NEUROFINANCE – AN UNDERSTANDING AND ASSESSMENT OF BIOLOGICAL DIFFERENCES WITH SPECIAL FOCUS ON GENDER DIFFERENCES FOR PREDICTING THE BEHAVIOR AND PERFORMANCE OF INVESTORS

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Abstract: Neurofinance explains how individual differences like gender, genes, neuroanatomy, and personality affect financial decisions. An attempt has been made in this paper to understand the biological differences with special focus on gender difference for predicting the behaviour and performance of investors. The study is descriptive in nature and it identified that women are perhaps more risk seekers or takers in societal decision making. High risk aversion is associated with low in-utero testosterone exposure in women. In comparison to that in men risk taking for gains is positively related to basal (salivary) testosterone.

Keywords: Neurofinance; Gender differences; Investment decision; Investment behaviour

JEL Classification: D87, D91, G41

Introduction

A new area of study called "neurofinance" uses an interdisciplinary strategy that combines economics, neurology, and psychology to improve the micro basis of financial decisions (Singhraul, 2022). A neuroeconomists is interested in both aberrations in neuroanatomy, such as brain lesions or structures, hormone levels, and neurotransmitter receptors, and variations in neurophysiology, such as changes in blood flow, electrical activity, neurotransmitter activity, and cellular metabolism. (Martin, 2009) Therefore for understanding the implications of neuroeconomic research first one need to understand basic neurobiology. Neurobiology will help to understand how the brain processes financial information and how individual decision arises within it. Non-invasive assessments of brain and physiological activity are included into neurofinance. The indirect indicators of regional brain activity are electroencephalography (EEG) and functional magnetic resonance imaging

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(fMRI) (Glover, 2011). Three major anatomical divisions of the human brain can be thought of as of interest. Each section carries out intricate operations. Analytical decisions making is performed by the outer layer whereas the middle layer takes care of motivational and emotional drives. The life sustaining physiological processes originates from the inner most cores. The cortex, which is the outer layer, is referred to as the brain's logistical center. The prefrontal cortex, one of the cortex's components, has a role in abstract thought, planning, calculation, learning, and strategic decision-making. The limbic system of the brain is referred to as the brain's emotional controller. Primitive drives and feelings like fear and excitement originate in the limbic system. The body's fundamental physiological functions, such as breathing, staying awake, and heart rate, are controlled by the midbrain, commonly known as the reptile brain. The neural pathways in the brain that deliver, integrate, and process information pass via its three layers. Nearly all human behaviour is governed by two primary brain processes: the reward approach (pleasure-seeking) and loss avoidance (pain-avoidance) systems. Neurofinance tries to explain how brain and physiological signals link to one another and cause individual variances in financial decision-making, in addition to exploring the impact of physiological signals including heart rate, skin conductance, eye movements, hormones, and heredity (Miendlarzewska, 2019). All of the research techniques used in neurofinance are correlational in nature and typically do not support causal inferences. Researchers influence neuronal and physiological signals utilizing direct transcranial magnetic simulation (TMS), by watching patients with brain injury, or by providing hormone- and neurotransmitter-manipulating drugs in order to establish a link between the observed behaviour and a cause (Miendlarzewska, 2019) Behavioral finance is somewhat included into neurofinance, but it also adds two key ideas – **(a)** Investigating the behaviors of financial market participants based on the biological (neural and physiological) mechanism and **(b)** Providing an alternative explanation based on physiological motivation for the apparent failure of standard finance theories.

Review of Literature

Spencer (1880) claimed that the principles of evolution, including natural selection, apply to both biological species evolving over geological time and human societies, social causes, and individuals.

Markowitz (1952) claimed that the process of choosing a portfolio begins with experience and observation and finishes with beliefs about how accessible securities would perform in the future. The researcher geometrically illustrated relations between beliefs and choice of portfolio according to the "expected returns" and "variance of returns" rules.

Fama (1970) explained the theory of efficient markets. The researcher argued that efficient market prices "fully reflect" available information. It thus implied those successive prices changes i.e., successive one -period return are

independent. The researcher assumed that successive changes or returns are identically distributed. The conditional and marginal probability distributions of an independent random variable are said to be equal under this method, which is also known as the random walk model.

Elliot & Thrash (2002) examined how approach and avoidance play a part motivation in personality models. According to the researchers, approaches and avoidance temperaments serve as the cornerstone for a number of fundamental aspects associated with trait adjective, emotional disposition, and motivational system approaches.

Hertwig et al. (2004) argued that choice behaviour can be drastically different when decisions are made based on descriptions versus decisions based on experience. According to prospect theory, when making judgments based on descriptions, people evaluate the likelihood of unusual events more heavily than they actually do. On the other hand the researchers found that people while making decisions from experience underweight the probability of rare events. The two explanations of this underweighting, reliance on relatively small samples of data and overweighting of freshly sampled data, were also investigated by the researchers.

Poldrack (2006) employed a Bayesian study of the BrainMap neuroimaging database to determine how much more support a "reverse inference" can provide for the engagement of a cognitive process. Reverse inference is a technique whereby the activity of a certain brain region is used to infer the involvement of a specific cognitive process.

Coates and Herbert (2008) reported the role of endocrine system in financial risk taking. While the traders were actually operating, the researchers collected endogenous steroid samples from them. They found that a trader's cortisol levels rise in response to both variation in his trading results and market volatility. The researchers postulated that while risk increases cortisol, greater testosterone may have a positive impact on the economy.

Rangel, A., Camerer, C., & Montague, P. R. (2008) proposed a framework for value-based decision making. The researchers created a representation of a decision problem and then investigated the internal states (i.e. hunger level), external states (i.e. threat level) and potential course of action (e.g. pursue a prey or not).

Preuschoff *et al.* (2008) examined how organism deals with probabilistic stimulus-reward associations. The researchers concluded that risk prediction must be included to their understanding of the neurological underpinnings of reward anticipation under uncertainty. When performing a straightforward gambling activity with variable risk, the researcher used functional imaging. The study revealed a strong correlation between human insula early onset activity and risk prediction error.

Sapienza, Zingales, & Maestripieri, (2009) discovered that women are less

willing to take risks than males. In a sample of less than 500 MBA students, the researchers looked at whether differences in salivary testosterone concentrations and prenatal testosterone exposure could explain between- and within-gender differences in financial risk aversion. Higher levels of circulating testosterone have been linked to lower risk aversion in women, but not in males, according to the study. The study also established that testosterone has non-linear effects on risk aversion regardless of gender.

Peterson (2010) stated that Neuroeconomics is not a separate field of neuroscience. It sheds light on the fundamental biological and psychological processes that lead to the development of personal prejudices, irrational conduct, and group purchasing and selling decisions. Comprehensive economic models of human economic behaviour and their underlying principles of decision-making can be constructed using neurofinance.

Cesarini, Johannesson, Lichtenstein, Sandewall, & Wallace (2010) discovered through the use of laboratory exercises that hereditary factors can account for 20% of the diversity in financial risk-taking.

Symmonds *et al.* (2011) indicated that both dispersion (variance) and asymmetry (skewness) of results have an impact on people's decision-making. The subjects were scanned using fMRI by the researchers, who also applied a unique behavioural paradigm in humans and fiddled with summary statistics. The study demonstrated that neuroanatomically distinct representations of variance and skewness capture behavioural sensitivity to these characteristics.

Kuhnen & Knutson (2011) discovered that while negative emotions like worry have the opposite impact, good emotional states like excitement encourage consumers to take chances and feel confident about their abilities to analyse investing possibilities. By suppressing information that conflicts with people's earlier decisions, beliefs are updated in order to preserve a favourable emotional state. Market factors or the results of prior actions may alter emotions and consequently affect forthcoming financial decisions.

Rudorf, Preuschoff & Weber (2012) studied the extent to which neural correlates of anticipation risk reflect individual risk preferences. Using fMRI, the researchers assessed the brain correlates of reward and risk prediction as well as the associated prediction errors during a straightforward card game of chance. In comparison to other groups, risk avoiders showed higher functional connectivity between the ventral striatum and anterior insula and frontal areas.

Charness & Gneezy (2012) it was found that women invest less than males do, making them seem more risk-averse financially. The researchers assembled the data from 15 sets of experiments with one simple underlying investment game. The researchers investigated the robustness of the findings of all the previous researchers.

Filippin & Crosetto (2014) reconsiders the widely held belief that women are less risk-tolerant than men, offering a breakthrough in understanding. The researchers gathered the micro data of an even larger sample of Holt and Laury replications and tried to show the magnitude of gender differences. The study identified the differences as significant but it is economically unimportant. The study came to the conclusion that there is a consistent correlation between gender disparities and the characteristics of the elicitation method used, particularly the availability of a safe option and set probability.

Ma, Hu, Pei, & Xiang (2015) researchers looked at how exposure to financial stimuli might impact people's motives, thoughts, and behaviours. The study was a comprehensive meta-analysis examining the available evidence on money priming.

Nasiriavanaki et al. (2015) the issue of how inter-individual differences affect risk-taking behaviour was looked into. The study's methodology was the "balloon analogue risk task (BART), which involved 48 healthy people inflating a virtual balloon in exchange for points despite an increased danger of the balloon exploding. The size of grey matter volume in the anterior insula was significantly positively correlated with BART score in participants who were at higher risk, according to research using the Voxel Based Morphometry (VBM) technique.

Cueva et al. (2015) the study's authors emphasized the potential impact of endogenous hormones, particularly testosterone and cortisol, on traders' ability to make sound financial decisions. When participants in an experimental asset market had their salivary cortisol and testosterone levels measured, the researchers discovered that both individual and aggregate levels of endogenous cortisol were predictive of future risk-taking and price instability. The study found that both cortisol and testosterone shifted investment towards riskier assets.

Ewa A. et al. (2019) offered examples of experimental studies and integrated the neural data to test hypotheses. The study paid special attention towards gender differences in financial decision making. The researchers combined approaches and findings of different fields to gain knowledge about investor behaviour.

Singhraul et al. (2022) said in their study that people's investing decisions are supposedly biassed and cognitive, carried out by brain processes. Thus, the researchers discovered that it is important to comprehend the psychological processes that contribute to the development of this prejudice.

Objectives of the Study

a) To understand the concept of neurofinance vis-à-vis traditional finance.

b) To examine how gender disparities in financial decision-making might be taken into account when studying and describing investor behaviour.

c) To identify the future application and scope of neurofinance.

Research Methodology

For the study data has been collected from secondary sources. The study is descriptive in nature. This paper aims to review and understand the concept of neurofinance and how it is different from traditional finance. In order to provide a comprehensive picture and synthesis of the current state of knowledge in this topic, the body of academic literature already in existence that is relevant to the field of neurofinance was reviewed. This paper highlights relevant concepts for better comprehending the psychology of investors. The paper is structured into three sections. The first section tries to understand the concept of neurofinance vis-à-vis traditional finance. The second segment seeks to investigate how investor behaviour can be researched and defined while focusing particularly on the disparities between genders when it comes to making financial decisions and the third section will identify the future application and scope of neurofinance. The data for the study has been collected from various past research works undertaken so far in the field of neurofinance.

Traditional Finance to Neurofinance

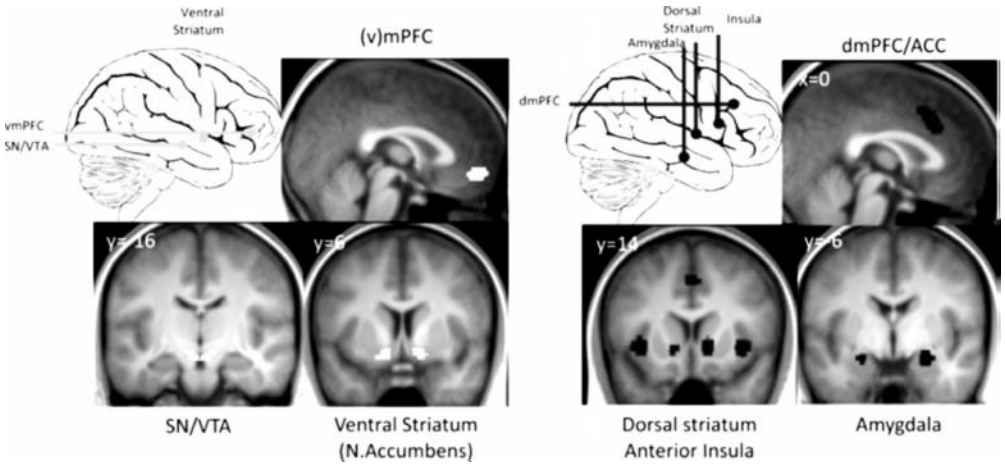
Traditional Finance centers on Efficient Market Hypothesis (EMH). According to this hypothesis it is believed that asset prices reflect all available information in the market. The idea argues that since market prices should only react to new information, it is challenging to consistently outperform the market on a risk-adjusted basis. According to traditional finance, it is impossible for anyone to buy discounted stocks or sell them for inflated prices because equities are assumed to constantly trade at their fair values on exchanges. However, EMH is frequently questioned and is quite contentious. According to proponents of the EMH, investing in a low-cost passive portfolio would be a superior choice for investors due to the randomness of the market. The Morningstar Inc. compilation Active/Passive Barometer study, published in June 2019, supported the EMH. Morningstar analyzed the performance of active managers across all categories to an index fund and exchange traded fund composite that was relevant (ETFs). According to the survey, only 23% of active managers were able to outperform their passive counterparts over a 10-year period starting in June 2009. On the basis of both theoretical and empirical evidence, the EMH's validity has been contested. There are many investors like Warren Buffet whose investment strategies been focused on undervalued stocks made billions and thus have beaten the market. In actuality, markets lack complete knowledge, most exhibit some level of inefficiency and in rare circumstances, and an efficient market might serve as an example of a failed market. Accepting the EMH in its strongest or most basic form, which states that all information in a market, whether public or private, is taken into account in a stock's price, may be challenging? EMH has undergone modifications to reflect the extent to which it can be utilised in markets. The current share price of a stock is estimated using all publicly available information, according to a

semi-strong form of EMH efficiency. To get higher gains, neither technical nor fundamental analysis can be used. In a weak kind of efficiency, the stock price today reflects every stock price from the past. Therefore, it is impossible to forecast and outperform the market using technical analysis. Since EMH is designed to account for risk, it only produces testable predictions when combined with a specific risk model. The research works till 1990 thus only focused on market anomalies that are deviations from specific models of risk. To sum up, it can be said that the efficient market hypothesis asserts that new information is immediately reflected in stock prices when it enters the market; Because of this, neither technical analysis, which examines historical stock prices to predict future prices, nor fundamental analysis, which examines financial data, may result in excess profits. Researchers who disagreed with EMH later developed the theory of momentum investing, which combines technical and fundamental analysis and asserts that some price patterns endure over time. There was a rise of another school of thought named as Behavioral Finance which challenged EMH stating that investors are guided by psychology more than by rationality and efficiency. Predicting the future by the help of fundamental analyses holds that certain valuation ratios predict outperformance and underperformance in future periods and all this challenges the so-called Efficient Market Hypothesis. Despite research identifying instances of short-term serial correlations that are not zero, suggesting the possibility of a detectable pattern, the short-term serial correlations between stock prices should be zero in a really efficient market. According to behavioural finance research, investors sometimes overreact to events and other times they underreact. A branch of behavioural economics known as behavioural finance was developed to objectively investigate and address concerns identified by traditional finance. It was shown that feelings, psychological biases, stress, and personality differences influence our financial decisions by combining findings from adjacent social sciences including psychology and sociology. Later, some researchers took it a step further and questioned how and why these breaches occur in the brain as well as if incorporating new information from the field of neuroscience could enhance existing models further, giving birth to the discipline of neurofinance.

Focusing Inside Investor's Brain

A need was felt for something advanced as behavioral finance typically identified and described market price anomalies and individual biases without explaining the causes of behavior and as a result the outcome of the researches under behavioral finance is difficult for any generalization or model generation. Neuroeconomists are consistently gathering the data required to create thorough economic models of human economic behaviour and decision making by utilizing research methods and technologies acquired from the discipline of neuroscience. The main objectives of recent research have been to comprehend

the mental mechanisms underlying risk taking, utility function and valuation, expectation formation, learning, information interpretation (such as under conditions of framing and reference points), probability assessment, and social influences on choices. At this juncture it is very important to have an idea about how human brains evolved over millennia by navigating our ancestors. According to conventional financial theory, money and goods are the sources of usefulness and wealth. According to biology and psychology, optimising this value is simply a small component of the larger goal of maximising our biological fitness (chances of survival) and general well-being. People may accept for less because they are unable to maximise their utility due to cognitive constraints. The fact that people frequently struggle with financial decisions should not come as a surprise given that the human brain has evolved over millions of years to exist in natural conditions. The outer layer of the brain is called cortex which is the brain's logistic center. The prefrontal cortex, one of the cortical regions, is responsible for abstract thought, planning, calculating, and strategic decision-making. The insular cortex is another portion of the cortex that is thought to be older in evolutionary terms and is structurally a part of the limbic system of the brain. The limbic system is the brain's emotional control centre and the source of instinctive motivations and feelings like fear and excitement. Due to evolutionary pressure two motivational tendencies has automatically been evolved which are often referred to as approach and avoidance also referred as reward and punishment. Both strategies relate to different parts of the brain. Two dopaminergic system organelles, the ventral striatum (left) and the substantia nigra (SN/VTA), are frequently linked to rewards and incentive-based learning. The insula and amygdala, on the other hand, are thought to be a part of an avoidance system.



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Humans and animals learn to choose behaviours that are rewarded and avoid behaviours that are punished through their interactions with the environment. Money and other secondary rewards are only valuable from an evolutionary perspective if they are associated with primary pleasures like food and sex. However, because our cerebral machinery doesn't understand the characteristics of secondary rewards, it attempts to maximise primary pleasures like food and sex. This maximisation of secondary reward causes biases and abnormalities in behaviour. This is demonstrated by the fact that "reinforcement learning" leads to the underweighting of low probability events prior to their occurrence and the overweighting of those events once they do. People tend to ignore the properties of mean reverting behavior and are likely to cause several behavioral biases when confronted to relate past returns or rewards with future gains. As a result, it is evident that financial choices are fundamentally distinct from those that influenced how the human brain developed. This is best established when our assumptions about the world are violated which is termed as "cognitive illusions". Cognitive illusions lead to suboptimal decisions. Thus in this paper an attempt has been made to examine the financial decisions using a neurobiological perspectives by paying special attention towards gender differences.

The foundation for forecasting investors' behaviour in relation to risk, ambiguity in investment decisions, and differences in financial decision making

The ventral striatum, midbrain, and bilateral insula were among of the brain regions studied in the earliest neurofinance studies to determine whether they responded to risk, uncertainty, and errors. According to current portfolio theory, human brains assess the predicted profit and risk of risky bets before deciding how valuable they are. One study found a relationship between individual differences in positive skewness preferences and the blood-oxygen-level-dependent signal, or BOLD. BOLD measures how much blood-deoxyhemoglobin is present in a certain area of the brain according to functional magnetic resonance imaging. It is used to indirectly infer the activation of the neurons in the inferior frontal gyrus, anterior insula, and ventral striatum. However, dorsomedial prefrontal brain activity (dmPFC) was linked to negative skewness. These results demonstrated the possibility that individual variations in affective and neurological responses can predict individual choice. The investigations also showed that while anterior insula activity is connected with risk-averse choices, ventral striatal activity is associated with risk-seeking financial decisions. In economics and finance risk and ambiguity are considered to be distinct forms of uncertainty and there exists well established behavioural models of choice under risk. However, it is still challenging to forecast an individual's choice when there is risk or ambiguity. According to some recent studies, risk and ambiguity share many of the same neurological roots. Individual risk

preferences are correlated with the regions of the posterior parietal cortex and intraparietal sulcus, but individual ambiguity preferences are substantially correlated with the regions of the prefrontal cortex and dorsolateral prefrontal cortex (DLPFC). However the level of sensitivity to ambiguity depends on the level of perceived confidence as humans are generally ambiguity averse. Neurofinance gave shape to "Anticipatory Affect Model". The nucleus accumbens (NAC) is thought to be activated when anticipating financial outcomes involving large, uncertain gains, while the anterior insula is thought to be activated when anticipating financial outcomes involving large, uncertain losses. This model clearly points out that emotions as well as anticipation play a crucial role in financial decision. There are various reasons behind individual differences in financial decision making. Few investors consistently outperform the market, and individual performance under similar market conditions varies substantially. Some of these inconsistencies may be explained by changes in the person's biological makeup, such as variations in their genes, pharmacological systems, morphology, and brain function. It is vital that these biological differences be understood and evaluated. There are various factors which can be attributed towards biological differences. The present study is focused towards only gender differences. However, along with that, certain other important characteristics like Genetics, Anatomy, Brain Activity and Hormonal changes have been assessed briefly. Thus the characteristics have been broadly grouped under two heads viz. GENDER DIFFERENCES and OTHER DIFFERENCES.

Gender Differences

It is generally acknowledged that women are often less (over)confident and more risk-averse than men. However, little research has been done on the causes of this discrepancy and how they can affect the financial markets. Women tend to invest in less hazardous options, according to several recurrent findings in behavioural finance and economics research. Two key criteria have been determined to adequately represent these gender disparities in risk tolerance. One is related to biological-based and the other is social-based. (Felton, Gibson, & Sanbonmatsu, 2003) According to the biological factor, sex and gender variations, which are influenced by hormones and genes, can be used to explain differences in risk tolerance in general. However, those who support the societal element contend that both genders learn social norms via the process of socialization and act in accordance with societal standards. Women are perhaps more risk seekers or takers in societal decision making. Low exposure to foetal testosterone is linked to high risk aversion in women. In contrast to males, basal (salivary) testosterone is positively correlated with risk-taking for rewards. There can be other factors too apart from general risk tolerance that may contribute towards difference in investment decision between men and women. Some of the research stated that

risk aversion could be due to subjectively lower financial self-efficacy. When it comes to social circumstances, women are just as risk-taking as men, but they are less likely to participate in potentially dangerous activities. According to a recent meta-analysis of behavioural economic experiments involving risky investment choices, women's higher risk aversion is an anomaly rather than the rule, and the differences between the sexes, while consistent, are tiny. Women professionals are just as overconfident as males, according to a report; however they are more prone to avoid competition in fictitious tournament situations. Men traded substantially more than women did, despite the fact that there is a negative association between trading volume and total return, according to a recent study of more than 11,000 unadvised individual investors in South Africa. (Willows & West, 2015) Males displayed higher levels of overconfidence, better risk tolerance, and stronger self-efficacy and self-attrition biases than females. As a result, the returns of men were more variable over the course of five years. Thus, it can be said that women tend to be less risk-tolerant and less optimistic about the likelihood of substantial returns than males when making financial decisions, but this behaviour does not equate to a higher level of total risk aversion. (Miendlarzewska, 2019)

The following table briefly explains the impact of Other Differences which includes Genetics, Anatomy, Brain Activity and Hormonal changes on investment decisions.

Table 1: Other Differences Predicting Behaviour & Performance of Investors

Parameters	Understanding & Assessment	Effect on Investment Decision
a) Genetics	• The study of genetics reveals if a particular type of behaviour in investors runs in the family or whether external factors have a substantial influence on investor behaviour. • The study can be done by comparing **monozygotic** and **dizygotic** twins in their investment behaviour. • Genetics plays a role if monozygotic twins are more similar than dizygotic twins in their choice of investments	• According to laboratory tests, genetic factors can account for 20% of the variation in financial risk-taking. (Cesarini, Johannesson, Lichtenstein, Sandewall, & Wallace, 2010). • Findings suggest that individual variations in financial decision making are to some extent heritable. • The studies states that genes which modulate the dopaminergic and

		serotonergic system influence financial decision making
b) Anatomy	• Structural differences or cortical thickness of brain regions and the thickness of the grey matter showcase individual variations in financial decisions	• According to one study, the grey matter volume of risk-averse participants differs from that of risk-seeking subjects. (Gilaie-Dotan et al., 2014) • Additionally, it was discovered that people who gambled money had greater grey matter volumes in their Centro Medial Amygdala Nuclei.
c) Brain Activity	• During all phases of financial decision-making, risk-averse subjects' brain activation appears to be different from risk-seeking people'.	• Risk-seeking people showed less activation in the ventral striatum and anterior insula during the expectation of a high-risk gamble's outcome than did risk-averse subjects. • Risk-averse people display fewer risk prediction error signals in the front insula, inferior frontal gyrus, and anterior cingulate.
d) Hormonal changes	• Financial decisions are affected by the role of testosterone and cortisol • A market boom followed by a crash is a result of the impacts of testosterone and cortisol, which are linked to greater risk-taking. • Neither of the hormones are associated with changes in low risk stock investment	• The stress hormone cortisol affected risk preferences while the testosterone induced increased optimism about price changes • Future economic risk taking in men are influenced by individual testosterone reactivity • The causal relationship between testosterone and optimism about future prices results in overpricing and bubbles in the market. • In the market experiment, there was no correlation between cortisol and risk-taking behaviour in women.

Source: Author's compilation from various literatures and previous experiments and researches

Conclusion and Recommendation

Neurofinance is still at a very early stage of development. The study above considered the research work and investigation of past researchers which were conducted inside the closed walls of laboratory and in a static environment. But in real life the financial decisions are undertaken in a dynamic environment which poses serious limitations about the generalization of the research work so far undertaken. Real-world data collection is particularly challenging for any study including physiological measurements. The first to test this theory was (Lo and Repin, 2002), who fitted seasoned stock traders with a biofeedback device to track changes in their body temperature, breathing rate, skin conductance, blood pressure, electromyographical signals, and heart rate in response to fleeting market occurrences. It is important for new financial market forecasting models to take into account context-dependent behavioural biases and even to take advantage of physiological signals' predictive capacity. Different countries having different cultures perceive financial information differently. This may pave the path for future investigation of different behavioural preferences leading to different aggregate behaviour. It is possible to use neurofinance to recognise one's own cognitive biases in order to make more informed judgements on their own without the assistance of others. Financial organizations can design their products to appeal to potential clients in the future, and by using neurofinance, it is feasible to monitor the body's physiological system in real time while making financial decisions.

Conflict of Interests

I/We declare/s that there are no conflict of interests that are directly or indirectly related to this research work.

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