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Understanding Testosterone and Estrogen in Context of Neurofinance: A Systematic Review

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Abstract: Recent behavioral and neurofinance studies have revealed that economic behavior has a multifaceted structure, encompassing various dimensions from biology and chemistry to psychology, psychoanalysis, psychopathology, and a range of syndromes. In this context, the pharmacological aspect of the subject, particularly the striking effects of neurotransmitters such as dopamine and serotonin on economic behavior, has been frequently examined in the literature. Another significant dimension of the finance-pharmacology relationship is the endocrine system, with studies focusing on hormones such as cortisol providing noteworthy findings. Along with cortisol, the other most intensively studied hormones are sex hormones (testosterone, estrogen, and progesterone). This study aims to make specific inferences based on existing findings in the literature regarding the effects of testosterone and estrogen on financial matters, thereby contributing to the current body of knowledge. In particular, the behavioral effects of testosterone's relationship with aggression and dominance, and estrogen's connection with sedation and inhibition, influence individuals' financial decision-making processes across a broad spectrum.

Keywords: Neurofinance, Testosterone, Estrogen, 2D:4D, Sex Hormones

Nörofinans Bağlamında Testosteron ve Östrojenin Anlaşılması: Sistematik Bir Derleme

Öz: Yakın zamanlarda yapılan davranışsal ve nörofinans çalışmaları, ekonomik davranışın çok katmanlı bir yapıya sahip olduğunu ve bunun biyolojiden kimyaya, psikolojiden psikanalize, psikopatolojiden çeşitli sendromlara kadar birçok ayağının bulunduğunu ortaya koymaya devam etmektedir. Bu bağlamda, konunun farmakolojik yönünde, özellikle dopamin ve serotonin gibi nörotransmiterlerin ekonomik davranış üzerindeki çarpıcı etkileri literatürde sıkça incelenmektedir. Finans-farmakoloji ilişkisinin bir diğer önemli boyutu olan endokrin sistemle ilgili olarak, özellikle kortizol gibi hormonlar üzerine yapılan çalışmalar, kayda değer bulgular sunmaktadır. Kortizol ile birlikte en yoğun biçimde incelenen diğer hormonlar ise cinsiyet hormonları (testosteron, östrojen ve progesteron) olup, bu çalışmada testosteron ve östrojenin finansal konular üzerindeki etkilerine ilişkin mevcut literatürde yer alan bulgulara dayanarak belirli çıkarımlar yapılarak literatüre katkı sağlanması amaçlanmaktadır. Özellikle testosteronun agresyon ve dominasyon ile ilişkisinin ve östrojenin sedasyon ve inhibisyon ile ilişkisinin yarattığı davranışsal etkiler, bireylerin finansal karar alma süreçlerini geniş bir spektrumda etkilemektedir.

Anahtar Sözcükler: Nörofinans, Testosteron, Östrojen, 2D:4D, Cinsiyet Hormonları

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Introduction

Neurofinance offers a broad perspective for understanding the neuropsychopharmacological (biological, chemical, neurological, and psychological) processes that shape individuals' financial and economic decision-making. Alongside behavioral economics, it has become evident that financial decisions are not solely based on rational and logical thinking but are also influenced by emotional, impulsive, and subconscious factors. Moreover, recent studies have highlighted the significant role of biological foundations, *particularly endocrine and neurotransmitter systems,* in financial decision-making processes. In this context, it is understood that these factors directly impact financial decision–making and economic behavior.

Testosterone and estrogen are steroid hormones derived from cholesterol that play crucial roles in biological processes. Testosterone is primarily produced in the *Leydig cells of the testes* in males, whereas females produce lower levels in the ovaries and adrenal glands. Widely recognized for regulating male secondary sexual characteristics, such as voice deepening, muscle development, and sperm production, testosterone also influences libido. On the other hand, estrogen is synthesized mainly in the ovaries, placenta, and adrenal glands in females and at lower levels in the testes in males. It regulates female secondary sexual characteristics, including breast development, menstrual cycles, and ovulation, and also it plays a significant role in brain function. Both hormones are lipophilic steroids capable of crossing the cell membrane and binding to specific intracellular receptors. Moreover, the interaction between testosterone and estrogen exerts profound effects on neurological function (Celec et al., 2015). Testosterone is notably implicated in modulating risk – taking behaviors, with evidence indicating sex – dependent differences in its effects. In males, increased testosterone levels are associated with a reduction in the volume of the medial orbitofrontal cortex (OFC), a structural variation linked to heightened risk-taking propensity. Conversely, females tend to exhibit a larger OFC, which appears to mitigate the risk-enhancing influence of testosterone (Peper et al., 2013). These findings contribute to a better understanding of the biological mechanisms underlying sex differences in hormone-driven behavioral responses.

Testosterone can also trigger behaviors derived from basic impulses such as anger and aggression, including risk-taking, competitiveness, dominance, courage, determination, and leadership. Central to these behaviors is the heightened activation of the *amygdala*, which mediates emotion, and fear-driven responses, and alterations in the *nucleus accumbens* (NAcc), which lead to an increased desire for reward and pleasure (Nofsinger et al., 2021). Moreover, testosterone has been shown to exert effects on brain regions associated with cognitive processes, such as the hippocampus and prefrontal cortex (PFC), where it enhances synaptic density and modulates neurotransmitter systems, thereby exhibiting neuroprotective properties that may delay cognitive aging (Apicella et al., 2008).

Although testosterone and estrogen are commonly known as male and female hormones respectively, both hormones are present in the bodies of all sexes (Vermeer et al., 2016). Their effects are not limited to sex – specific functions but also have broad implications in cognitive and neurological domains. Beyond their roles related to sex characteristics, testosterone significantly influences the direct alteration of individuals' perceptions, attitudes, behaviors, and psychological states (Apicella et al., 2008). These effects are closely linked to an individual's genetic makeup and can impact neurological and economic behavior. For instance, in behavioral and neurofinancial contexts, these hormones exert direct and indirect influences on key issues such as loss, risk, ambiguity, motivation, cognitive functions, prosociality, impulsivity, and learning (Fairley et al., 2024). Moreover, environmental factors can modulate the effects of these hormones; for example, exposure to sunlight can affect hormone levels, which in turn may alter behavioral traits such as sexual drive, aggression, and competition. Such hormonal effects may manifest as collective behaviors in financial markets, with low testosterone levels in populations associated with reduced motivation and social decline (Barzilai, 2023).

Another important aspect related to testosterone is prenatal testosterone exposure, indicated by the 2D:4D ratio. This ratio is defined as the length of the index finger (2D) relative to the ring finger (4D), where a lower 2D:4D ratio reflects higher prenatal testosterone exposure. Conversely, a higher ratio indicates a greater influence of estrogen and is typically observed more frequently in females, which correlates with lower risk – taking tendencies. A low 2D:4D ratio, *meaning the index finger is shorter relative to the ring finger*, serves as a genetic marker associated with elevated prenatal testosterone levels, which may predispose individuals to increased risk-taking behavior. This hormonal influence can lead to more volatile investment preferences, greater financial risk-taking, and stronger presence in competitive environments (Nofsinger et al., 2018). Coates et al. (2009) found that traders with a low 2D:4D ratio tended to survive longer in the market and achieve higher profits. Furthermore, the gains and losses of high – *frequency traders over a 20* – month period were linked to their 2D:4D ratios, suggesting a relationship between this biomarker and financial success. Prenatal testosterone exposure also shapes financial decision–making processes over the long term, with elevated prenatal testosterone levels potentially guiding individuals toward more volatile investments, highlighting the enduring impact of early hormonal influences on economic behavior (Nofsinger et al., 2018).

Another key aspect that helps us better understand sex differences in testosterone is that the average testosterone levels in males are 5- 10 times higher than those in females. These elevated levels contribute biologically to aggressive behaviors in men, whereas in women, estrogen plays a suppressive role over the effects of testosterone during youth. After menopause, as estrogen levels

decline, the influence of testosterone may become more pronounced, potentially leading to increased aggression in some women (McDermott et al., 2007). Although testosterone and estrogen sometimes exhibit opposing effects, testosterone's conversion into estrogen via the aromatase enzyme endowing it with certain estrogenic properties (Wood et al., 2024). Consequently, the effects of these hormones extend beyond biology to shape individuals' social and economic behavior. A thorough investigation of hormonal influences within neurofinancial and behavioral contexts will enhance our understanding of sex differences, neurological correlates of hormones, and behavioral tendencies. This paper synthesizes and discusses existing literature on the roles of sex hormones in loss, risk, ambiguity, reward, punishment, learning, motivation, cognition, impulsivity, and prosociality from both behavioral and neurofinancial perspectives.

Interactions with Other Neurotransmitters

Testosterone can shape risk-taking decisions through its interaction with serotonin-like neurotransmitters (Apicella et al., 2015). This interplay exerts a strong influence on emotional and cognitive control during individuals' financial decision–making processes. Specifically, the effect of testosterone involves an interaction with the dopaminergic system in the brain's reward centers, potentially increasing preferences for risky rewards. In other words, testosterone may disrupt emotional balance and promote impulsive behaviors (Mehta et al., 2015a), which can result in behavioral outcomes such as excessive risk-taking or, conversely, aversion. Conversely, the interaction between estrogen and serotonin modulates risk and ambiguity decision–making toward greater flexibility and emotionality (Hampson, 2018). Estrogen increases serotonin receptor density and interacts with serotonin to enhance emotional regulation and foster more controlled long-term decision–making. As estradiol levels increase, women tend to make more deliberate and future-oriented decisions. Additionally, the estrogen-serotonin interaction may cause fluctuations in women's preferences in competitive and risky environments (Wozniak et al., 2009). By modulating serotonin receptors and metabolism, estrogen influences emotional state regulation and alters serotonin signaling during stressful situations, thereby effecting decision–making processes (Hubbard et al., 2016).

The interaction between testosterone and serotonin can significantly influence cognitive control processes. Variations in testosterone levels may affect individuals' cognitive abilities, particularly in areas such as decision–making, problem-solving, and planning (Oefelein et al., 2000). While serotonin plays a stabilizing role in mood regulation and impulse control, testosterone tends to enhance risk-taking and competitive behaviors. This contrast provides critical insights into how the balance between testosterone and serotonin can shape decision–making mechanisms (Stanton, 2017). In scenarios where serotonin levels are predominant, the stimulatory effects of testosterone on risk-

taking may diminish. This indicates that the testosterone and serotonin systems play opposing but interactive roles in financial decision–making processes (Ferjančič et al., 2024). Furthermore, this interplay highlights the importance of their joint influence on the regulation of biological and psychological functions. Through its interaction with the serotonin system, testosterone may exert neurobiological effects on emotional states, anxiety, and social behavior (Apicella et al., 2015), underscoring the value of assessing both hormones concurrently. On the other hand, testosterone's potential suppression of the serotonin system can amplify risky decision-making and lead to irrational behaviors (Nadler et al., 2018). However, prenatal testosterone levels may support the functional development of serotonin circuits, facilitating rational, patient, and cognitively demanding financial decisions and offering a new perspective on the biological underpinnings of risk-taking behavior (Bosch–Domènech et al., 2013).

The interaction between testosterone and estrogen with the dopaminergic system differentiates risk-taking behavior across genders. Under the influence of testosterone, men tend to make bolder and riskier decisions, whereas women, influenced by estrogen, are generally more cautious and deliberate in their choices. Estrogen increases female sensitivity to dopaminergic agents such as amphetamines, which may further amplify their risk-averse tendencies (Orsini et al., 2016). In this interplay, testosterone modulates reward processing by enhancing dopamine release, which can drive individuals toward higher risk-taking and preference for immediate rewards. Its influence on dopamine transporters and receptors plays a key role in shaping financial decision–making in reward–related contexts (Herbert, 2018; Apicella et al., 2014). Conversely, the dopamine-estrogen interaction leads to more cautious and calculated risk assessment in women. Elevated estrogen levels are associated with increased patience and a preference for long-term rewards, guiding decision-making toward more deliberate outcomes. Through its modulation of dopamine, estrogen may also contribute to reduced impulsivity in female behaviors (Smith et al., 2014).

Testosterone increases risk-taking tendencies, while high cortisol levels generally promote risk aversion and cautious behavior. Elevated testosterone levels can drive investors who have experienced losses to take greater risks, whereas high cortisol levels tend to support more conservative decision-making approaches (Nofsinger et al., 2018). The interaction between testosterone and cortisol plays a critical role in understanding how hormones influence behavior. The 'Dual Hormone Hypothesis' posits that testosterone enhances behaviors such as aggression and dominance only when cortisol levels are low; however, meta-analyses suggest that cortisol modulates the effects of testosterone and that this relationship does not hold uniformly across all contexts (Nadler et al., 2021). While testosterone can facilitate more controlled and strategic decision-making processes, cortisol is typically associated with low-risk choices. As cortisol is a stress-related

hormone, it increases the tendency to opt for safer options and reinforces risk aversion. In contrast, testosterone influences response inhibition and cognitive control, playing a distinct role in risk assessment. Therefore, the interaction between testosterone and cortisol can affect individual decision-making in diverse ways (Shields et al., 2019). Moreover, neurotransmitters such as serotonin and cortisol indirectly shape the influence of testosterone on social status and risk-related decisions. The interplay between testosterone and cortisol exerts a strong influence on social behavior and risk-oriented decision-making. Testosterone and serotonin are key in determining risk tolerance, social motivation, and fear responses, whereas cortisol and serotonin help regulate these processes (Sherman et al., 2016). Ultimately, the interaction between testosterone and cortisol may also amplify impulsive and aggressive behaviors. High testosterone levels, when combined with low serotonin and cortisol levels, have been associated with intensified aggression and impulsivity (McDermott et al., 2007).

In Risk and Uncertainty

As widely recognized, the fundamental finding regarding sex hormones and risk is that testosterone tends to increase risk-taking behavior, whereas estrogen generally suppresses it (Orsini et al., 2021). One of the primary mechanisms linking testosterone to risk-taking is its association with aggressive tendencies. Another critical pathway is its inhibitory effect on cognitive activity in the prefrontal cortex, which leads to heightened impulsivity (Nave et al., 2017). Additionally, testosterone may induce *euphoria* and produce *dopamine-like effects*, which can reduce *anxiety* and promote *irrational risk-taking* behaviors often observed in situations such as financial bubbles (Desmoulins-Lebeault et al., 2023). Another significant factor through which testosterone promotes risk-taking is its capacity to weaken threat perception, allowing individuals to experience less internal conflict in the face of risk and underestimate potential losses (Wagels et al., 2017). These effects are shaped not only by genetic and environmental conditions but also by intra-individual variations, particularly among women across different phases of the menstrual cycle. Research indicates that hormonal fluctuations during these phases can influence mood, stress responses, and risk-taking behavior. Notably, testosterone levels tend to rise during ovulation, which has been linked to increased competitiveness, boldness, and aggression. Thus, both endogenous (naturally produced) and exogenous (externally administered) testosterone have been consistently associated with heightened risk-taking behaviors (Desmoulins-Lebeault et al., 2023; Cook & Crewther, 2019). The connection between testosterone and risk is reinforced by increases in impulsivity and intuitive decision-making (Nadler et al., 2018).

The increased tendency toward risk-taking may similarly reduce anxiety in ambiguous situations (Celec et al., 2015), thereby promoting bolder approaches and enabling individuals to make quicker and more decisive choices in the face of ambiguity (Stanton et al., 2021; Tan & Vyas, 2016). For instance, studies have shown that rats administered testosterone tend to adopt a ‘go big or go home’

strategy, making riskier choices rather than attempting to cope with ambiguity, suggesting a courageous rather than avoidant orientation toward risk (Wood et al., 2024). Furthermore, testosterone appears to increase risk-taking behavior specifically under ambiguous conditions by influencing emotional and preconscious processes, while such effects are diminished when risks are clearly known, indicating that testosterone's influence on deliberate, strategic decision-making may be limited. That is, testosterone may drive individuals to act more boldly in emotionally charged, high – pressure situations, but this effect tends to wane in contexts requiring logical evaluation and clearly defined risk assessments (Goudriaan et al., 2010). These unconscious effects can also lead to an increase in risky and disadvantageous decisions, as testosterone may disrupt the balance between reward and punishment processing, an impact particularly pronounced under ambiguity or potential loss (van Honk et al., 2004). Such hormonal influences are especially relevant in domains like entrepreneurial behavior or investment in high-risk financial instruments, such as cryptocurrencies (White et al., 2006). In contrast, estrogen generally supports more cautious and reflective decision-making processes, representing a different approach to coping with ambiguity (Smith, 2023). Finally, on a broader societal level, conclusions regarding the effects of sex hormones often rely on superficial interpretations. A nuanced understanding of how these hormones interact with biological sex differences and influence behavior during crises or financial decision-making requires careful consideration of complex social and cultural factors (Fisher, 2015).

Testosterone plays a significant role in coping with ambiguity. Increased testosterone levels encourage individuals to exert more effort and pursue new opportunities when faced with risky situations. The rise in testosterone following a loss is associated with the 'near–miss' effect, whereby individuals become more motivated and inclined to take greater risks when they come close to winning or achieving a goal (Vermeer et al., 2016). In this sense, elevated risk orientation also manifests as increased chasing behavior after losses (Sanchez-Pages & Turiegano, 2010). In summary, the shift in risk perception related to testosterone levels can lead to heightened reward-seeking behavior and excessive optimism (El Ahdab et al., 2023). This effect may also reduce avoidance behavior by promoting more composed and calculated decision-making (Armbruster et al., 2021). Notably, high testosterone levels tend to amplify these effects, whereas low levels may be associated with greater avoidance and loss aversion. However, this is not a universal rule: the effects of testosterone may also appear under hypoactivation, suggesting that the hormone follows an inverted-U function (as described by the Yerkes-Dodson Law), whereby moderate levels of testosterone are thought to influence aversive behavior most significantly (Stanton et al., 2011; Stanton, 2017). In other words, both excessively high and low testosterone levels may lead to marginal effects on risk-related behavior. Additionally, testosterone has implications for framing effects: under positive framing, *when individuals focus on potential gains*, testosterone may promote

increased risk-taking by encouraging a focus on rewards and opportunities. This may result in bolder decisions aimed at maximizing gains. However, under negative framing, *when attention is directed toward potential losses*, testosterone may lead to greater risk aversion, prompting more cautious and restrained decision-making. These two divergent framing effects are directly related to behavioral economics concepts such as loss aversion (Votinov et al., 2022).

On Rewarding and Learning Processes in the Brain

The role and influence of testosterone within the reward system is closely linked to risk-taking behavior, particularly through its action on the nucleus accumbens (Cook & Crewther, 2019; Nofsinger et al., 2021). In general, testosterone has been observed to enhance operant responses in situations where both reward and punishment are present, meaning individuals tend to exhibit stronger and more pronounced behaviors in response to outcomes associated with either rewards or penalties. This may lead individuals to make riskier decisions in pursuit of rewards while becoming less sensitive to the potential consequences of punishment (Tan & Vyas, 2016). Moreover, testosterone appears to shift individuals toward less submissive and more dominant responses to threats, thereby restructuring the functioning of reward and punishment systems. This can result in more aggressive and self-interested decisions in the face of social threats, allowing the reward-punishment mechanism to operate in a more strategic and calculated manner (Geniole et al., 2019). Testosterone also contributes to increased perseverative behavior, promoting persistent repetition of actions in pursuit of a goal (Wood & Serpa, 2020). Elevated testosterone levels may enhance sensitivity within the reward and punishment system and trigger behaviors described as 'moral aggression', characterized by punitive and aggressive responses (Burnham, 2007). Rising testosterone levels also strengthen individuals' inclination to seek future rewards. This phenomenon aligns with the 'Winning Hypothesis', which suggests that prior successes elevate expectations for future success and shape motivational orientations toward rewards. In this context, testosterone increases the perceived attractiveness of rewards and enhances the sense that future rewards are attainable (Oliveira & Oliveira, 2014).

Another important factor in the relationship between rewards and testosterone is impulsivity. Testosterone's effects on the dorsal striatum (DS) can lead individuals to prefer smaller, immediate rewards, which may influence the balance between rewards and punishment. Rather than increasing the subjective value of rewards, testosterone affects action-selection processes, potentially triggering irrational decisions, such as impatience. This can result in a preference for model-free (trial-and-error) learning strategies over model-based (future-oriented) strategies during the learning process (Laube et al., 2020). The relationship between reward and testosterone is also significant because testosterone increases the perception of reward particularly in definitive victories, and this enhanced perception

can reinforce motivation by increasing future competitive behaviors (Mehta et al., 2015c). Additionally, testosterone's influence on brain regions involved in reward processing may improve cognitive functions such as verbal memory and processing speed, thereby strengthening neurological functions related to learning and memory (Janowsky, 2006).

Estrogen, particularly through its modulatory effects on dopamine, facilitates more controlled and deliberate decision-making (Smith et al., 2014). Estrogen promotes patience in temporal reward preferences, thereby increasing the tendency to delay economic decisions (Takahashi et al., 2008). Additionally, estrogen modulates reward processing and emotional learning under stress by enhancing the activation of brain regions associated with reward and emotional memory, such as the ventral striatum and amygdala, which can lead to alterations in risk and punishment evaluation processes (Hubbard et al., 2016). Estrogen supplementation in males has been shown to reduce risky choices and decrease 'win-stay' behavior, illustrating how hormonal effects influence individual choices in decisions involving rewards and punishments. By increasing risk aversion tendencies, estrogen promotes cautious decision-making before focusing on rewards (Orsini et al., 2021). Finally, owing to its antioxidant properties, estrogen's neuroprotective role may have beneficial effects on both learning and reward anticipation processes (Marefati et al., 2019). These findings underscore the significant effects of testosterone and estrogen on decision-making processes, particularly regarding reward and punishment mechanisms, risk assessment, and learning strategies. Understanding how hormonal fluctuations shape individuals' economic and social decisions, especially in contexts involving rewards and punishments, is increasingly improving.

In Motivation

Testosterone serves as a key motivational driver of risk-taking behaviors in men, particularly in social contexts aimed at enhancing reproductive success, such as interactions with attractive women. This suggests that testosterone operates as an evolutionarily shaped motivational strategy, and men engage in risk-taking to gain greater opportunities in social and reproductive domains. Similarly, women may exhibit behaviors aimed at increasing their sexual attractiveness, and relevant hormones can lead women to engage in comparable risk-taking and strategic decision-making. The fundamental motivation for both sexes is to enhance reproductive success, although these strategies may manifest differently due to biological differences and social roles (Ronay & Hippel, 2010b). Testosterone influences not only sexual motivations but also social and economic decision-making processes, leading individuals to adopt more strategic and occasionally biased decisions to achieve their motivational goals. In terms of time horizon, testosterone emerges as a hormone that affects both short- and long-term motivations. Men with elevated testosterone levels tend to engage more in social interactions, seize opportunities, and interact with women. It has been observed that testosterone

strengthens these motivations particularly in situations where individuals perceive themselves as attractive and have high self-assessments. Thus, testosterone shapes overall motivational processes not only by enhancing sexual attractiveness and desire but also by promoting strategic decision-making in social and economic contexts (Goetz et al., 2024).

Testosterone directs individuals through motivations such as resource acquisition, status enhancement, and social competition (Stanton, 2017). The male-dominated nature of the financial sector, influenced by testosterone, tends to drive men to take greater risks and aim for larger gains, whereas the influence of estrogen is generally lower. This is because women are expected to be more cautious when making financial decisions (McDowell, 2010). Additionally, testosterone is a key hormone that supports individual self-confidence, entrepreneurial tendencies, and leadership motivation. By boosting individuals' self-confidence, testosterone encourages risk-taking and greater effectiveness in leadership (Barzilai, 2023). This operates in a cyclical manner: testosterone increases motivation according to individuals' expectations of success and gains, and this heightened motivation directs them toward financial risks. In particular, as success and earnings are achieved, rising testosterone levels further encourage investors to take more risks (Njegovanović, 2018). Conversely, decreased testosterone levels can reduce motivation, negatively impacting individuals' desire and effort to achieve personal goals (Oefelein et al., 2000). Lower testosterone levels may lead individuals to exhibit more cautious, reserved, and dependent behaviors, fostering decisions that involve less risk-taking and greater cooperation, potentially contributing to more collectivist social structures (Barzilai, 2023).

Testosterone can shape motivational processes, leading individuals to take higher risks and make erroneous decisions. Moreover, by disrupting the balance between reward expectation and motivation, it encourages greater risk-taking for larger rewards (Wood & Serpa, 2020). In financial markets, this motivation can manifest as excessive confidence and risky investment decisions (Nadler et al., 2015). Testosterone can enhance motivation by increasing reward expectancy through reward systems such as the ventral striatum, particularly in individuals with low motivation. However, this effect is not observed in individuals with high motivation, indicating that the hormone exerts a variable influence depending on motivational state and highlighting a complex mechanism modulating neurofinancial decision-making processes (Oliveira & Oliveira, 2014).

On Cognitive Decision-making

Estrogen and testosterone possess neuroprotective and antioxidant properties biologically, enhancing neurogenesis and neural plasticity, thereby providing protection against stress and neurodegenerative diseases such as Alzheimer's, Parkinson's, Huntington's, Multiple Sclerosis (MS), and Amyotrophic Lateral Sclerosis (ALS). These hormones directly or indirectly preserve and strengthen the cognitive

structure of the brain. Estrogen additionally reduces neuroinflammation, preventing cognitive decline and potentially exerting positive indirect effects on decision-making processes in the brain (Duncan, 2020). The biological effects of sex hormones manifest in individuals' decision-making and behavioral mechanisms as well as psychological and psychopathological conditions. Testosterone modulates cognitive subsystems involved in decision-making, such as risk-taking, memory, attention, and mechanistic processing (Janowsky, 2006). Furthermore, testosterone and estrogen enhance abstract reasoning abilities, providing significant benefits in situations that require rapid decisions under stress and ambiguity (Nicolaou et al., 2018). Testosterone influences executive functions, such as cognitive flexibility and working memory, via effects on the prefrontal cortex, whereas estrogen shows prominent modulation, particularly on working memory and cognitive control. Specifically, testosterone's effects on the ventromedial prefrontal cortex (vmPFC) and estrogen's influence on the dorsolateral prefrontal cortex (dlPFC) are associated with improved performance in tasks involving cognitive flexibility and information manipulation (Trahms et al., 2010). The positive effects of estrogen on the prefrontal cortex during the early postmenopausal period may enhance women's cognitive flexibility and economic decision-making processes, indicating that estrogen influences not only cognitive control but also financial and economic decisions (Girard et al., 2017).

The temporo-parietal junction (TPJ) in the brain plays a crucial role in social cognition and attributing value to others, and testosterone has been found to suppress activity in this region, thereby reinforcing selfish and short-term decision-making tendencies (Ou et al., 2021). This finding highlights how testosterone modulates social and cognitive processes. However, the accelerating effect of testosterone on cognitive processes has both advantages and disadvantages. Increased cognitive speed facilitates the use of heuristics and System 1 thinking for rapid outcomes, but it can also lead to intuitive, reactive behaviors and irrational decisions (Nadler et al., 2018; Wu et al., 2018). These effects have multifaceted impacts on cognitive reflection and may result in different outcomes depending on specific variables (Stanton, 2017). Moreover, sex differences, age, cultural, and genetic factors also shape the relationship between sex hormones and cognitive function (Celec et al., 2015). Testosterone plays a significant role in cognitive domains, such as spatial memory, and when converted to estrogen, it can also affect verbal memory. This demonstrates that hormonal effects vary according to sex and cognitive domain (Janowsky, 2006).

Finally, prenatal exposure to testosterone (and/or estrogen) influences cognitive processes, particularly cognitive reflection and analytical thinking. The effects of these hormones shape the strategies that individuals use for decision-making and risk management. The 2D:4D digit ratio, a biological marker indicating prenatal testosterone levels, is associated with cognitive processing capacity; a lower 2D:4D ratio correlates with higher prenatal testosterone and enhanced cognitive

performance (Bosch-Domènech et al., 2014). Testosterone supports analytical thinking and cognitive reasoning abilities; notably, higher prenatal testosterone in females is linked to superior performance on the 'Cognitive Reflection Test' (CRT). Additionally, testosterone levels increase cognitive control capacity, enabling a more analytical and patient approach when faced with risky situations (Brañas-Garza & Rustichini, 2011; Bosch-Domènech et al., 2013).

In State of Impulsivity

Testosterone interacts with the brain's reward processing networks by increasing dopamine release, which in turn activates the dorsal striatum (DS). DS enhances the appeal of short-term rewards, thereby promoting impulsive and impatient decision making. Elevated testosterone levels strengthen the tendency to seek immediate gratification and rewards rather than engage in long-term thinking (Laube et al., 2020). Additionally, testosterone's influence on orbitofrontal cortex weakens impulse control, leading to increased aggression and risk-taking behaviors, which results in more impulsive decisions (Oliveira & Oliveira, 2014). In this context, high testosterone levels encourage greater risk-taking and bold decision-making during social interactions, consequently increasing impulsivity (Smith & Apicella, 2017). While testosterone may drive individuals toward aggressive strategies, lower testosterone levels tend to promote more controlled and deliberate decision making (Mehta et al., 2017). This suggests that when testosterone levels are elevated, individuals are more prone to perceive short-term risks, make faster decisions, and target immediate rewards (Nofsinger et al., 2018). Moreover, testosterone can impair emotional regulation and punishment avoidance functions, contributing to more speculative, risky, and uncalculated choices (El Ahdab, et al., 2023). Testosterone particularly increases impulsivity in unconscious and automatic decision processes, whereas high levels may also reduce emotional reactivity, leading to more calculated, risk-based decisions. On the other hand, estrogen counterbalances this impulsivity by exerting a regulatory effect (Goudriaan et al., 2010).

Estrogen enhances cognitive processing and the ability to evaluate emotional states, thereby promoting avoidance of impulsivity and indicating a decision-making approach that involves greater control and patience (Bhattacharjee et al., 2021). The opposing effects of testosterone and estrogen in this domain represent a significant factor differentiating decision-making process (Knight et al., 2022). However, very low levels of both testosterone and estrogen can also produce similar effects. This phenomenon is known as the 'Inverted-U Effect' where decision-making tendencies become more neutral or even less impulsive when hormone levels are either excessively low or high (Barel et al., 2017; Takahashi et al., 2006). Moderate levels of testosterone are associated with more risk-averse and cautious behaviors toward ambiguity, whereas very low or high levels increase the likelihood of impulsive decisions (Stanton et al., 2011).

These hormones can also weaken emotional and cognitive control, leading to faster and sometimes irrational decisions, which may result in excessive trading and prices exceeding their fundamental values in markets (Nadler et al., 2018). Elevated testosterone levels contribute to impulsive and bold financial decisions, creating positive feedback loops such as the 'winner effect'; as an individual wins, they take increasingly greater risks, which can lead to further gains or losses, perpetuating a self-reinforcing cycle (Coates & Herbert, 2008). However, this cycle may manifest as an *overconfidence bias*, where individuals overestimate their own behaviors and engage in excessive risk-taking that ultimately sabotages themselves (Dalton & Ghosal, 2018). Lastly, the association between testosterone levels and delay discounting suggests that the hormone plays a significant role in decision-making process involving ambiguity and is one of the factors influencing such behaviors. This finding is important for understanding how people perceive risk and ambiguity when evaluating future rewards (Doi et al., 2015).

Prosociality – Altruism – Empathy

Individuals with high testosterone levels tend to make moral decisions in a more calculated and utilitarian manner, exhibiting reduced emotional responses and a more self-interested approach. The influence of testosterone extends beyond physical aggression to affect emotional insensitivity and cold, deliberate decision-making processes, offering significant insights into how hormones shape moral and financial behaviors. Specifically, testosterone decreases generosity towards socially distant individuals, impacting the perception of social distance during decision-making and potentially leading to more impulsive and spontaneous actions (Wu et al., 2019; Armbruster et al., 2021). In this context, elevated testosterone may cause individuals to prioritize personal gain, weakening prosocial behaviors such as empathy and cooperation in social settings. High testosterone levels promote a more calculating and self-centered approach in interpersonal interactions, particularly in financial and competitive situations, while also limiting emotional regulation and empathy skills (Zak et al., 2009). Moreover, in men, this hormonal profile increases social discounting rates and induces cautious behavior regarding unreciprocated help, leading to heightened risk perception under ambiguity and, consequently, reduced generosity (Olson et al., 2016). However, testosterone can also reduce experiences of stress and fear, enabling more pragmatic and socially beneficial choices in moral decision-making. Nevertheless, this effect varies depending on prenatal hormone exposure and individual differences (Montoya et al., 2013).

The effect of testosterone involves the incorporation of social factors such as justice, reputation, and competition into decision-making process. High testosterone levels increase risk perception and resistance to social challenges, leading to more confrontational and courageous decisions (Burnham, 2007). Furthermore, testosterone's impulsivity-enhancing effect can promote risk-taking behaviors

and social competition (Garcia et al., 2017). In this context, testosterone elicits sharper responses to ambiguity in men, whereas estrogen supports more flexible, empathetic, and emotionally driven decision-making process in women (Olson et al., 2016). Estrogen's modulatory effects on social behaviors can control impulsivity, especially in contexts involving social memory and recognition (Garcia et al., 2017). However, testosterone can reduce trust in both men and women (Herbert, 2020, pp. 52 – 56). Additionally, testosterone influences the oxytocin and vasopressin systems, enhancing social bonding and empathy, which in turn promotes prosocial behaviors and a greater tendency to cooperate in social interactions (Garcia et al., 2017). Consequently, increases in testosterone levels suppress empathy, generosity, honesty, and prosocial behaviors, while amplifying punitive tendencies and strategic self-interest motivation (Zak et al., 2009; Serpell & Cook, 2021).

Individuals with high testosterone levels tend to exhibit reduced emotional responsiveness and adopt a more self-interested approach, making moral decisions that are more calculating and utilitarian. The influence of testosterone extends beyond physical aggression to affect emotional insensitivity and cold decision-making processes, providing important insights into how these hormones shape individuals' moral and financial behaviors. Testosterone particularly decreases generosity toward socially distant individuals, altering the perception of social distance in decision-making and potentially leading to more impulsive and spontaneous actions (Wu et al., 2019; Armbruster et al., 2021). In this context, elevated testosterone levels may weaken prosocial behaviors such as empathy and cooperation within social settings by promoting greater self-interest. Moreover, high testosterone levels are associated with more calculating and selfish behavior in interactions, *especially in financial and competitive situations*, while simultaneously limiting emotional regulation and empathy skills (Zak et al., 2009). This effect increases social discounting rates among men, leading to cautious behavior regarding unconditional helping and heightened risk perception under ambiguity, which results in reduced generosity (Olson et al., 2016). On the other hand, testosterone may reduce individuals' experience of stress and fear, enabling more pragmatic and community, oriented choices in moral decision-making. However, this effect varies depending on prenatal hormone exposure and individual differences (Montoya et al., 2013). Thus, testosterone's influence on decision-making can lead individuals to act either more selfishly or more strategically and utilitarian, balancing personal interests with social contexts.

Discussion

Behavioral finance possesses a multidisciplinary structure nourished by fields, such as neuroeconomics and neuropsychopharmacology, integrating a wide range of factors that influence investor behavior. In this context, it encompasses diverse determinants ranging from herd behavior (Medetoğlu & Saldanlı, 2019; Keskin & Aytüre, 2025), the hormonal basis of financial decision-

making (Erkan & Kavas, 2022), and loss aversion tendencies (Köroğlu, et al., 2022) to anxiety and personality-driven behavioral differences (Çömlekçi & Şamandar, 2019), market anomalies (Tufan & Sarıçiçek, 2013), emotional and cognitive factor, and psychological aspects, such as overconfidence (Keskin, 2022, 2025). Building on these behavioral perspectives, neurofinance extends the scope of analysis by incorporating biological and neurological mechanisms underlying financial decision-making.

In the context of neurofinance, the endocrine system and neurotransmitters directly or indirectly influence numerous individual, societal, economic, and financial outcomes (Zak & Fakhar, 2006). In particular, testosterone affects individuals' risk-taking tendencies and often leads to bolder decisions, especially under uncertain and emotional conditions. This effect can strengthen the desire to compensate for losses and encourage risk-involving behaviors. In contrast, estrogen may promote more prudent decision-making. The effects of these hormones vary depending on genetic and environmental factors, as well as influences such as the menstrual cycle, while social and cultural contexts also shape these behaviors. Furthermore, testosterone impacts reward and punishment systems by motivating individuals to exert greater effort toward rewards, whereas simultaneously desensitizing them to punishment. This hormone encourages aggressive and persistent behaviors and elevates reward expectancy, making future successes appear more attractive and valuable. On the other hand, estrogen facilitates more controlled and patient decisions by extending expectations, increasing the willingness to delay gratification, and modulating reward processing and emotional learning under stress.

Testosterone influences individuals' self-confidence, thereby affecting leadership, entrepreneurship, and financial decision-making; however, motivation loss and more hesitant behaviors may emerge when testosterone levels decline. This hormone shapes motivational processes, increasing risk-taking tendencies, yet it can also lead to overconfidence and erroneous decisions. Testosterone and estrogen enhance brain functions through neuroprotective and antioxidant effects, promoting neurogenesis and cognitive plasticity while providing protection against stress and neurodegenerative diseases. Testosterone affects risk and decision-making processes, often playing a guiding role that can result in rapid and sometimes irrational choices, but it also strengthens cognitive functions such as cognitive flexibility and working memory. Estrogen improves cognitive control and economic decision-making, enhancing women's cognitive flexibility. Additionally, factors such as prenatal hormone exposure and the 2D:4D digit ratio influence cognitive processing capacity and analytical thinking abilities. Conversely, testosterone impacts the brain's reward-processing networks, increasing impulsive and fast decisions, promoting focus on immediate rewards, and reinforcing aggressive behaviors. Estrogen, on the other hand, facilitates more controlled and patient decision-making,

balancing impulsivity. The levels of both hormones play crucial roles in decision-making processes, where excessively low or high levels can lead individuals to adopt more neutral or highly impulsive decision styles. Finally, elevated testosterone levels tend to direct individuals toward a more calculating and self-interested approach, reducing emotional responsiveness and weakening empathy in social contexts. Particularly in financial and competitive situations, testosterone may promote more selfish and strategic decisions, potentially hindering prosocial behaviors. However, the effects of these hormones vary based on individual differences and prenatal hormone influences. In some cases, they may reduce stress and fear, enabling more pragmatic choices that benefit society.

In conclusion, scientific evidence strongly supports that hormones, particularly endocrine factors such as testosterone and estrogen, significantly shape individuals' economic and financial decision-making processes. The effects of these hormones are not solely rooted in biology but are also influenced by genetic, environmental, and social conditions. Moreover, biological markers such as prenatal hormone exposure and the 2D:4D digit ratio guide individuals' cognitive processes and decision-making abilities. Ultimately, financial and economic decisions are shaped by the interaction of hormones and neurotransmitters, and it is essential to consider these biological influences alongside social contexts and individual differences.

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