Neurofinance: A Conceptual Framework

التمويل العصبي: إطار مفاهيمي

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Abstract:

Recent research in finance and brain science has widely acknowledged that sentiments perform a substantial function in decision-making. This understanding contrasts with the twentieth-century view of finance, which advanced by formulating models based on theoretical approaches, revealing that individuals made financial decisions by demonstrating rational behaviors. Neurofinance is a growing field of study that seeks to improve insight of financial decision-making through integrating cognitive and brain science perspectives with financial theories. This review strives to explore the notion of Neurofinance. tracing its historical development and examining its intersections with other disciplines. The paper utilized resources such as articles, books, and theses in the field to synthesize fundamental findings and trends in Neurofinance research.

Keywords: **Neurofinance, financial decision-making, financial behavior.**

ملخَّص:

أظهرت الأبحاث الحديثة في مجال التمويل وعلوم الاعصاب بأن المشاعر تؤدي وظيفة كبيرة في عملية صـــنع القرار المالي. ويتناقض هذا الفهم مع وجهة نظر القرن العشــــرين للتمويل، والتي تقدمت من خلال صـــــياغة نماذج تعتمد على

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أساليب نظرية، وكشفت أن الأفراد يتخذون القرارات المالية من خلال إظهار سلوكيات عقلانية. التمويل العصبي هو مجال دراسي متنامي يسعى إلى تحسين رؤية عملية صنع القرار المالي من خلال دمج وجهات النظر المعرفية وعلوم الاعصاب مع النظريات المالية. تسعى هذه الورقة البحثية إلى وضع إطار مفاهيمي للتمويل العصبي من خلال استكشاف مفهوم التمويل العصبي، تتبع تطوره التاريخي ودراسة تقاطعاته مع التخصصات الأخرى.

استخدمت الورقة مصادر بيانات مثل المقالات والكتب والأطروحات في هذا المجال لتجميع النتائج والاتجاهات الأساسية في أبحاث التمويل العصبي.

الكلمات المفتاحية: التمويل العصبي، اتخاذ القرارات المالية، عدم الوضوح، المخاطر، السلوك المالي.

الهدف الرئيسي من هذه الورقة هو التركيز على القضايا الرئيسية وتقديم مجموعة مختارة من النتائج الأولية. حيث تسلط الضوء على مجالات البحث المحتملة التي قد تسفر عن فوائد اقتصادية وإقامة روابط بين علم الأعصاب وتطبيقات الأعمال العملية، وخاصة في اتخاذ القرارات المالية اليومية. لتحقيق هذا الهدف، **تهدف الورقة إلى الأهداف التالية:**

1- تقديم اطار مفاهيمي للتمويل العصبي.

2- استكشاف التطور التاريخي للتمويل العصبي تتبع تطوره التاريخي ودراسة تقاطعاته مع التخصصات الأخرى للحصول على رؤى حول تعقيدات عملية صنع القرار المالي

الكلمات المفتاحية: **التمويل العصبي، اتخاذ القرارات المالية، عدم الوضوح، المخاطر، السلوك المالي.**

1. Introduction:
1.1 Theoretical Background

Neurofinance is a captivating intersection of neuroscience and finance that offers intriguing prospects through the intricacies of making financial decisions (Singhraul & Batwe, 2022) . This introduction sets the stage for a more in-depth examination of how insights from Neurofinance can inform and shape our understanding of the dynamics influencing financial decisions and market behaviors. Neurofinance uses brain imaging to investigate the mental processes involved in financial decision-making. It represents the intersection of psychology, neuroscience, and financial behavior (Ardalan, 2018). Different hypotheses, like behavioral economics and neuroscience for evolution, consider neurobiology as the foundation for behavior. In contrast, neuroscience has a relatively modest impact on these approaches. Neurofinance research provides a mental rationale for investment choices, such as investing during volatility, and illustrates how emotions influence trading (Kabir, 2020).

People's lives are significantly influenced by a multitude of financial decisions made at various economic levels. A prime example is the mortgage decision of a household, which holds substantial implications for its financial well-being. Government policies often impose restrictions on the types of mortgages available and their defining parameters. Mortgage rates and availability, shaped by the collective impact of millions of homeowners' decisions, are further influenced by corporate and governmental choices regarding the bundling and trading of mortgages (Forbes, 2024).

The functioning of this financial ecosystem depends on awareness at at various tiers, including homeowners' ignorance as well as credulity to general sentiment influencing policy, to big banks' accurate assessment of the institutional risk present throughout the intricate contemporary financial system. The Great Recession and the 2008 financial crisis serve as illustrations of how errors and unfavorable incentives in this system can spiral out of control and cause catastrophe. There hasn't been much cognitive or neuroscientific research on the processes underlying financial decisions until recently (Hu et al., 2022).

According to the standards of risk-reward compromises, individuals are expected to possess a sizable and diversified portfolio of stocks, investing a significant portion of their assets in the stock market. Nonetheless, a substantial amount of empirical data demonstrates that

shareholder practices frequently differ from this normative standard. The aforementioned irregularities produce a stylized array of evidence that describes the trading behaviors of specific investors. (Barber & Odean, 2013).

Initial Neurofinance research focused on the neural links of these two crucial factors, as the compromise between risk and reward is central to both mental and reasonable financial decision-making hypotheses. According to this study, investing in riskier assets was linked to increased The latter finding is consistent with the hypothesis that the anterior region contributes to the interoception of emotional and physiological states, including unpleasant experiences like pain and uncertainty neural activity in the VSt, Investing in safer assets proved to be linked to brain conduct in the anterior cortex (Kuhnen & Knutson, 2005). The latter result is in line with the idea that the anterior insula plays a role in the interoception of emotional and physiological states, including unpleasant experiences such as pain and uncertainty (Knutson & Huettel, 2015). Initially, in the investigation of price determination for assets, the efficient markets hypothesis was one of the major conceptual advances. Essentially, this hypothesis posits that prices should reflect all available information if markets are efficient (Fama, 2014). It is also possible for The investor's mood (which changes over time) to influence stock prices. Investors may be more willing to take risks when they're feeling good. Economists have explored this relationship by examining how weather and athletic events affect stock returns. For instance, even after accounting for snow and rain, stock returns tend to be higher on sunnier days (Sun et al., 2023) . Nevertheless, research utilizing field data is unable to identify the specific cognitive processes that give rise to valuing repercussions. In this case, does an uptick in disposition alter a shareholder's risk tolerance, or does it merely raise their expectations for profits, or perhaps both? According to recent experimental findings, mood influences financial decision-making through both preferences.

Like individual trading research, aggregate asset pricing has very little neuroscientific support. In one study, researchers tracked brain activity as exploratory investors sought to establish the fact that synthetic price fluctuations shifted due to insider knowledge about stock values held by other investors. The dorsomedial frontal cortex, widely recognized for its role in the brain's cognitive processes, exhibited increased activity. Individuals with the highest income levels performed

better on the 'vision of consciousness' test, aligning with their ability to deduce the motives of others (Toma, 2023).

A price bubble occurs when the valuations of assets rise substantially above their real worth, as determined by statistical data, and then 'crash,' returning to their original value. Bubbles are frequently investigated through laboratory experiments by establishing their recognized worth. This is accomplished by providing subjects with an asset that depreciates over 15 trading periods. Prices typically rise and peak in experiments far above the intrinsic value. However, when subjects participate repeatedly, the bubbles are smaller and last for a shorter duration (Teall, 2023).

One fMRI study that used this paradigm found that neurons in the adjacent and dorsomedial PFC regions were more sensitive to an investor's portfolio worth in market sequences that featured bubbles. Furthermore, those areas were more strongly coactivated during bubbles. The propensity to engage in the bubble was also connected with the intensity of movement within the ventromedial PFC (vmPFC). These findings imply that bubbles are related to the orchestration of mentalizing and valuation in the adjacent and lateral prefrontal areas. (De Martino et al., 2013).

In an extended fMRI research, exploratory properties with an initial intrinsic worth were created over fifty dealing intervals. Twenty subjects traded among themselves to determine prices in their entirety (A pair had been examined). Prices were tracked by activity in the nucleus accumbens, and bubbles were frequent . The insula cortex exhibits differential activity across profitable and failing investors, frequently peaking around a year before the bubble explosion. This suggests the existence of a neural 'early-warning signal' linked to feelings of uncertainty or discomfort (De Martino et al., 2013).

1.2 Problem statement

Neurofinance incorporates behavioral finance to some extent but has a couple of main objectives: (a) clarifying the biophysical (brain and biological) procedures that underlie stock market respondents' behaviors, and (b) delivering a psychologically driven, different justification for the evident collapse of conventional finance models (Tseng, 2006) . This paper provides a conceptual framework of Neurofinance, focusing on essential aspects and presenting various indicative findings. Given the limitations of this paper, it does not delve into every aspect of Neurofinance.

1.3 Aims and objectives

The main aim of this paper is to concentrate on key issues and present a selection of initial findings. Subsequently, it highlights potential research areas that may yield economic benefits and establish connections between neuroscience and practical business applications, particularly in everyday financial decision-making.

To fulfill this Aim, the Paper has the following objectives:

1. Investigate the concept of Neurofinance.

2. Explore the historical evolution of Neurofinance to gain valuable insights into the intricacies of financial decision-making.

For the reader's convenience, the author has included a glossary in Table 1, encompassing the most frequently used terms throughout the text.

Table 1. Glossary of Neuroscientific and Financial Terms

Term	Definition
Finance Terms	
Ambiguity	In contrast to risk, which entails well-defined possibilities, ambiguity involves uncertainty, wherein the potential outcomes are not fully understood.(Jin et al., 2024)
Disposition effect	The inclination to retain investments that have declined in value and divest those that have risen in price.(Cheng et al., 2024)
Efficient market hypothesis	The concept of an efficient market proposes that, at any particular moment, the valuations of assets incorporate all relevant accessible data.(Kilic et al., 2023)
Expected utility theory	According to this model, individuals select challenging alternatives based on their anticipated standards of benefit, which are a ranked average of possible results. The values are assigned according to the probabilities of each result.(Rushworth et al., 2011).

IPO	(IPO) is the initial public offering, representing the first sale of a business's stock on a public exchange.(Jiang & Li, 2013).
Irrational exuberance	A scenario in which investors overestimate the state of the economy and the stock market by anticipating long-term stock valuations and economic strength. In their pursuit of ever-higher returns, investors may overlook declining economic fundamentals, leading to bidding wars that drive prices even higher. Irrational exuberance contributes to financial crises.(Mesly, 2023).
Modern portfolio theory	This framework explains how to utilize variance analysis to construct a portfolio that enhances anticipated earnings for a specific level of uncertainty. (Wang et al., 2024).
Reflection effect	In the theory of prospective, whenever choice encompass potential losses alongside gains, individuals' preferences for negative outcomes tend to mirror their preferences for positive outcomes more often than not.(Boorman & Sallet, 2009)
Risk	The variability in reward outcomes arises when estimates for each result are available.
Neuroscience terms	
BOLD signal	The BOLD signal represents the concentration of dehydrated haemoglobin in a specific neural region, as detected by (fMRI). This indicator is used to infer the functioning of neurons within the neural network.(Camerer et al., 2005)
Dopamine	Dopamine functions as a brain chemical, which is an element distributed by brain cells to transmit signals to to other brain cells. The dopamine signalling, extending from (VTA) in the cerebral to (NA) and the frontal cortex, is critical in reward-based learning.(Pirtosek et al., 2009).

EEG	positioned on the forehead to non-invasively capture the brain's electrical activity with precise temporal resolution in milliseconds.(Dorow et al., 2018)
FMRI	Noninvasively evaluates fluctuations in oxygen levels in the blood in the cerebral cortex with outstanding physical accuracy. The BOLD signal is used to assess incident or stimulus-related brain function. (Kuhnen & Knutson, 2005)
TMS	Transcranial magnetic stimulation stimulates specific areas of the brain's outer sections. A magnetic coil, also known as a 'curl,' uses electromagnetic induction to generate small electrical currents in the brain continent directly beneath it. The frequency of stimulation determines whether there is an enhancement or suppression of cortical activity.(Wu et al., 2021)

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2. CONCEPTUAL FRAMEWORK

2.1 Neurofinance

In recent years, the integration of fields involving psychological science and neuroscience with economics and finance has provided new insights into markets and investor behavior. Neurofinance is an emerging discipline that examines financial markets using neurological technology to study investment attitudes (Dedu & Turcan, 2010). Consequently, neuroscience provides another type of information, known as cognitive information, that can elucidate investor behavior. Specifically, distinct neural networks are responsible for various facets of how individuals act. The application of neurology to enhance understanding of how individuals make financial decisions has given rise to a new field known as Neurofinance (Ahmad et al., 2017).

Individual financial choices are additionally get impacted by cognitive processes that occur beyond perception and are inherently independent. Neuroscience focuses on specific areas of the brain related to decision-making. Different parts of the brain communicate with each other via neural channels and procedures that govern the way people feel, practices, and activities (Sapra & Zak, 2008). Furthermore, all the topics being examined in neuroscience are relevant to the explanations sought by a finance researcher. (Camerer et al., 2005) advocates conducting a more in-depth analysis of financial choice behavior by integrating expertise in finance, psychology, and neuroscience. Given that the cerebral cortex is the most complex organ in the human body, it is frequently referred to as the "black box".

According to (Walter et al., 2005) , The various regions of the cerebral cortex are inextricably linked, and their interaction is evident in overall human behavior. Due to dopaminergic neurons, specific regions of the brain, including the mesencephalon, the ventral end of the striatum and adjacent pallidum, the anterior cingulate gyrus, the prefrontal cortex (primarily orbitofrontal neurons), and the hippocampus, form the reward system (Bermejo et al., 2011).

The data related to the anticipated reward or loss passes through neurological pathways, where it undergoes essential cognitive and mental processes, serving as the foundation for the formulation of fundamental motor and mental strategies, eventually leading to the final decision. These procedures are the outcome of vital logic involving multiple reasonable possibilities and alternatives for desired outcomes (reward/penalty) based on psychological variables (Lee, 2013). The

analysis of risk, reward, and unpredictability, along with their neural basis, is part of the process for making financial choices. (DeWitt, 2014) argues that for a decision to be significant, it has to integrate previous outcomes (such as rewards) and signals from the ongoing mental process. The neural and subcortical components are interconnected within the framework of reward-centered behavior, influencing decision-making and other related activities, such as memory storage (Markett & Reuter, 2014).

2.2 Neurofinance's emergence, growth, and diversification

Neurofinance is a rapidly developing discipline that investigates the impact of the brain on investment decision-making. While the previous concept of behavioral finance connected neuroscience and behavioral science to finance, Neurofinance aims to elucidate the fundamental basis for the outcomes associated with these behaviors.

(Kuhnen & Knutson, 2005) published the research in Neurofinance employing the FMRI (functional magnetic resonance imaging) approach. This study elucidates how the deviance from reasoning in economic choices is prompted by a fundamental neural process occurring in specific areas of the brain when the Nucleus Accumbens (NAcc) is activated prior to making risky decisions. Furthermore, the findings revealed that two distinct neural circuits, the Nucleus Accumbens (NAcc) and the frontal isolation, can influence skepticism of risk and conservative decisions. However, these results demonstrate that such influences play an important role in financial decision-making (Kuhnen & Knutson, 2005).

Likewise, (Hsu et al., 2005) employs neurological imaging to investigate the stimulation of the orbital frontal cortex and amygdala during the process of making ambiguous choices. Furthermore, (Tseng, 2006) defines Neurofinance as the study of cognitive finance and its impact on financial decisions. (Peterson, 2007) argues for the existence of distinct structures for taking chances and aversion to risk practices, as well as the significance of influences in financial decisions. According to (Knutson et al., 2003) , the anticipation of a reward stimulates the Nucleus Accumbens (NAcc), while the actual understanding of the incentive activates the middle part of the prefrontal cortex.

On other hand , The decision-making procedure includes several phases, involving understanding, participation, assessment, process decision-making, and implementation (Bermejo et al., 2011). These

phases are interconnected in such a way that they result in an unambiguous decision. Every phase in the decision-making process originates in various parts of the brain. (Pirtosek et al., 2009) Explain that the central nervous system is divided into three sections: the cortex, the cerebellum, and the brainstem. The financial selection procedure involves assessing uncertainty, incentives, and ambiguous scenarios, along with their neural foundations. The primary factor in decision-making depends on predicting the rewards associated with incentives, uncertainty, or loss variables linked to that specific decision. (Ouzir et al., 2024). The neurotransmitter is primarily involved in motivational estimation or evaluation, encompassing a variety of cognitive processes (Pirtosek et al., 2009).

Table 2, From a theoretical standpoint, the literature contributes to the emerging discipline of Neurofinance.

Table 2: Main literature in Neurofinance modeling:

Research Author (s)	Objects	Neuroimaging Method Employed	results
(Bechara et al., 1999)	IGT's automated form of a gambling process.	SCR	VMF and the hippocampus serve distinct functions in decision-making, and damage to the hippocampus results in compromised decisions.
(Miyapuram et al., 2012)	In both cases, sensations are linked to hypothetical financial rewards. In test 1, sensory cues for both motivating and nonrewarding depictions are provided, while test 2 employs stimuli with	FMRI	Test 1 mobilized the frontal lobe and the central nervous system, while test 2 gradually activated the midbrain.

	restricted servings, featuring three hypothetical incentives and resulting in the same genuine incentive.		
(Cappelen et al., 2014)	Participants involved were instructed to work and earn concurrently during the pre-scanning phase, and during the neuronal imaging phase, they were to evaluate their earnings distribution.	FMRI	Money is rewarding. The striatum demonstrated activity while deviations in income distribution were observed.
(Lucarelli et al., 2015)	An automated version of the Iowa Gambling Task (IGT) psycho-physiological task.	SCR	The designed and validated money-emotion interactions algorithm.
(Dorow et al., 2018)	The 'Investor' program is a free tool that simulates stock market trading to assess psychological impact and investment productivity.	EEG	Individuals were more likely to avoid the psychological impact, and gains in stocks were associated with increased fluctuations in heart rate and brainwave activation.

Source: Created by the authors based on the literature mentioned above.

Accordingly, Neurofinance investigates how to evaluate information about uncertain, time-limited, perilous, and tactical financial options. It also explores the ways in which sentiments, biases, anxiety, and individual traits (such as gender, DNA, neurons, and character traits) influence financial decisions. The interaction between an individual's specific investment decisions and their neurology. According to Neurofinance, a person's brain can be classified into three primary regions. The cerebrum, the brain's largest and most rational region, contains the limbic system and cerebellum, which enable individuals to make reasonable financial choices. The midbrain is in charge of hearing, vision, and movement, whereas the hindbrain/little brain is in charge of essential bodily functions (Kuhnen & Knutson, 2005).

Finally, we must pose a critical question: why do scholars undertake the challenging task of cerebral visualization? A thorough understanding of the workings of the mind is crucial because much of our knowledge about the brain relies on an incomplete comprehension of its actual functioning. Academic research on the structure and functioning of the cerebral cortex employs a variety of techniques. Scientists can utilize technological advances to investigate virtually every brain connection within the properly functioning brain (Kable & Glimcher, 2009).

2.3 Financial Decision Making: Distinguishing Traditional Finance, Behavioral Finance, and Neurofinance

Conventional economics centers around the concept of an efficient market, which posits that consistently outperforming the market is not feasible (Ardalan, 2018). It assumes that every available detail is logically measured and reflected in prices, allowing little room for speculation (Wen et al., 2023). Highly profitable investors, along with prolonged economic bubbles, pose challenges to the conventional efficient market, casting doubts on its validity. The main presumption is that individuals are rational beings equipped with accurate information, enabling them to make choices that optimize their (predicted) utility, comes under scrutiny and appears to be commonly breached [(Cohen, 2005), (Wang et al., 2023)]. Consequently, these models frequently fall short in elucidating how individuals make decisions in real-life situations.

Recently, the field of behavioral finance has emerged to characterize and explain persistent prejudices and variations from the

theory of rational decision-making. [(Rossmo & Summers, 2022), (Bhui et al., 2021), (Bennett et al., 2023)].

These domains gained significance following the execution of a set of behavioral studies in which they explored decisions involving risky options To measure these variances (Tversky & Kahneman, 1992). They then developed the theory of prospect, encapsulating two key findings: (a) the significance of losses outweighing gains, leading to distinct value behaviors for losses and gains, and (b) a tendency for individuals to assign more weight to low probabilities while giving less weight to medium and high probabilities, resulting in an unpredictable adjustment of likelihoods. Additionally, it elucidates (c) the reflection effect, revealing that individuals are prone to be cautious when anticipating profits and cautious when confronted via eventual losses [(Camerer, 1998), (Madan et al., 2017), (Tversky & Kahneman, 1992)].

While many studies show that integrating behavioral and psychological insights can narrow the gaps between theory and empirical evidence, there is still room for improving the ability to foresee capabilities of such more feasible theories (Paule-Vianez et al., 2020). Neurofinance aims to enhance frameworks for financial decisions and market behavior by investigating the neural processing of financial information and decision-making mechanisms in the brain.

2.4. A Perspective from a Neuroscientific standpoint

When conventional finance and economics discuss optimizing utility and wealth, they typically refer to financial securities and products. However, from a biological and psychological standpoint, it is argued that maximizing this utility is just one facet of attaining a broader objective—to enhance vitality and overall health. Cognitive constraints could also hinder individuals from expanding their utility, leading them to settle for adequate or 'acceptable' results rather than the ideal one [(Cohen, 2005),(Shuraida & Titah, 2023)].

Since the human brain has grown over millions of years to thrive in natural settings rather than financial markets, it's unlikely that people frequently struggle with financial decisions. Darwinian pressures have ingrained in humans two vital motivational tendencies: approach and avoidance. [(Elliot & Thrash, 2002), (Knutson & Greer, 2008)]. They are linked to both positive and negative emotional states, commonly known as incentives and sanctions (Alcaro & Panksepp, 2011). Even though they have contrasting impacts on behavior, it is believed that the two

mechanisms are governed by separate but closely interconnected neural pathways (Bromberg-Martin et al., 2010). The brain regions linked to financial concepts such as reward and risk, as well as emotions, are encompassed in both the approach and avoidance systems.

While a substantial body of literature emphasizes the role of uncertainty in disdain, distress, compassion, and mental states, an equally extensive literature explores its role. Initially, the amygdala was predominantly linked to the identification of mental significance, particularly in anxiety, which became more apparent before its eventual involvement in financial decisions [(Canessa et al., 2013), (Weller et al., 2007), (De Martino et al., 2010)]. Finally, these neurological structures have developed techniques to quickly adapt to diverse situations. This process refers to the brain's ability to flexibly alter its structure and functions, serving as the foundation for learning in humans. Humans gain from interactions with their surroundings to make choices associated with incentives and avoid those associated with sanctions. The dopaminergic system plays a vital role in reward-based learning by facilitating the acquisition of knowledge based on both primary and secondary rewards (Valentin & O'Doherty, 2009). Several irrational financial behaviors are consistent with reward-driven understanding. In this context, choices that resulted in gains are positively reinforced and, consequently, are more likely to be repeated. For example, shareholders choose to acquire shares they had initially sold for a profit (Cheng et al., 2024).

The probability of investors participating in an IPO auction is higher when they have previously experienced significant returns in such auctions(Jiang & Li, 2013). Individuals who experience significant gains and minimal variability in their investments are inclined to increase their savings rate compared to shareholders who haven't had such advantages (Choi et al., 2009).

Wealth and other supplementary incentives derive their value primarily from their association with primary incentives. Although these supplementary incentives activate identical cerebral techniques, this may not always lead to impartially suitable choices. Unlike consumable rewards such as nourishment, cash is non-perishable and experiences less degradation over time, leading to less steep discounting (Odum, 2011). Furthermore, supplementary incentives are likely to have influenced the growth of the technique and reduction structure. As a result, our brain cells are oblivious to the characteristics of supplementary incentives and

tend to maximize their value in the same way they do with elementary incentives. Consequently, our cognitive systems aren't exceptionally adept at making sound financial decisions.

Indeed, these biases in behavior, such as a focus on extreme outcomes and a preference for relative, subjective gains over objective ones, are likely attributed to their biologically adapted nature, and could clarify the widely recognized phenomenon of 'irrational exuberance' in financial markets (Mesly, 2023).

Collectively, financial decisions differ significantly from the selection procedures that shaped the evolution of the human brain. This distinction becomes apparent in instances of Mental delusions arise when our preconceived notions regarding our surroundings are debunked. Given the stark contrast between financial markets and natural environments, assumptions face more frequent violations, resulting in Inadequate choices. This is akin to illusory vision, where the cerebral cortex generates erroneous impressions based on misconceptions. Analyzing financial decisions from a neurobiological standpoint can uncover the implicit—potentially incorrect—assumptions and provide insights into perplexing financial phenomena. It can contribute to enhancing future financial and economic models, shedding light on individual variations in economic decision-making, understanding the reason certain individuals embrace uncertainties while others avoid them, and elucidating the factors influencing changes in our preferences over time.

3. Neurofinance as a Foundation for Predicting Investor Behavior

Traditional economic models suggest that choices involve optimizing (anticipated) utilities through (anticipated) worth, susceptibility to (variation), and (unpredictable) risks. As these hypotheses were not based on natural or mental concepts, early Neurofinance investigated whether the human cerebral cortex continuously tracks utilities, projections, uncertainties, and risks.

The utilization of fMRI revealed that certain brain regions, including The striatum in the ventral central nervous system, along with dual insulation, reacts to uncertainty and blunders when evaluating risk (Preuschoff et al., 2006). This indicates that the human cognitive system assesses the value of uncertain wagers by considering their expected

incentive and uncertainty, aligning with the principles of modern portfolio theory (Wang et al., 2024).

Neural associations are also being investigated for other summaries of data frequently employed in economics, including the variety of results and an imbalance in the pattern of effects (tilt). In a particular investigation, the utilization of the mean-variance-skewness model to simulate behavioral choices unveiled that variance triggered activation in the parietal cortex. Moreover, variations in individual preferences for positive skewness were found to correlate With BOLD stimulation in the inferior frontal gyrus, anterior insula, and ventral striatum. In contrast, stimulation of the frontal lobe of the (dmPFC) was found to be associated with negativity, while no specific cerebral region demonstrated an overall association with tilt (Symmonds et al., 2011).

Similarly, it was discovered that movement in the ventral striatum (the nucleus accumbens; NAcc) correlates with a human being's inclination towards biased wagers, whereas movement in the frontal insula was associated with the reduction of biased wagers. These results indicate that variations in impact and brain reactions could offer insights into individual decision-making (Wu et al., 2011). In A 2012 systematic review of research on financial risk-taking discovered that the statistical characteristics of risky financial options (comparing excessive vs. minimal average, variation, and tilt) cause movement in the adjacent cerebellum. Moreover, both the average and variation were observed to activate both sides of the anterior insula and the frontal lingual cortex—regions associated with dedication and anticipated energy expenditure (Wu et al., 2012), In conflict resolution, as well as in performs like sense of balance and compassion, the meta-analysis encompassed only four studies directly comparing high and low skewness. It revealed that overall skewness triggered activity The one on the ventral side, which comprises the NAcc. However, no in-line stimulation of the anterior insula was observed. The results of these investigations indicate that adjacent striatal movement is associated with taking risks in investments, whereas anterior insula movement is correlated with risk-avoidant choices in capital obligations. This is consistent with the indication of forecasting risk oversights [(Botvinick et al., 1999),(Brown & Braver, 2008), (Singer et al., 2009), (Kuhnen & Knutson, 2005)].

These findings suggest that decision-making is facilitated by subcortical regions chronologically beyond cerebral surfaces, as well as the isolated cerebral cortex, rather than newly developed neocortical

regions. This indicates an essential function for influence in making financial choices.

3.1. Neural Processing of Risk and Ambiguity

Examining how the cerebral cortex responds to risk and other uncertainties has important implications for financial decision-making. In many real-world scenarios, such as establishing climate predictions for distant vacation spots or participating in activities with undetermined regulations, possibilities are determined from limited or contradictory evidence (Schultz et al., 2008). At the opposite end of the spectrum, as seen in activities like roulette gambling, probability can be reliably assessed through considerations of relative frequencies, examination of event histories, or reliance on established theories (Chung et al., 2024). These two types of unpredictability are called ambiguous and uncertain, respectively. Ambiguity refers to scenarios that are unreliable, where chances of outcomes are not entirely predictable, as opposed to risk, where chances can be determined (Bardakhchyan & Allahverdyan, 2023).

Real-world investment choice involves a range of risk and ambiguity (uncertainty). Although certain uncertainties are susceptible to mitigated and projected, some remain inherently unchangeable(Lo & Mueller, 2010).

regarded to be separate types of ambiguity. Cognitive frameworks focusing on decisions under risk are appropriately developed, yet predicting individual choices for both risk and ambiguity remains challenging. Therefore, Neurofinance holds the potential to Address two unanswered concerns: (a) Are risk and ambiguity really separate principles, or are they simply distinct features of one single situation? (b) Can we identify additional factors (e.g., neurological signals) when humans investigate and assess wagers to improve decision forecasting? As we will explore In the following section, an examination of how the brain processes risk and ambiguity unveils a complexity beyond the presumptions that underlie conventional economic and financial theories. Several research investigations have identified exclusive stimulation, which matches results based on risk decision-making processes.

In line with findings in decision-making under risky conditions, certain studies noted activation in the insular region in response to ambiguity and uncertainty in categorization (Fairley et al., 2022),

(Grinband et al., 2006). The results of neuroimaging studies comparing risk and ambiguity, however, present an inconsistent pattern. For instance, when examining ambiguity, (Chung et al., 2024)

conducted a study investigating decisions Examining both confident and ambiguous economic results, they utilized three scenarios in experiments to differentiate between ambiguity and risk based on various degrees of data. The findings showed that the adjacent frontal cortex and the hippocampus were more activated in response to ambiguity than to risk. On the other hand, risky wagers have been linked to increased BOLD stimulation in dopamine-related areas, including the dorsomedial cortex (mature cells), the precuneus, and the premotor cortex. Following this, (Fairley et al., 2022) discovered that, on the whole, risk and ambiguity utilize similar neural substrates, such as the insula. However, they observed that specific areas of Individual risk-taking tendencies were discovered to be associated with regions of the posterior portion of the parietal cortex and intraparietal sulcus, while the dorsolateral prefrontal cortex (DLPFC) showed a significant association with ambiguity inclinations.

Supporting this discovery, the application of transcranial magnetic stimulation (TMS) to the intraparietal sulcus resulted in a decrease in risk-taking during trials involving decisions with inherent risks (Wu et al., 2021). Despite behavioral differences between choices made under risk and ambiguity, with no observed correlation in aversion levels between the two, In the two scenarios, sentimental significance was related to BOLD movement in the mPFC, the cerebellum, the posterior cingulate cortex, and the amygdala. Particularly, no specific brain region was purely related to either ambiguity or risk variables, challenging prior results that indicated a separation of neural networks (Chung et al., 2024).

In summary, the degree of risk is associated with stimulation in the insula, the cortex, and parallel brain regions, whereas the connected cortex, the hippocampus, and frontal cortical regions (DLPFC, mPFC) are involved in processing ambiguity. However, A small body of evidence supports the idea of a multifaceted separation between risk and ambiguity (Chung et al., 2024). Accurately forecasting probability and risk, as well as encountering errors in assessing risk, may influence the learning of anticipated rewards. This function is attributed to subcortical dopaminoceptive structures (Chumbley et al., 2014). Further investigation into the decision-making process, especially within the

framework of knowledge acquisition, is needed regarding ambiguity, are encouraged. These inquiries anticipate further applications in the field of Neurofinance [(Thuy & Benoit, 2023),(Payzan-LeNestour et al., 2013), (Monosov, 2020)].

3.2 Approaches to Financial Decision Making

Neurofinance provides a promising opportunity to differentiate between conflicting theoretical frameworks in the comprehension of financial decision-making. As an initial step, scientists have aimed to pinpoint the neural counterparts of various behavioral models. For example, studies utilizing fMRI have demonstrated that the principal representation of the expected utility of an option occurs in the mPFC and NAcc, a finding consistently replicated [(Knutson et al., 2003), (Seymour et al., 2007)].

Generally, individuals exhibit nonlinear probability functions, assigning greater weight to low probabilities and lesser weight to the midst highest risks. This pattern agrees with the theory of prospects and challenges anticipated utility theory (Sun et al., 2022). The BOLD reaction in the cortex and cingulate gyrus, related to value coding, exhibited an exponential probability function (Rushworth et al., 2011). Additionally, the frontal operculum near the insula, responsible for risk processing, indicates that chance is stored nonlinearly in the brain. This supports key aspects of prospect theory, with the slope corresponding to aversion to risk in gain scenarios and the slope corresponding to taking risks in loss scenarios, illustrating the reverberation impact. However, as discussed (Boorman & Sallet, 2009), these promising findings indicate that imaging studies do not exclusively support expected utility and prospect theory.

An alternative approach to decision-making under uncertainty, employing mean-variance analysis (Fereydooni et al., 2024), is likewise supported by research (Weller et al., 2007). Essentially, the study suggests that the magnitude of risk influences how one interprets worth in the cerebral cortex (Weller et al., 2007)

Furthermore, Neural data has been utilized to assess hypotheses of investor practices, such as the 'realization utility' theory of trading proposed by (FRYDMAN et al., 2014). In an experimental market setting, participants traded three types of stocks while fMRI data were collected. movement in the ventromedial prefrontal cortex (vmPFC) associated with investment gain, capturing decision revenue. according

to realization utility theory. However, the relationship wasn't relevant to the net anticipated worth of future profitsIn contrast, the ventral striatum, an area known for storing modifications to compared incentive worth, demonstrated an upbeat reaction when participants sold (noticed) profits as compared to keeping them as well. The brain data offered conclusive proof for the essential procedure behind the realization utility model.

(Frydman & Camerer, 2016) employed a mimicked investment situation and fMRI to show that in the dearth of holdings, information of an upward trend in prices causes a reward forecasting incorrect signal in the ventral striatum. This indicator represents the dissatisfaction related to selling prematurely. When the price refresh display appeared following the participant's investment choice, the activity of neurons in the ventral striatum dropped as the price of recently sold shares rose. Specifically, the fMRI signal in the ventromedial prefrontal cortex (vmPFC) showed a negative correlation with the foregone capital gain when a participant had the opportunity to repurchase the stock.

Expanding on previous studies that unveiled brain activity associated with counterfactual information about unchosen rewards (Lohrenz et al., 2007), these results support the notion that regret is also a contributing factor to the concept of realization utility. Neurofinance research aims to generate novel, naturally motivated economic decision-making frameworks, while also assessing current ones. Among the increasingly prevalent frameworks currently is the predictive influence framework. The above framework contends that predicting financial results, particularly those with uncertain significant advantages, is likely to elicit positive excitement and stimulate the NAcc. In contrast, predicting financial results involving uncertain substantial losses tends to trigger negative feelings and activate the frontal insula(Knutson & Greer, 2008). The distinguished stimulation of these neural networks and emotional states results in approach and avoidance attitudes, demonstrating that psychological excitement regarding outcomes can influence behavior. Hence, in contrast to conventional Financial scenarios, the predictive effect structure a multitude of experimental findings demonstrating the influence of emotions [(Baker & Wurgler, 2007);(Habib et al., 2015); (Nguyen & Noussair, 2014) ; (Schwager & Rothermund, 2013)]. The role of anticipation [(Kuhnen & Knutson, 2011);(Ma et al., 2015)] is pivotal in shaping financial decisions.

4. Distinguishing Traditional Finance, Behavioral Finance, and Neurofinance: What Sets Them Apart?

Based on the previous discussions in this paper, for further clarification, we will outline the main differences between Traditional Finance, Behavioral Finance, and Neurofinance in Table 3.

Table 3: Differentiating Traditional Finance, Behavioral Finance, and Neurofinance

	Traditional Finance	Behavioral Finance	Neurofinance
Approach	Conventional Finance advocates for rational investors and markets.	Behavioral finance posits the existence of markets and investors influenced by irrational behavior.	Neurofinance involves the examination of individuals who make decisions or think emotionally rather than rationally.
	It enables the development of a rational portfolio.	By applying behavioral finance principles, we can construct the optimal portfolio.	It aids in crafting an outstanding and refined portfolio.
Methodology	Conventional financial models are based on an approximation of real market conditions.	Considering real challenges tied to human behavior, behavioral finance provides solutions.	It integrates neurotechnology to analyze the psychology of investors in the financial market.
	Conventional Finance delineates the appropriate	Behavioral finance explores the actions	It elucidates the rationale and the cognitive processes behind

	behavior for investors.	undertaken by investors.	an individual's behavior.
Purpose	**Conventional financial statements presume optimal investment conduct.**	**Behavioral finance assumptions are contingent on the financial behavior of an investor.**	**Neurofinance is a comprehensive exploration seeking to comprehend the external reasoning of an investor.**

Source: Created by the authors based on (Baker & Wurgler, 2007), (Bennett et al., 2023), (Dedu & Turcan, 2010).

Hence, distinguishing Traditional Finance, Behavioral Finance, and Neurofinance involves examining their distinct approaches to understanding and scrutinizing financial decision-making. Traditional Finance underscores rational decision-making, assuming individuals consistently optimize utility and objectively evaluate risks. In contrast, Behavioral Finance recognizes the impact of psychological factors and emotions on financial choices, acknowledging deviations from rationality in human behavior. Neurofinance takes it a step further by exploring The brain processes that govern making financial choices using insights from neuroscience to comprehend how the brain functions in financial contexts. Essentially, these three fields provide unique viewpoints, with Traditional Finance relying on rational models, Behavioral Finance integrating psychological perspectives, and Neurofinance introducing neurological considerations into financial analysis.

5. Conclusion

This paper employs secondary data sources, categorizing it as a conceptual analysis research. The goal is to delve into the concept of Neurofinance and trace its historical development, seeking valuable perspectives on the intricate nature of decision-making in finance. The author foresees that this paper will contribute to future empirical research, specifically in analyzing individual investment behavior and decisions. The intention is to establish a foundation for the exploration and advancement of Neurofinance within the realm of behavioral finance research.

The primary observation is that Neurofinance is still in its early stages, providing Innovative insights into how individuals process financial data and its effects on financial decision-making. However, the most crucial and potentially thrilling developments are anticipated in the future. The decision-making process in humans is intricate and influenced by a myriad of factors. In the realm of finance, Neurofinance is a relatively recent discipline. One of its significant findings pertains to the pivotal role emotions play in financial decision-making. The goal is to connect cognitive abilities with investment behavior. In the field of neuroeconomics, which is a current trend in modern finance, the scrutiny of human behavior and reactions extends to the level of neurophysiological analysis. This active trend aims to address issues related to biases in investor behavior.

Individuals vary significantly in terms of concepts like risk aversion, time preference, and preferences. Recently, technological advancements in neuroscience have allowed us to uncover the neurological locations where these differences exist. This progress enables the identification of neural mechanisms responsible for human decision-making. It is currently acknowledged that this conflict is rooted in neurology and is delineated by distinct brain regions. The interplay among these brain regions shapes authentic human behavior, offering understanding of the various ways people act. The basis for making judgments lies in the investor's impartial and objective perspective. This information should encourage scholars and academics to adopt brain mapping technologies for analyzing investors' financial decisions. Understanding how their brains operate contributes to individuals' positive and continual development in their investment strategies.

The author aims for this review to serve as inspiration for future empirical research in Neurofinance.

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(Neurofinance: A Conceptual Framework)   Dr. Nesrin A. Abbas

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(Neurofinance: A Conceptual Framework)   Dr. Nesrin A. Abbas

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