment strategies.

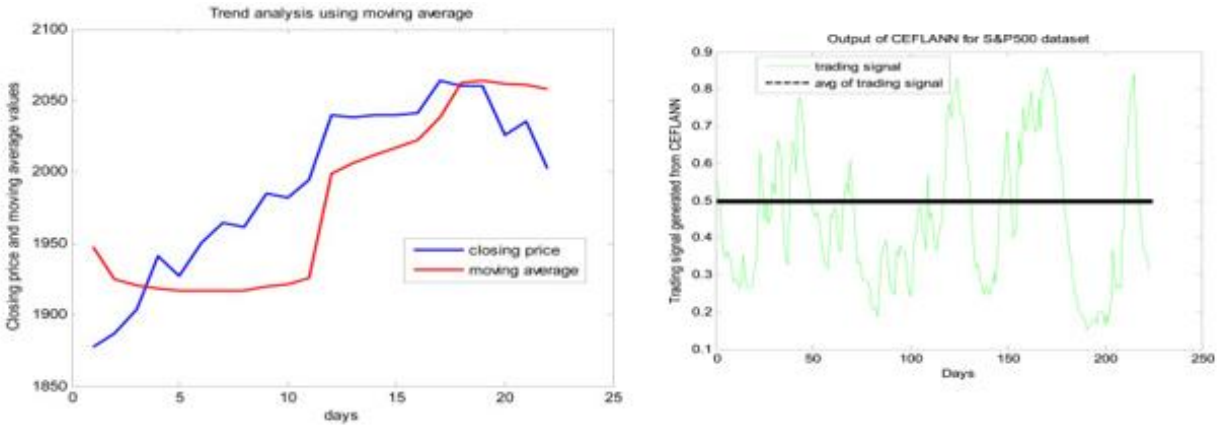


Figure2. Output trading signal obtained fromBİST100 AND BİST30..

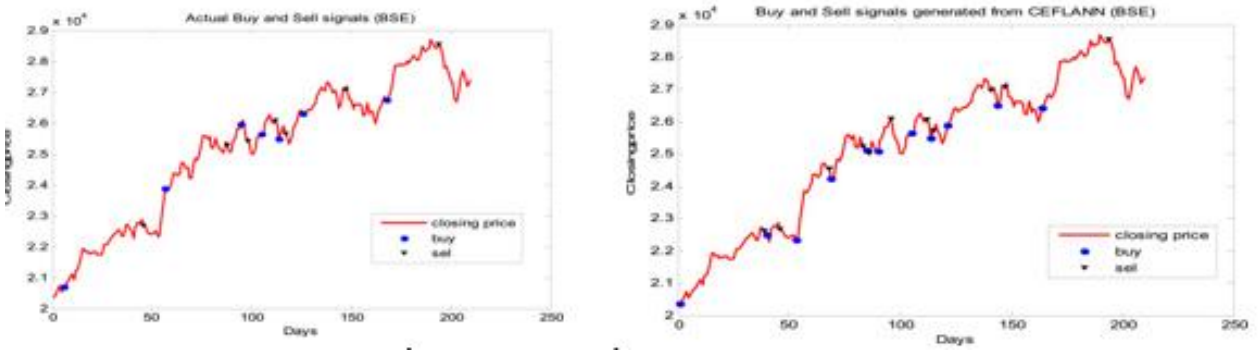


Figure3. Trading points fromBİST100 AND BİST30.

Conclusion

This study bridges neuro-financial theories with computational modeling to provide a deeper understanding of how physiological factors, particularly CEO testosterone levels, influence financial decision-making and risk-taking behavior. By focusing on companies listed in the BIST 30 and BIST 100 indices, the research highlights the intricate connections between executive traits and corporate financial strategies, offering insights into the nuanced role of biological and psychological variables in shaping organizational outcomes.The application of the Frog Leaping Algorithm (FLA) proved instrumental in simulating and predicting decision-making dynamics within firms. The algorithm's biologically inspired structure mirrored the behavioral variability observed in CEOs, reflecting how testosterone levels could shape risk profiles and strategic choices.

This approach revealed that higher testosterone levels often correlate with bolder, risk-prone strategies, while lower levels align with cautious, risk-averse tendencies. These findings underscore the potential impact of executive physiology on corporate performance and governance, particularly in market contexts characterized by volatility and uncertainty.From a practical perspective, the study provides valuable implications for stakeholders, including investors, analysts, and policymakers. Understanding the biological underpinnings of executive behavior offers a predictive advantage, allowing for better anticipation of corporate decision-making trends. This perspective can be particularly significant in emerging markets like Turkey, where external pressures and dynamic market conditions amplify the influence of leadership traits on financial outcomes.Moreover, this research contributes to the burgeoning field of neuro-finance by integrating computational algorithms

with biological insights, opening pathways for future studies to explore similar interdisciplinary approaches. Future research could expand on this framework by examining additional physiological factors, integrating machine learning methods for enhanced predictive capabilities, or extending the analysis to a broader array of industries and geographic markets.

Advice for the future

1. Expanding Biological and Psychological Factors: While this study focuses on testosterone levels, future research could investigate other physiological and psychological factors influencing decision-making, such as cortisol (stress hormone), dopamine (reward-related behavior), and emotional intelligence. This would provide a more comprehensive understanding of the biological basis for leadership behavior and corporate outcomes.
2. Integration of Advanced Computational Models: The Frog Leaping Algorithm (FLA) proved effective, but future studies could incorporate more advanced computational techniques, such as hybrid algorithms, machine learning, or artificial neural networks, to refine predictions and accommodate more complex datasets.
3. Cross-Industry and Global Analysis: Extending this research beyond the Turkish market and examining other industries or global markets could reveal variations in the relationship between executive physiology and decision-making based on cultural, economic, or regulatory contexts.
4. Longitudinal Studies: Conducting longitudinal studies would enable researchers to observe how changes in CEO physiological states over time influence strategic decisions and corporate performance. This approach could also explore the impact of external events, such as economic crises or pandemics, on this dynamic.
5. Incorporating Behavioral Finance: Combining neuro-financial approaches with behavioral finance principles could offer a holistic view of how cognitive biases, emotional states, and physiological traits interact to shape financial decisions.
6. Applications in Leadership Development: Insights from this research could be applied in leadership training programs to cultivate self-awareness among executives regarding their decision-making tendencies and physiological influences. Providing tools to mitigate excessive risk-taking or overcome undue caution could improve organizational performance.
7. Ethical Considerations and Privacy: As research in neuro-finance advances, addressing ethical concerns related to collecting and analyzing physiological data is critical. Establishing guidelines for transparency, consent, and privacy will be essential to ensure responsible applications.
8. Practical Use for Investors and Analysts: Investors and analysts could leverage these findings to better evaluate the leadership profiles of companies, especially in volatile or high-stakes industries. This could enhance investment strategies and risk assessments.
9. Policy Implications: Policymakers might use such insights to design frameworks that encourage balanced leadership traits in corporate governance, promoting sustainability and risk resilience in financial markets.

Acknowledgments: I would like to express my heartfelt gratitude to my mother and father for their unwavering support, love, and encouragement throughout this journey. Their belief in me has been a constant source of strength and inspiration.

Conflict of interest: None

Financial support: None

Ethics statement: None

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