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Citation: Pezzulo, G., Nuzzi, D. & Rigoli, F. (2026). Why we value things more as we are about to lose them: A reference-based theory. *Neuroscience & Biobehavioral Reviews*, 184, 106613. doi: 10.1016/j.neubiorev.2026.106613

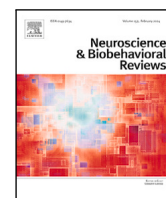
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Why we value things more as we are about to lose them: A reference-based theory

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ARTICLE INFO

Keywords:

Subjective value
Reference-based evaluation
Expectation
Scarcity

ABSTRACT

A common belief is that we only truly appreciate things or people when we are about to lose them. This phenomenon is often observed in real-world scenarios, such as when people place greater value on a meeting with a friend who is about to leave or, in marketing, when consumers are willing to pay more for a flight with only a few tickets remaining. But why does this happen? This paper explores the dynamics behind this behavior, focusing on how subjective value increases as reference standards – understood as expectations about the future availability of valuable events or opportunities – decline over time. We introduce a computational model to investigate how subjective value varies in response to shifting reference standards and uncertainty about them, leading to increased valuation as the expected future availability of events diminishes near a deadline. The model also demonstrates how this rising subjective value increases the likelihood of exerting effort to secure valuable opportunities before they are lost. Through simulations, we examine the psychological and economic implications of reference-dependent valuation. Our simulations show that the simple principle of a declining reference point as a deadline approaches explains shifts in subjective value and effort-based choices, providing a mechanistic account of phenomena previously linked to scarcity, FOMO, and related effects. This novel theory offers a testable, mechanistic explanation for why subjective value and effort-based decisions change over time, shedding light on reference-dependent behavior in both everyday and high-stakes decision-making contexts.

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1. Introduction

“It is loss which teaches us about the worth of things”. – Arthur Schopenhauer

In psychology and neuroeconomics, it is well documented that the impending loss of an opportunity or resource often enhances its desirability, as individuals become more attuned to its potential unavailability (Tversky and Kahneman, 1974; Kahneman and Tversky, 1979; Ariely, 2008). This effect is widely exploited in marketing strategies, such as limited-time offers, which capitalize on the increased perceived value of a product when availability is restricted (Cialdini, 2001). Similarly, in behavioral economics, the prospect of losing access to a resource can trigger heightened urgency and motivation (Frederick et al., 2002). More anecdotally, a common belief is that we only truly appreciate things or people when we are about to lose them. A classic example in marketing is when people are willing to pay more for a flight when only few tickets remain available. Understanding the mechanisms behind these changes in subjective value is crucial for developing a comprehensive framework of human valuation and motivation. However, a fundamental question remains: why do we tend to assign more value to something that we are about to lose or that is available for only a short period?

Classical accounts of this phenomenon rest on influential psychological frameworks, including the scarcity principle (Cialdini, 2001), commodity theory (Brock, 1968), and the fear of missing out (FOMO) (Przybylski et al., 2013). The scarcity principle states that items become more attractive as they become less available, an idea extensively applied in marketing and decision-making research. Relatedly, commodity theory posits that scarce items are perceived as more valuable and desirable than those that are readily available; see Lynn (1991) for a review of empirical evidence supporting this claim. The concept of FOMO extends these ideas to social and digital contexts, highlighting how individuals' anxiety about missing rewarding opportunities or experiences can drive heightened engagement and impulsive behavior (Przybylski et al., 2013). However, while these explanations capture behavioral tendencies, they remain largely descriptive rather than mechanistic. Concepts like scarcity, commodity, and FOMO appeal to observed effects but do not explain why people exhibit these behaviors or what underlying cognitive or computational processes generate changes in subjective value. A complete account requires a formal, predictive model that specifies why and how subjective value shifts in response to expectations about the future unavailability of opportunities.

Furthermore, the same theoretical framework should also account for how increases in subjective value enhance the motivation to exert effort in order to secure such opportunities. Previous computational models have examined how effort exertion changes as a function of approaching deadlines. In general, effort-based decisions can be modeled as a comparison between the costs of investing effort and the associated benefits (Shenhav et al., 2013; Kool and Botvinick, 2018; Botvinick and Braver, 2015; Parr et al., 2023; Proietti et al., 2025; Rangel et al., 2008). At each point in time, observed effort can be described as increasing with the subjective value of an event and decreasing with the cost required to secure it (Shenhav et al., 2013; Kurzban et al., 2013; Klein-Flügge et al., 2016). Therefore, if subjective value increases near a deadline – when one is about to lose a valued opportunity – the willingness to exert effort increases as well, as documented empirically (Bonezzi et al., 2011; Emanuel et al., 2022). The key question is, again why subjective value increases. The model proposed by Emanuel et al. (2022) suggests that what changes as a deadline approaches is the

opportunity cost, defined as the value of the best foregone alternative. For example, when a person is engaged in a focal task (e.g., studying) and a deadline draws near, the value of alternative tasks (e.g., playing video games) decreases, since they can be postponed until after the deadline with minimal cost. Moreover, selecting an alternative task becomes intrinsically more costly, as compensating for the lost time to complete the focal task becomes increasingly difficult. However, by emphasizing opportunity costs and the competition between focal and alternative activities, the model does not directly address whether the subjective value of a task or event – such as visiting a friend who is about to leave or securing a limited-time offer – can change in itself, independent of the availability of alternatives.

The issue of how subjective value changes over time is also key in computational models of procrastination—a widespread finding being that people tend to delay effortful tasks. A key insight across many of these proposals is that, as a deadline approaches, the subjective evaluation of reward changes due to temporal discounting (Akerlof, 1991; O'Donoghue and Rabin, 1999; Durakiewicz, 2016; König and Kleinmann, 2005). People might therefore delay initiating a task because they initially undervalue its outcome, whereas as the deadline approaches, the perceived value and urgency of the task increase. Assuming that value discounts follow hyperbolic functions – meaning they decrease more steeply over time – models such as temporal motivation theory predict preference reversals (Steel, 2007). Specifically, exerting effort for a greater reward may seem less valuable than opting for a smaller, immediate gain when the deadline is distant, but more valuable as the deadline approaches. Other models suggest that not only reward value but also effort cost may be discounted, though possibly at different rates. For example, if, when evaluating a future opportunity, the required effort is underweighted relative to the future reward, the opportunity can seem appealing initially but unattractive when the time comes to act (Soman, 1998). Similarly, procrastination may arise because the discounting function is steeper for effort than for reward, meaning that postponing a task feels much less effortful, but not much less rewarding, compared to doing it immediately (Le Bouc and Pessiglione, 2022). However, these models assume that the subjective value and urgency of events increase merely as a function of temporal proximity, without providing a mechanistic explanation for why this change occurs or how other factors, such as uncertainty, modulate the process.

In this study, we offer a novel account of why subjective value and effort-based decisions change over time, and in particular when individuals anticipate losing something, drawing on a reference-based theory of subjective value. According to this perspective, valuation depends on dynamically shifting reference points or standards (Rigoli and Pezzulo, 2022; Bhui et al., 2021; Köszegi and Rabin, 2006, 2007; Louie et al., 2013; Woodford, 2012). Reference-based theories propose that an event's perceived value can increase as external or internal standards decline. Crucially, we assume that the standard reflects expectations about the future availability of valuable events, such as meeting a friend, finding a good job, or encountering a valuable marketing offer from now on. Moreover, the uncertainty around the standard captures the degree of confidence in these expectations.

Based on this principle, we suggest that a meeting with a friend feels more valuable when the friend is about to leave, a job offer appears more attractive when market conditions worsen, and a marketing offer seems more valuable as it nears expiration, due to a lowered reference point, reflecting diminished expectations of future opportunities. This effect is further amplified when uncertainty about the standard is low, indicating high confidence in the expectation of losing these opportunities. Likewise, a lowered reference point increases the motivation to exert effort to obtain a valued event, such as spending extra time with a

friend, intensifying job applications, or queuing early at a store to claim a limited-time offer. This paper quantitatively models this effect and examines how subjective value and effort allocation evolve in response to shifting expectations.

In sum, this paper has a dual objective. First, it advances the idea that subjective value is shaped not by opportunity costs or temporal discounting, but by changing expectations about an event's future availability—and the uncertainty surrounding those expectations. Second, it shows that a declining reference point as a deadline approaches – reflecting diminishing expectations of future opportunities – provides a mechanistic basis for shifts in subjective value and effort-based decisions as opportunities become scarce, offering a potential explanation for phenomena linked to scarcity, FOMO, and related effects.

In the remainder of this article, we formally introduce our reference-based theory of how the subjective value of an event (e.g., meeting a friend) and the associated effort-based decisions (e.g., whether to invest effort in meeting the friend) change as reference standards, reflecting expectations about future availability, shift (e.g., when the friend is about to leave). We then present simulations that manipulate reference standards and their associated uncertainty to examine their effects on subjective value and effort-based decisions. To preview our results, the simulations show that as expectations of future opportunities decline – such as when a friend is about to leave or a limited offer is about to expire – the subjective value of the event increases, especially under low uncertainty, leading to greater motivation and effort to secure it. Finally, we systematically discuss how our novel theory relates to prior accounts of shifting subjective value and effort, including phenomena such as scarcity, commodity theory, FOMO, temporal discounting, and opportunity costs. Together, our novel theory provides a mechanistic explanation of why people tend to value things more as they are about to lose them, with implications for psychology, neuroeconomics, and marketing.

2. Methods

In this section, we introduce the two fundamental equations that form the basis of our simulations, one for subjective value and one for effort-based decisions.

2.1. Modeling the reference

We propose that the subjective value of an event (or opportunity) is not static but depends on a dynamic reference point, which reflects the agent's expectations about the future availability of that event. Given an event with a fixed objective value O and a deadline time T , we define the objective value function over time as:

$$O(t) = \begin{cases} O, & \text{if } t < T \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

This function simply states that before the deadline, the agent can obtain the objective value O , whereas after the deadline, the opportunity is lost.

We define the reference $R(t)$ as the agent's expectation of this value over future times. Since $O(t)$ becomes zero after the deadline, the total future availability is finite. We assume that an agent estimating the reference computes a sample mean over a future window of length W , which can be interpreted as the agent's temporal horizon. The reference is thus given by:

$$R(t) = \mathbb{E}_k [O(t+k)] \approx \frac{1}{W} \sum_{k=0}^W O(t+k) = \begin{cases} O, & \text{if } t < T - W \\ O \left(\frac{T-t}{W} \right), & \text{otherwise} \end{cases} \quad (2)$$

This formulation captures the dynamics of availability: if the agent is far enough from the deadline ($t < T - W$), the reference standard coincides with the full objective value, $R(t) = O$. However, as time progresses and the deadline enters the agent's horizon ($t \geq T - W$),

the reference linearly decreases from O to 0. For example, consider an event valued at $O = 1$ and an agent with a 10-day horizon ($W = 10$). If the deadline is distant (more than 10 days away), the reference remains at the full value, $R = 1$. However, if the deadline is close, for instance, with only 3 days remaining, the reference drops to reflect the scarcity of future opportunities, becoming the ratio of the remaining time to the full horizon $R = 3/10 = 0.3$. Note that, in our formulation, subjective valuation only considers whether an opportunity is available (or not) between the moment the evaluation is made and the deadline, not how many times it can be obtained. As a result, the model treats events that can be repeated (e.g., meeting a friend) and events that are one-off (e.g., claiming a limited-time offer) in the same way.

Crucially, in scenarios involving multiple events, each event is evaluated against its own specific reference $R(t)$, determined by its unique objective value and deadline. Furthermore, we can account for the possibility that agents devalue distant future events relative to immediate ones. We introduce a discount factor $\gamma \in (0, 1]$ to future times by defining the reference as the discounted sample mean $R(t) = \mathbb{E}_k [\gamma^k O(t+k)]$. In this context, γ represents the agent's temporal focus; a lower γ indicates that the agent's expectation is driven primarily by the immediate future, whereas a γ close to 1 implies an equal weighting of the entire horizon. Introducing this discount factor causes the reference $R(t)$ to decrease non-linearly as the deadline approaches, accelerating the perceived loss of opportunity.

2.2. Modeling subjective value

Building on the definition of the reference $R(t)$, we model the subjective value of an event using a logistic function dependent on the difference between the objective value and the reference, modulated by uncertainty. As explained in [Rigoli and Pezzulo \(2022\)](#), the rationale is that subjective value is not determined in isolation, but, rather, in relation to expectations shaped by past experiences and contextual factors. When the reference standard shifts, the perceived value of the same event can change dynamically.

The subjective value function $S(R, O)$ is given by:

$$S(R, O) = \frac{1}{1 + e^{-\frac{O-R(t)}{\sigma}}} \quad (3)$$

where O represents the objective value of the event, $R(t)$ is the reference standard at time t as defined in Eq. (2), and σ represents uncertainty about the standard (with higher values reflecting greater uncertainty). An equivalent way to write Eq. (3) is $S(R, O) = \text{sigmoid}((O - R(t))/\sigma)$, where $\text{sigmoid}(x) = 1/(1 + e^{-x})$. In this formulation, the reference point $R(t)$ is subtracted from the outcome O , and the resulting difference is scaled by σ . The transformed quantity is then passed through a sigmoid function, ensuring that the resulting subjective value is bounded between zero and one. This approach is standard in contemporary models of reference-dependent evaluation (e.g., [Rigoli, 2019](#); [Rigoli and Pezzulo, 2022](#); [Zavlis et al., 2024](#)).

In this formulation, $S(R, O)$ represents the subjective value, which is distinct from the fixed objective value O . As the reference $R(t)$ declines over time, reflecting the diminishing expectation of future availability as the deadline approaches, the difference $O - R(t)$ increases. Consequently, the function shifts toward a higher subjective value. This illustrates how, as opportunities become scarcer, their perceived importance increases, even if their objective value remains unchanged. Additionally, the function exhibits nonlinearities due to the sigmoidal shape of the exponential term and includes the uncertainty parameter σ , which modulates the rate at which subjective value increases as standards decline.

In [Appendix A.1](#), we provide a formal proof demonstrating that a monotonic increase in subjective value over time is guaranteed whenever the reference $R(t)$ is monotonically decreasing, regardless of the specific functional form of that decline (e.g., whether linear or non-linear).

2.3. Modeling the choice between two events

In addition to modeling subjective value, we capture how declining standards influence the choice between two events, A and B , with objective values O_A and O_B .

Following the approach of Klein-Flügge et al. (2016), we compute the probability of choosing event A as a function the difference between the subjective values of the two events, A and B . The decision probability is:

$$P(\text{Event}_A) = \frac{1}{1 + \exp(-\beta(S_A - S_B - \Delta C))} \quad (4)$$

where $S_A = S(R_A, O_A)$ and $S_B = S(R_B, O_B)$ are the subjective values of the events and ΔC is the difference in the effort costs between them. The parameter β is an inverse temperature, assumed to be individual-specific, that controls sensitivity to the difference between the subjective values and effort costs of the two events. This formulation ensures that as the perceived benefit of an event increases relative to the alternative, driven by changes in the reference $R(t)$, the probability of choosing it also increases.

2.4. Modeling the decision to exert effort to secure a valuable event

Finally, we model how declining standards influence the willingness to exert effort to realize a valuable event. Most models of effort-based decisions assume that the probability of exerting effort increases with the subjective value of a reward and decreases with the associated effort cost, though they differ in their mathematical formulations (see, e.g., Shenhav et al. (2013), Kurzban et al. (2013), Klein-Flügge et al. (2016)).

Here, we compute the probability of choosing to exert effort to realize a valuable event, based on the difference between the subjective value of the event, $S(R, O)$, and an effort cost C , which we assumed to be fixed for simplicity. This model is particularly suited to contexts in which the choice concerns whether to exert effort to secure a valuable opportunity (e.g., whether to wake up early to claim an offer). The decision probability is derived from a logistic function:

$$P(\text{Effort}) = \frac{1}{1 + \exp(-\beta(S(R, O) - C))} \quad (5)$$

where $S(R, O)$ is the subjective value of the event and C is its effort cost. The parameter β is an inverse temperature, assumed to be individual-specific, that controls sensitivity to the difference between subjective value and effort cost.

Below, we illustrate simulations using the equations of subjective value, choice between alternative events, and effort-based decisions to simulate the effects of an approaching deadline. These simulations showcase the dynamic nature of subjective valuation and decision-making under time constraints.

3. Results

In this section, we present a series of simulations illustrating how declining reference standards influence the subjective value of opportunities and, in turn, choice behavior and the willingness to exert effort to secure them. We explore four distinct scenarios to show that our framework produces consistent qualitative behavior across varied contexts. In all simulations, unless otherwise stated, we assume an agent with a horizon window of $W = 10$ time steps. In the simulations of decisions between alternative events, we use the same inverse temperature parameter ($\beta = 10$), indicating relatively high sensitivity to differences in subjective value. Additionally, in all simulations except the third, we assume a time-invariant effort cost of $C = 0.8$ for all events, implying that the difference in effort costs (ΔC) is zero. While we select specific parameter values for illustrative purposes, we show in Appendix A.1 that the core result, a monotonic increase in subjective value and effort probability as the deadline approaches, holds generally, provided the reference standard declines over time.

3.1. Scenario 1: Two events with distinct objective values and the same deadline

In our first simulation, we consider a standard scenario where two events share the same deadline at $T = 11$. We define a high-value event with objective value $O_1 = 1.0$ and a low-value event with objective value $O_2 = 0.1$. We assume both events have the same effort cost $C_1 = C_2 = 0.8$. This setup parallels the real-world example of meeting a friend who is about to leave the country: O_1 represents a “long meeting” (highly desirable), while O_2 represents a “short meeting” (less desirable). We simulate the evolution of subjective value and effort probability under three distinct levels of uncertainty: low ($\sigma = 0.3$), medium ($\sigma = 0.5$), and high ($\sigma = 1.0$).

Fig. 1 presents the results. As the deadline approaches, the reference $R(t)$ for both events declines linearly from the objective value to zero (Fig. 1a). Consequently, the subjective value $S(R, O)$ for both events increases (Fig. 1b). This occurs because the denominator in Eq. (3) shrinks as the reference drops. Notably, the shape of this increase depends heavily on uncertainty: low uncertainty ($\sigma = 0.3$) produces a convex, rapidly accelerating rise in subjective value near the deadline, whereas high uncertainty ($\sigma = 1.0$) results in a flatter, more linear increase.

We next examine how these shifts affect decision-making. When the agent chooses between securing the high-value or the low-value event (Eq. (4)), the probability of selecting the former increases over time (Fig. 1c). This mirrors the “friend” example: as the departure date nears, the difference in subjective values between the highly and lower valued events increases—which in turn increases the probability to select the former. In this scenario, lower uncertainty (dark purple line) leads to a strictly higher probability of exerting effort compared to higher uncertainty (light pink line) throughout the timeline, as the agent is more confident in the widening value gap between the two events.

Finally, we consider the case in which the agent decides whether to exert effort to secure a valuable opportunity by comparing its subjective value against a fixed cost, set to $C = 0.8$, which lies between the objective values of the two events considered here (Eq. (5)). This scenario is analogous to the experiment by Emanuel et al. (2022), where participants must decide whether to invest physical effort (pressing buttons) to hit targets for points before a game ends. As shown in Fig. 1d, for the high-value event (blue lines), the probability of exerting effort rises sharply as the deadline approaches, consistent with the empirical finding that effort intensifies near the end of a task. For the low-value event (red/orange lines), the subjective value does not exceed the fixed cost, resulting in a consistently low probability of action regardless of the approaching deadline. This demonstrates that the scarcity effect amplifies motivation primarily for opportunities that are already deemed valuable.

3.2. Scenario 2: A time-constrained, high-value and high-cost event versus a permanently available, low-value and low-cost event

In our second simulation, we explore a scenario where one event is time-constrained and has a higher value and effort cost, while the other is permanently available and has a lower value and effort cost. The former event has higher value ($O_1 = 1.0$), higher effort cost ($C_1 = 0.8$), and a deadline ($T = 11$). The latter event has a lower value ($O_2 = 0.3$), lower effort cost ($C_2 = 0.5$) and no deadline. This setup captures the dilemma between a focal task, such as “finishing homework” due by a specific time (or the end of the day), and an alternative activity like “playing video games”, which is always available and has a constant objective utility.

Fig. 2 illustrates the results. For the homework task (O_1), the reference $R(t)$ declines linearly as the deadline approaches, mirroring Scenario 1. However, for the video game (O_2), because there is no

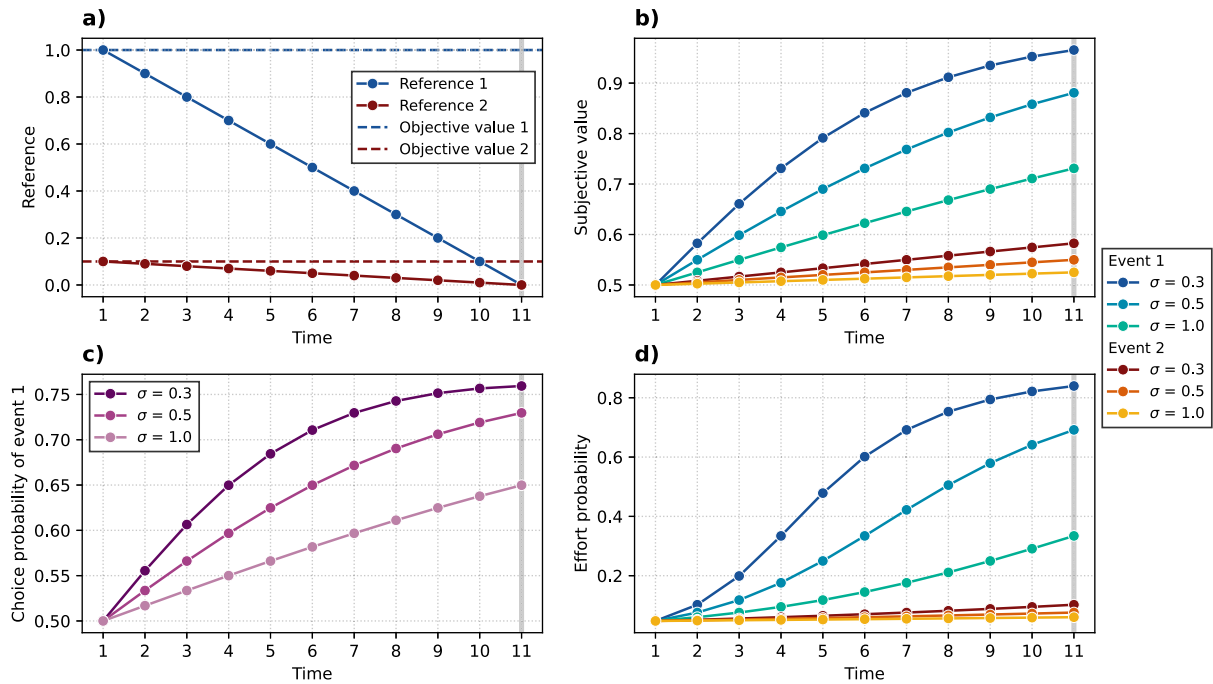


Fig. 1. Scenario 1: Distinct objective values, same deadline. (a) Evolution of the reference $R(t)$ for two events with objective values $O_1 = 1.0$ (blue dashed line) and $O_2 = 0.1$ (red dashed line). The reference (solid lines with markers) is computed as a moving average over a horizon $W = 10$, declining linearly as the deadline ($T = 11$) approaches. (b) Subjective value $S(R, O)$ for both events. The colors represent different levels of uncertainty: $\sigma = 0.3$ (darkest), $\sigma = 0.5$ (medium), and $\sigma = 1.0$ (lightest). Blue/green hues correspond to the high-value event (O_1), while red/yellow hues correspond to the low-value event (O_2). (c) Probability of selecting the high-value event (O_1) over the low-value event (O_2). Different shades of purple represent the uncertainty levels ($\sigma = 0.3, 0.5, 1.0$). (d) Probability of exerting effort to secure a valuable event against a fixed effort cost $C = 0.8$. Blue/green lines represent the probability for O_1 , and red/yellow lines for O_2 . The vertical gray line represents the deadline time.

deadline, the reference remains constant and equal to the objective value ($R(t) = O_2 = 0.3$) throughout the timeline (Fig. 2a).

The effect on subjective value is distinct for the two events (Fig. 2b). For the event with a deadline (O_1), subjective value rises as the reference drops. Conversely, for the event without a deadline (O_2), the subjective value remains constant at 0.5. This occurs because, when the reference equals the objective value ($O - R(t) = 0$), the exponent in the logistic function becomes zero, yielding $S(R, O) = 0.5$ regardless of the uncertainty level σ . Consequently, the three lines for O_2 (representing $\sigma = 0.3, 0.5, 0.8$) overlap perfectly in the plot. This highlights that uncertainty modulates the valuation only when there is a discrepancy between the objective value and the reference expectation.

As a consequence of this divergence, the probability of choosing to do homework over playing video games increases steadily (Fig. 2c). Initially, the agent prefers the low cost (“video games”) alternative, but as the deadline approaches, the specific “scarcity” of the homework opportunity boosts its value relative to the stable value of gaming, shifting the preference.

Similarly, when evaluating effort against a fixed cost (Fig. 2d), the probability of exerting effort for the homework increases sharply. In contrast, the probability of exerting effort for the video game remains constant. This successfully reproduces the intuition that approaching deadlines selectively enhance motivation for the urgent task without altering the appeal of stable alternatives.

3.3. Scenario 3: Two events with identical objective values and different deadlines

In our third simulation, we examine how the temporal distance to a deadline affects decision-making when two events have identical objective values ($O_1 = O_2 = 1.0$) and effort costs ($C_1 = C_2 = 0.8$) but different expiration times. The first event has an imminent deadline at $T_1 = 11$, while the second event has a later deadline at $T_2 =$

16. This scenario mirrors a common academic dilemma: a researcher plans to submit papers to two equally prestigious conferences, but the submission deadline for the first is imminent, while the second is due later.

Fig. 3 displays the results. A key feature of this simulation is the interaction between the deadlines and the agent’s time horizon ($W = 10$). As shown in Fig. 3a, the reference for the urgent event ($R_1(t)$) begins declining immediately at $t = 1$. However, for the less urgent event, the deadline $T_2 = 16$ is initially outside the agent’s 10-step time horizon. Consequently, $R_2(t)$ remains constant at the objective value of 1.0 until $t = 6$, at which point the deadline enters the horizon and the reference begins to drop.

This delay creates a temporal shift in subjective valuation (Fig. 3b) and effort against a fixed cost (Fig. 3d). The curves for the urgent event (O_2) are identical to those of the less urgent event (O_1), simply shifted by 5 time steps. For the first 5 steps, the subjective value of the less urgent event remains at baseline (0.5), while the value of the urgent event rises steadily.

The interaction between these dynamics is most evident in the choice probability (Fig. 3c), which we plot until T_1 (since the comparison becomes impossible once the first opportunity is lost). Initially, the probability of prioritizing the urgent event (O_1) increases, peaking at $t = 6$. This is because, in this first phase, only the subjective value of the urgent event increases. However, after $t = 6$, the deadline for the second event enters the agent’s time horizon, and its subjective value begins to rise. The relative advantage of the urgent event diminishes, decreasing the probability to select it. Notably, the decline in probability is steeper under low uncertainty, leading to an inversion around $t = 10$. This arises from a saturation effect: under low uncertainty, the subjective value of the urgent event quickly nears its maximum. Consequently, when the second deadline enters the horizon, the rapid increase in the second event’s value narrows the value gap more aggressively than under high uncertainty, where value adjustments are more

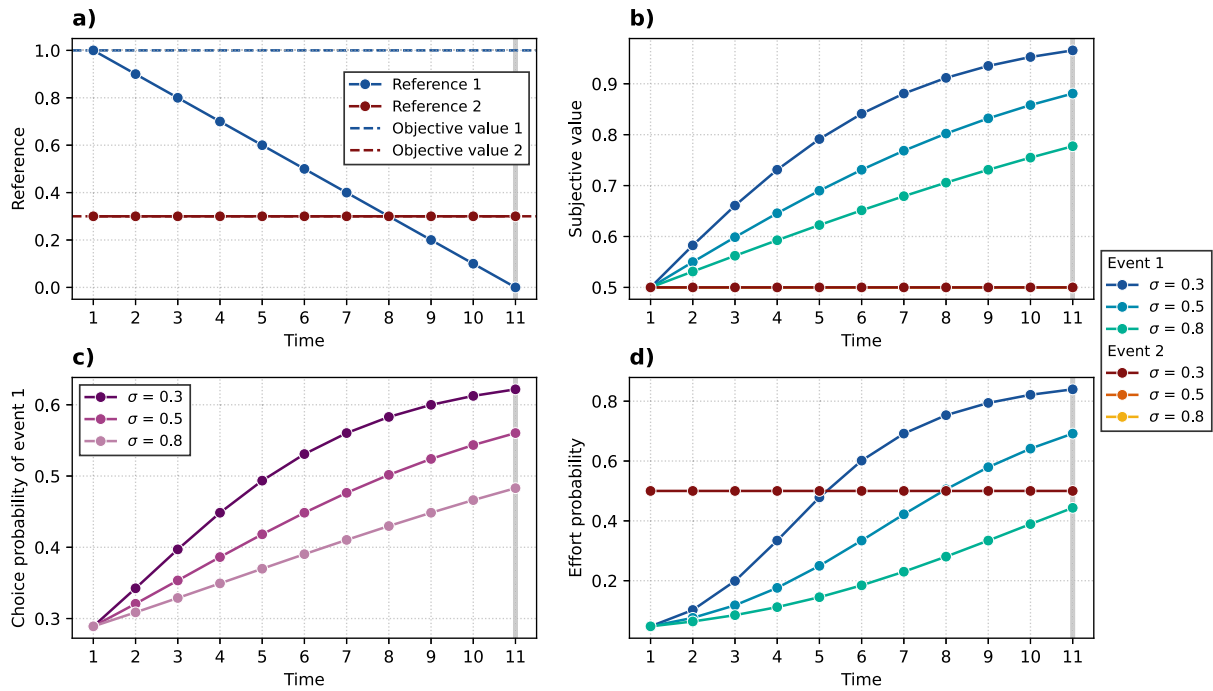


Fig. 2. Scenario 2: Imminent Deadline vs. No Deadline. (a) Evolution of the reference $R(t)$. $O_1 = 1.0$ (blue dashed line) has a deadline at $T = 11$, causing its reference (blue solid line) to decline. $O_2 = 0.3$ (red dashed line) has no deadline, so its reference remains constant at $R(t) = 0.3$ (red solid line). (b) Subjective value $S(R, O)$ for both events. For O_2 the lines overlap at $S = 0.5$ because $O_2 = R(t)$. The colors represent uncertainty levels: $\sigma = 0.3$ (darkest), $\sigma = 0.5$ (medium), and $\sigma = 0.8$ (lightest). (c) Probability of selecting the urgent event (O_1) over the stable event (O_2). (d) Probability of exerting effort to secure a valuable event against a fixed effort cost $C = 0.8$. The vertical gray line represents the deadline time for the first event. Note that different from the previous simulations, here the second event has no deadline. Furthermore, the two events have different effort costs ($C_1 = 0.8$ and $C_2 = 0.5$).

gradual. Despite this, the probability of selecting the first event (the most urgent paper) remains strictly above 0.5, indicating its persistent prioritization.

3.4. Scenario 4: Influence of temporal discounting

Finally, in our forth simulation, we explore the impact of the temporal discount factor γ . In the previous scenarios, we set $\gamma = 1$, implying that the agent weights all future moments within the time horizon W equally. However, as discussed in Section 2.1, a discount factor $\gamma < 1$ implies that the agent places less weight on future availability, causing the reference standard to decline non-linearly. To analyze this, we consider two events with objective values $O_1 = 1.0$ and $O_2 = 0.5$, both sharing a deadline at $T = 11$ with a horizon $W = 10$ and having the same effort cost $C_1 = C_2 = 0.8$. We fix the uncertainty at $\sigma = 0.5$ and compare three discount factors: $\gamma = 1.00$ (no discounting), $\gamma = 0.95$, and $\gamma = 0.90$.

Fig. 4 illustrates the results. As shown in Fig. 4a, the discount factor fundamentally alters the shape of the reference decline. When $\gamma = 1.00$ (blue/dark red lines), the reference decreases linearly. However, as γ decreases (lighter shades), the reference curve becomes concave, starting from a lower value, being more flat in the early stages and then dropping more rapidly in the later stages where it becomes more similar to the non-discounted case. This reflects the agent's reduced valuation of future availability: even when the deadline is distant, the "effective" future availability is lower because distant moments are heavily discounted.

This decline in the reference leads to an earlier increase in subjective value (Fig. 4b). For $\gamma = 0.90$ (green/yellow lines), the subjective value is significantly higher at $t = 1$ compared to the non-discounted case, as the agent perceives the resource as "scarcer" sooner.

Consequently, this shifts decision dynamics and the motivation to exert effort forward in time. The probability of choosing the high-value event (O_1) over the low-value event (O_2) starts at a much higher

baseline for $\gamma = 0.90$ than for $\gamma = 1.00$. This occurs because the absolute drop in the reference point is larger for the high-value event (O_1) than for the low-value event (O_2), leading to a wider gap in subjective value when discounting is strong. Similarly, when evaluating events against a fixed cost (Fig. 4d), the lower discount factor results in a higher probability of exerting effort throughout the timeline. This suggests that "impatient" agents (lower γ) who discount the future heavily may paradoxically appear *more* motivated to act early, as they do not fully consider the future availability of opportunities.

4. Discussion

It is often noted that we only truly appreciate things when we are about to lose them or when they are available only for a limited time. Various studies show that the impending loss of an opportunity or resource – such as the chance to meet a friend who is about to leave or the opportunity to buy an item with a limited-time offer – often increases its desirability, as individuals become more attuned to its potential unavailability (Tversky and Kahneman, 1974; Kahneman and Tversky, 1979; Ariely, 2008). In economics and marketing, the scarcity or unavailability of items is widely recognized as a factor that increases their perceived value and strongly influences consumer behavior (Cialdini, 2001; Brock, 1968). Scarcity – such as limited-time promotional offers – is among the most commonly used marketing strategies to persuade customers to make purchases. The concept of "fear of missing out" (FOMO) (Przybylski et al., 2013) is similarly assumed to reflect the anxiety or motivation that arises when individuals perceive that desirable opportunities are limited or may soon become unavailable.

However, mechanistic explanations for the increased appreciation of things as they become less available are lacking. In this study, we present a model that integrates reference-based subjective value and effort-based decision-making. It captures how individuals assess the value of events relative to a reference standard – representing an expectation about the future availability of events – and the uncertainty

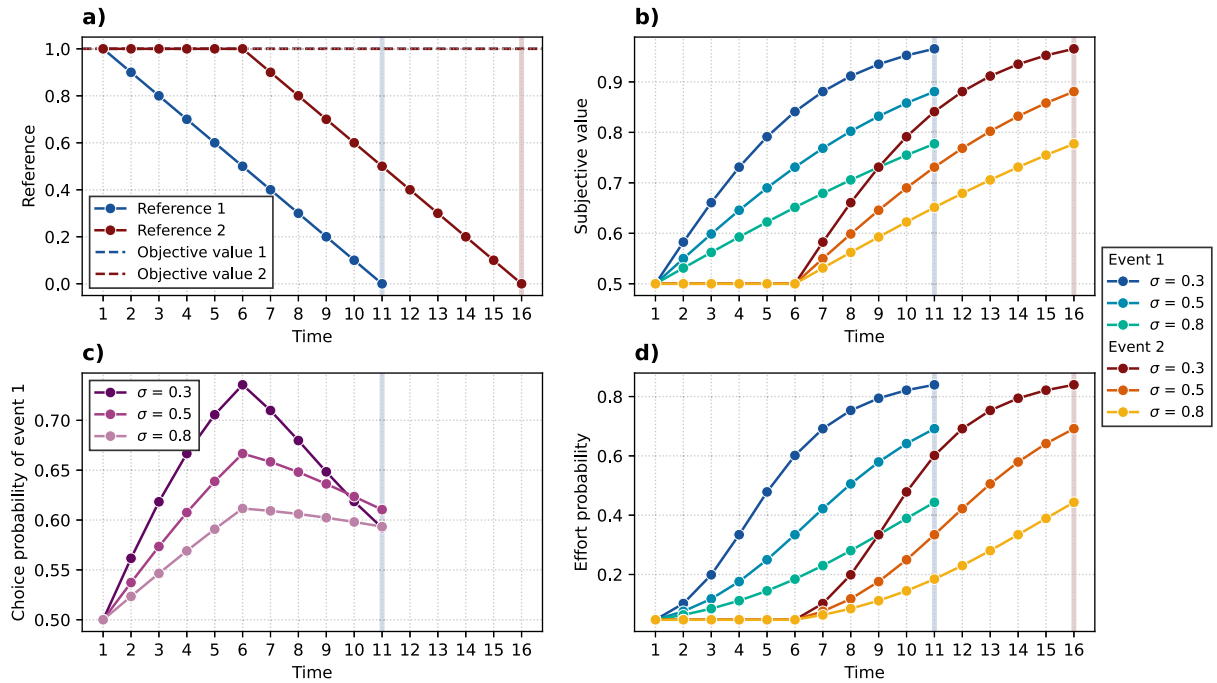


Fig. 3. Scenario 3: Different Deadlines with Identical Objective Values. (a) Evolution of the reference $R(t)$. Both events have objective value $O = 1.0$. O_1 (blue) has a deadline at $T_1 = 11$ (vertical blue line), while O_2 (red) has a deadline at $T_2 = 16$ (vertical red line). Note that R_2 remains constant until $t = 6$ because the deadline is outside the window $W = 10$. (b) Subjective value $S(R, O)$ for both events. The curves for O_2 are identical to O_1 but shifted by 5 time steps. (c) Probability of selecting the urgent event (O_1) over the later event (O_2). The probability peaks at $t = 6$ when the second deadline enters the horizon. The plot ends at $t = 11$ as O_1 expires. (d) Probability of exerting effort to secure a valuable event against a fixed effort cost $C = 0.8$. Uncertainty levels are $\sigma = 0.3$ (darkest), $\sigma = 0.5$ (medium), and $\sigma = 0.8$ (lightest).

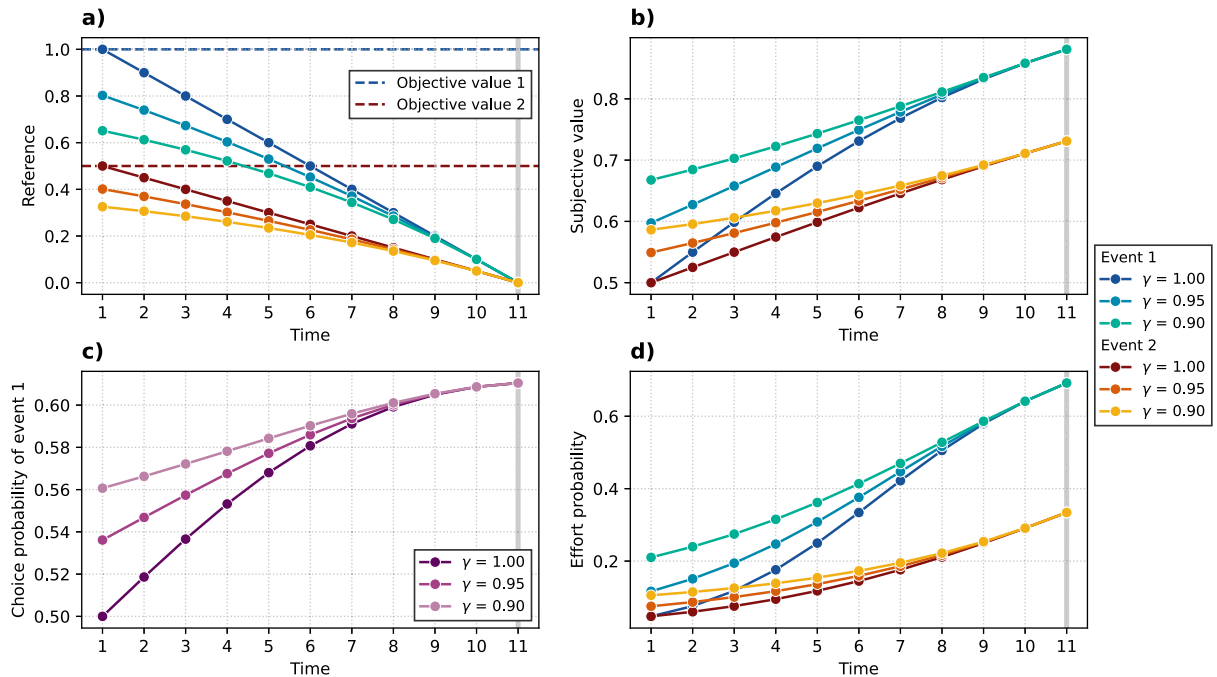


Fig. 4. Effect of the temporal discount factor γ . (a) Evolution of the reference $R(t)$ for two events ($O_1 = 1.0$, $O_2 = 0.5$) with the same deadline ($T = 11$). While $\gamma = 1.00$ (darkest lines) produces a linear decline, lower values of γ (lighter lines) cause the reference to drop non-linearly. (b) Subjective value $S(R, O)$. Stronger discounting (lower γ) leads to an earlier rise in subjective value. (c) Probability of selecting O_1 over O_2 . Lower γ increases the initial preference for the high-value event. (d) Probability of exerting effort to secure valuable events against a fixed effort cost $C = 0.8$. Uncertainty is fixed at $\sigma = 0.5$ for all conditions.

surrounding this standard. It also captures how agents choose between events and whether to exert effort to secure them as a function of this evaluation.

A crucial innovation in our model is the conceptualization of the standard as an expectation about future, valuable opportunities. This sets our proposal apart from previous reference-based theories, in which the reference is based on the history of past events rather than expectations of future occurrences (Rigoli and Pezzulo, 2022; Köszegi and Rabin, 2006). This expectation naturally decreases as a deadline approaches, such as when a valuable person is about to leave or when a limited-time offer is available to purchase a desired item. Under this framework, when an item is readily available, the reference point remains high and the item's subjective value is relatively low. However, as the item becomes less available, the reference point declines, boosting its subjective value. This explains why the same event or item can suddenly appear more desirable when it is about to become unavailable, even without any intrinsic change in its utility. Another key aspect of our model is the inclusion of uncertainty about the standard, represented by the parameter σ . The simulations show that different levels of uncertainty in evaluating events lead to varying sensitivities to shifts in the standard. Specifically, higher uncertainty results in a flatter subjective value function, making individuals less responsive to changes in standards compared to situations with lower uncertainty. This underscores the importance of incorporating uncertainty into decision-making models, to reflect the influence of confidence in one's expectations on the magnitude of subjective value adjustments.

Through simulations, we show that our reference-based model captures how subjective value rises as the reference standard declines, while also revealing nonlinearities in this process. This dynamic mirrors real-world decision-making, where events or opportunities are perceived as more valuable the less available they become—and the more certain one is about their unavailability (Cialdini, 2001; Brock, 1968; Lynn, 1991). Our simulations further examine how these value shifts shape choices between valuable events and the willingness to exert effort to secure them. We found that as a deadline approaches, the difference in subjective value between high- and low-valued events increases (unless the former subjective value saturates), which in turn strengthens preferences for higher-valued events and increases the willingness to exert effort to obtain them (Scenario 1). We also found that approaching deadlines shift preferences toward time-constrained, higher-value events (e.g., doing homework) over permanently available alternatives (e.g., playing video games), even when the latter may initially be preferred due to their lower cost (Scenario 2). Finally, the model captures more complex dynamics, including non-monotonic shifts in priority when multiple deadlines compete (e.g., submitting multiple papers with different deadlines, Scenario 3), as well as the accelerating effects of temporal discounting on perceived urgency (Scenario 4). Note that by adjusting the model's parameters the subjective values can be made to saturate, yielding more complex dynamics such as inversion effects in choice probabilities like those seen in Scenario 3. These results highlight how scarcity and approaching deadlines influence the salience of opportunities and the trade-offs between effort and reward, a pattern commonly observed in real-world decision-making scenarios (Ariely and Loewenstein, 2005; Buehler et al., 1994; Gneezy and Potters, 1997; Kahneman and Tversky, 1979; Emanuel et al., 2022).

Taken together, these results serve as a proof-of-concept that our reference-based theory can mechanistically capture the rise in subjective value for opportunities expected to become less available, as well as the increased preference and tendency to exert effort to secure them—phenomena related to scarcity (Cialdini, 2001), commodity (Brock, 1968), and FOMO (Przybylski et al., 2013). Importantly, the trend – the increases in subjective value and effort – is the key feature in this demonstration; the precise quantitative values are less critical, as they vary depending on modeling choices, such as the specific effort-based decision model (e.g., Eqs. (4), (5), or alternatives) and parameter

settings. Applying this framework to empirical data would require systematic model comparison and parameter fitting to human behavior.

While our proposal is theoretical, it aligns with a substantial body of empirical research on context-sensitive changes in subjective value and effort-based decision-making, which we review below.

4.1. Relations with previous accounts of scarcity, commodity, and FOMO

Various studies assessed that the value and desirability of items change as a function of their (un)availability. Such studies often measure participants' self-reports, purchase intentions, or the effort they are willing to invest in obtaining a product. Consistent with principles of scarcity (Cialdini, 2001) and commodity theory (Brock, 1968), findings show that items are perceived as more valuable under conditions of scarcity (see Lynn (1991) for a review). In marketing, limited-time and limited-quantity messages reliably increase consumers' purchase intentions (Aggarwal et al., 2011) and enhance the perceived value of promotional offers (Inman et al., 1997); see also Suri et al. (2007), Aggarwal and Vaidyanathan (2003). Relatedly, Zhu et al. (2018) showed that urgency alone, such as an approaching deadline, can increase motivation independently of the objective importance of the task.

Our model connects to these findings by offering a mechanistic account of why scarcity or approaching deadlines increase perceived value. Existing explanations often appeal to beliefs and heuristics: for example, scarcity may signal exclusivity or higher price (Lynn, 1991), or may enhance the sense of uniqueness associated with rare items (Brock, 1968). By contrast, in our model the effect arises from reference-dependent value assessment: as expectations about future availability decline, the reference point falls, thereby boosting the subjective value of the item. This mechanism also relates to regret theory (Loomes and Sugden, 1982), which emphasizes anticipated regret from missing an opportunity. Both accounts highlight the role of future expectations, but our model formalizes how such expectations – and their uncertainty – dynamically alter subjective value.

Our proposal also offers a formalization of the concept of FOMO. Coined in the marketing literature, FOMO refers to the apprehension of missing an important opportunity (Hodkinson, 2019; Milyavskaya et al., 2018). In our framework, FOMO can be understood as arising when expectations about future opportunities are low: a small reference point increases present subjective value, motivating greater effort to secure current opportunities. Conversely, when expectations about future opportunities are high (a large reference point), FOMO does not arise and individuals are less motivated to act immediately.

In sum, our model offers a unifying framework for diverse findings showing that scarcity, urgency, and deadlines increase perceived value and desirability. It introduces a novel reference-based account that formalizes these effects in terms of declining expectations about future opportunities and the uncertainty surrounding them. However, most existing empirical studies do not systematically manipulate these core variables (e.g., the expected future opportunities to meet with a friend and the associated uncertainty, as in Fig. 1). Future work that directly manipulates these dimensions would allow for stronger tests of the model's predictions and enable empirical calibration of its parameters.

4.2. Relations with previous accounts of temporal discounting

Another approach to explain changes in subjective value and effort-based decisions near a deadline appeals to temporal discounting, which appears in several forms. Temporal discounting is often invoked to explain procrastination, particularly our tendency to delay initiating effortful tasks. Various theories attribute this behavior to the fact that the subjective evaluation of task-related rewards increases as the deadline approaches (Akerlof, 1991; O'Donoghue and Rabin, 1999; Durakiewicz, 2016; Konig and Kleinmann, 2005). People initially delay tasks because they undervalue the outcome or do not perceive it as urgent; as the deadline nears, temporal proximity reduces the discount

(or increases urgency), making the task appear more valuable and effort worthwhile. Additionally, it has been suggested that effort, like reward, may also be temporally discounted, and that procrastination arises because the discounting curve is steeper for effort than for reward (Le Bouc and Pessiglione, 2022). A related proposal is that individuals often undervalue outcomes that require substantial effort, particularly under uncertainty (Ariely, 2008).

Our proposal relates to these findings in that the probability of making an effortful choice increases as a deadline approaches (e.g., Fig. 1C–D), consistent with procrastination research. However, we do not assume *a priori* that subjective value or effort inherently change over time due to discounting. Our simulations demonstrate that this increase in value occurs even without temporal discounting (i.e., with $\gamma = 1$). As shown in Fig. 4, including a discount factor ($\gamma < 1$) is not necessary to generate the scarcity effect, but simply modulates the temporal dynamics by accelerating the rise in subjective value. Rather than focusing solely on temporal discounting, we offer a mechanistic account in which these changes emerge from reference-based computations: as expectations about future opportunities decline near a deadline, the subjective value of events (and their urgency) increases. By incorporating uncertainty into the calculations of subjective value and effort, our model may better capture subtleties of these processes that depend on uncertainty (Ariely, 2008; Eluchans et al., 2025).

A related approach, the temporal decision model (Zhang and Feng, 2020), posits that individuals decide when to initiate a task by comparing anticipated outcome utility with perceived task aversiveness, both of which change as the deadline approaches. Task initiation occurs when expected utility exceeds aversiveness. Empirical validation involved participants reporting their perception of task aversiveness and expected utility across different time points, showing that expected utility increased hyperbolically as the deadline approached. This pattern mirrors predictions of our model under low uncertainty (Fig. 1), consistent with the low task uncertainty reported by participants. While our model offers a potential mechanistic explanation of these findings, a direct quantitative comparison – via fitting our model to empirical data – remains an open avenue for future research.

4.3. Relations with previous accounts of opportunity costs

Another prominent explanation for changes in subjective value and effort near deadlines appeals to *opportunity costs*, or the value of foregone alternatives. A large body of work shows that people increase effort as they approach deadlines or goals (Bonezzi et al., 2011; Emanuel et al., 2022; Katzir et al., 2020), echoing classic behaviorist findings that animals exert greater effort when nearing a reward—the *goal-gradient hypothesis* (Hull, 1932; Kivetz et al., 2006). For example, in a videogame study participants pressed keys to hit targets before a deadline and showed a linear increase in effort until the opportunity to score ended (Emanuel et al., 2022). The authors explained this pattern as reflecting shifting opportunity costs: as the deadline for the focal task approached, alternative tasks lost value because they could be postponed, whereas the focal task could not, motivating increased effort.

Our model provides an alternative account. Rather than focusing on trade-offs with alternatives, it explains rising effort through reference-based evaluation: the subjective value of the focal task itself increases as expectations about future opportunities decline. This allows us to account for subjective value dynamics even in situations where no salient alternative tasks are available. Notably, the simulation results shown in Fig. 2 qualitatively matches the empirical pattern observed by Emanuel et al. (2022), with an increase of preference for doing homework over playing video games, despite the value of the latter not changing. Therefore, our framework offers a distinct mechanistic interpretation of decisions involving postponable alternatives. While opportunity cost accounts posit that the value of the postponable alternative declines, our simulations suggest that it remains stable, while

the value of the deadline-bound task rises. This produces the same prioritization of the urgent task, but derives it from the scarcity of the focal event rather than the devaluation of the alternative. Quantitative alignment, however, would require fitting our model parameters for subjective value (Eq. (3)) and effort (Eqs. (4) and (5), or variants) to individual participants' data, which remains a promising direction for future work.

4.4. Limitations and future directions

While this study offers a theoretical framework to explain how subjective value and the probability of exerting effort to secure valued opportunities change as a function of reference standards and the uncertainty surrounding them, it presents only qualitative simulation results. Future research could extend this approach by quantitatively fitting the model to human behavioral data, particularly in contexts involving subjective valuation and effort-based decisions under deadline pressure.

Furthermore, the model presented here could be extended in several directions. One possible extension involves additional factors that contribute to increased valuation as deadlines approach. For example, a limited-time offer might seem more valuable not only because of its scarcity but also due to the anticipated cost of searching for future offers or the potential regret of missing it. Furthermore, although we have presented our theory as an alternative to accounts such as loss aversion and temporal discounting, these frameworks may capture complementary rather than competing mechanisms. Indeed, our results regarding the influence of the discount factor (Fig. 4) suggest that temporal discounting can coexist with reference-dependent valuation, acting to accelerate the decline of the reference point and amplify the scarcity effect. Future work could test whether our model can be refined by incorporating elements from previous theories—for instance, the well-documented asymmetry between gains and losses emphasized in prospect theory (Kahneman and Tversky, 1979). Extending the model in this way could provide a richer account of human decision-making, particularly in contexts where both effort and reward interact. Another potential extension of the model is rendering effort cost time-varying, allowing it to capture scenarios in which the effort required to achieve an outcome increases as the deadline approaches. The model can also be extended to include additional sources of uncertainty. For example, it can accommodate uncertainty about the objective value of an outcome by combining it with the uncertainty of the reference. Similarly, the model can account for uncertainty about two (or more) deadlines by defining a new reference as the average of the individual references for each deadline and combining their variances, resulting in greater overall uncertainty. Subjective value and effort can then be computed relative to this combined reference, allowing them to increase over time even in the absence of clearly defined expectations.

Finally, future work can explore the implications of our proposal for the study of psychopathology. Recent work has employed reference-dependent models to explain various forms of mental illness including depression, anorexia, apathy, and addiction (Rigoli, 2022; Rigoli and Martinelli, 2021, 2023; Rigoli and Pezzulo, 2023; Rigoli et al., 2021). Some of these conditions, namely, depression, anorexia, and addiction, have been interpreted as stemming from an exaggerated reference point (Rigoli et al., 2021). For instance, as also classical set-point models suggest (Ahmed and Koob, 1998; Keramati et al., 2017; Koob and Le Moal, 2001), addiction is proposed to arise when repeated drug consumption magnifies the reference point, in turn producing tolerance and withdrawal symptoms (Rigoli and Pezzulo, 2023). As the example of addiction illustrates, the idea is that some forms of mental illness emerge because past experience has altered the reference point in a dysfunctional way. Yet, the present paper suggests that an abnormal reference might not only be caused by past experience, but also by unrealistic expectations about availability of reward in the future. Some types of apathy, for instance, might stem from an inflated expectation

about average future reward. In turn, this might lead to discounting the opportunities currently available, and to an unwillingness to exert effort to seize those opportunities—being unwillingness to put effort a cardinal symptom of apathy. A promising research avenue is to examine implications for psychopathology of an inflated reference point due to unrealistic expectations of future rewards (Parr et al., 2022; Maisto et al., 2021; Pezzulo et al., 2024; Tschantz et al., 2022; Pezzulo, 2014; Barrett et al., 2016; Seth and Friston, 2016; Paulus et al., 2019; Van den Bergh et al., 2017).

5. Conclusion

In conclusion, this paper aimed to fulfill a dual objective. First, it advanced a novel reference-based theory of subjective value, proposing that subjective value is shaped by changing expectations about an event's future availability and the uncertainty surrounding those expectations. Second, it showed that the simple principle of a declining reference point as a deadline approaches – reflecting diminishing expectations of future opportunities – explains shifts in subjective value and effort-based choices, potentially providing a mechanistic account of phenomena previously linked to scarcity, FOMO, and related effects.

Beyond its theoretical contribution, the model provided a practical framework for analyzing the dynamics of subjective value, decision-making and effort under deadlines. It can be fitted to empirical data on subjective value assessment and effort-based decisions, enabling the quantitative validation of its predictions and the estimation of individual parameters—such as initial valuations, levels of uncertainty, and whether individuals incorporate alternative opportunities or fixed costs in their effort allocation. By combining theoretical precision with empirical applicability, this approach offers a promising tool for advancing research on decision-making in psychology, behavioral economics, and neuroeconomics.

Acknowledgments

This research received funding from the European Research Council under the Grant No. 820213 (ThinkAhead), the Italian National Recovery and Resilience Plan (NRRP), M4C2, funded by the European Union – NextGenerationEU (Project IR0000011, CUP B51E22000150006, “EBRAINS-Italy”; Project PE0000013, “FAIR”; Project PE0000006, “MNESYS”), and the Ministry of University and Research, PRIN PNRR P20224FESY and PRIN 20229Z7M8N. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. We used a Generative AI model to correct typographical errors and edit language for clarity.

Appendix A. Supplementary information

A.1. Proof of monotonicity of subjective value

We examine the temporal behavior of the subjective value $S(R(t), O)$ based on the properties of the chosen reference function $R(t)$. For brevity, we denote the subjective value simply as S . By the chain rule, the time derivative of S is given by:

$$\frac{dS}{dt} = \frac{\partial S}{\partial R} \frac{dR}{dt} \quad (6)$$

Recall that the subjective value is defined by the logistic function (Eq. (3)):

$$S(R, O) = \frac{1}{1 + e^{-x}}, \quad \text{where } x = \frac{O - R(t)}{\sigma} \quad (7)$$

The derivative of the standard logistic function $f(x) = (1 + e^{-x})^{-1}$ with respect to its argument x satisfies $f'(x) = f(x)(1 - f(x))$. Applying the chain rule to the argument x with respect to R , we observe an

additional factor of $\frac{\partial x}{\partial R} = -\frac{1}{\sigma}$. Thus, the partial derivative of S with respect to R is:

$$\frac{\partial S}{\partial R} = -\frac{1}{\sigma} S(1 - S) \quad (8)$$

Substituting this back into the expression for the total time derivative, we obtain:

$$\frac{dS}{dt} = -\frac{1}{\sigma} S(1 - S) \frac{dR}{dt} \quad (9)$$

Since S is the output of a logistic function, it is bounded such that $0 < S < 1$. Consequently, both S and $(1 - S)$ are strictly positive quantities. Additionally, the uncertainty parameter σ is positive by definition. Therefore, the sign of the time derivative $\frac{dS}{dt}$ is determined entirely by the sign of $-\frac{dR}{dt}$. Specifically:

$$\frac{dS}{dt} \geq 0 \iff \frac{dR}{dt} \leq 0 \quad (10)$$

This result proves that if the subjective value is modeled as a logistic function of the reference and objective value, it will monotonically increase over time if and only if the reference standard monotonically decreases over time. Crucially, this implies that the specific functional form of the reference decline (e.g., linear vs. non-linear) does not alter the qualitative behavior of the model; any monotonically decreasing reference function will result in a monotonically increasing subjective value.

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