

The Stress-Response Costs in Decision Making

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Abstract

Incoming information brings in news which could be neutral, good, or bad. However, the brain and the body's response to bad news is much stronger and sustained. Bad news may trigger the human stress-response system which creates a chemical bath in both the brain and the body. In particular, the stress hormone, cortisol, is released, which provides a quick boost of energy to the body and the brain. However, repeated or continuous exposure to cortisol exacts substantial costs on both the brain and the body. We argue that it is implausible to assume that the brain, which ultimately is the seat of all decision-making, completely ignores all such costs. In this article, we show that the inclusion of such costs provides a unified explanation for the Allais paradox and the Ellsberg paradox and makes predictions that are empirically supported. We further show that such costs potentially contribute to high and countercyclical equity-premia.

Keywords

Allais Paradox, Ellsberg Paradox, High Equity-Premium, Countercyclical Equity-Premium

1. Introduction

Incoming information brings news which could be neutral, good, or bad. The brain and the body's response to bad news is much stronger and sustained than to other types of news.¹ In particular, bad news may trigger the human stress-response system, which creates a chemical bath for the brain and the body in

¹It is well-established that the reactions in the brain and the body to bad news are much stronger and sustained than reactions to good news (see Soroka et al. (2019) and references there in, Soroka and McAdams (2015) among others). Good news may make one feel temporarily elated but such benefits are small (so ignored here) when compared with the stress response costs of bad news that have major implications for mental and physical health. In economics and psychology literature, the notion of loss aversion (a large literature spawned by Kahneman and Tversky (1979)) is intuitively based on this differential response.

which several hormones, enzymes, and other substances are released.² In particular, the stress hormone, cortisol is released, which facilitates a boost of energy that increases one's capacity (both mental and physical) to deal with the adverse situation. However, repeated or continuous exposure to cortisol exacts a substantial cost on both the brain and the body.³ We argue that it is implausible to assume that the brain (also responsible for maintaining the body), which ultimately is the seat of all decision making, completely ignores these costs while choosing among alternatives.

To fix ideas, imagine a choice between keeping \$100 in a safe bank account or investing \$100 in a stock. In a safe account, the money is guaranteed to grow from \$100 to \$105. However, with the risky stock, let's say that based on existing information, the future payoff could be either \$200 or just \$50. Should one keep money in the safe bank account or invest it in the risky stock? The traditional answer to this question is that compare the utility benefit of \$105 from the safe choice with the utility benefit (expected, discounted) of the payoff from the risky stock and pick the option with the higher benefit. We argue that the above description is incomplete and that there are additional stress-response costs associated with the risky stock that must also be considered. For example, after investing in the stock, new information may arrive that adversely changes the payoffs. This may trigger a stress-response exacting a cost on both the brain and the body. Even if new information does not change the payoffs, stress-response may follow from the realization of the bad outcome (stock price falling to \$50 in our example). We argue that the brain, which ultimately is the decision-maker (DM), considers such anticipated stress-response costs in decision making.

In the economic literature, two prominent phenomena which are generally considered to be in violation of the expected utility framework are the Allais paradox and the Ellsberg paradox. We show that including a consideration of the anticipated stress-response costs resolves both the Allais paradox and the Ellsberg paradox by making them consistent with the expected utility framework. We show that the more nuanced view of decision making presented here (by including the stress-response costs) makes predictions regarding the Allais paradox and the Ellsberg paradox which hold up well to empirical scrutiny. We also show that inclusion of the stress-response costs potentially contributes to the equity-premium being high and countercyclical, which are considered as puzzling phenomena in the literature.

Allais paradox has spawned a large literature (see [Huck and Muller \(2012\)](#) and references therein for evidence/discussion on various factors that have been found to be important for the Allais paradox), and similarly, Ellsberg paradox has given rise to a large literature that aims to explain it (see [Trautmann and van de Kuilen \(2015\)](#) for a review of evidence/discussion on the Ellsberg paradox). Allais paradox demonstrates a violation of expected utility by manipulating a comparison

²See [Godoy et al. \(2018\)](#) for a comprehensive overview on stress neurobiology.

³For a review article that summarizes these costs, see [Yaribegi et al. \(2017\)](#).

between a sure outcome and a risky bet. We show that the paradox disappears if the anticipated stress-response costs are also considered which are absent from the sure outcome but matter for the risky choice. Ellsberg paradox has motivated a large literature on ambiguity aversion by manipulating a comparison between a lottery with known odds and a lottery with unknown odds (Machina & Siniscalchi, 2014). We show that the inclusion of the additional stress-response costs associated with missing information (in the lottery with unknown odds) effectively resolves the Ellsberg paradox within the expected utility framework. Hence, what appears as ambiguity aversion may be a special case arising from the functioning of the stress-response system.

There is a body of direct evidence (field experiments as well lab experiments) suggesting that people evaluate safe and risky choices with different utility functions (see Serfilippi et al. (2019), Andreoni and Sprenger (2012) and Gneezy et al. (2006) among others). A growing body of literature explores the implications of such a difference in various contexts (Serfilippi et al., 2019; Siddiqi, 2017). A significant body of literature points out that violations of standard expected utility maximization are substantially less prevalent when only uncertain payoffs are involved (Camerer, 1992; Harless & Camerer, 1994; Starmer, 2000), indicating that behavior at or close to certainty is fundamentally different from behavior away from certainty. In the framework presented in this article, such differences arise due to anticipated stress-response costs. That is, certain and uncertain utility may be identical but due to additional stress-response costs associated with the risky choice, they appear different if such costs are ignored.

The reaction to bad news in the brain and the body may continue long after its first arrival if further thoughts are spawned that serve to keep the stress-response system switched on. Such thoughts become internal stressors (internal sources of stress) which are a major contributor to chronic stress (prolonged low-level of stress).⁴ Thoughts associated with self-blame (associated with feeling the emotion of regret) are an example that may arise if a bad outcome follows a decision combined with the knowledge that a better outcome would have resulted from the alternative choice.⁵ There is a large body of literature in economics and psychology on the role of anticipated regret in decision making (see Bleichrodt and Wakker (2015) and refereces therein). In the framework developed in this article, thoughts of self-blame associated with regret are internal stressors; hence, regret can be considered a special case of the framework.

It is well-established that the cumulative stress matters (known as “allostatic load” in the literature). In other words, the stress-response costs arising from a particular negative event is higher if there are other stressors already present (see Guidi et al. (2021) for a systematic review of the literature showing that cumulative stress matters in assessing the cost of an individual stressful event). A robust empirical finding is that the equity premium is countercyclical (see Cochrane

⁴See Seiler et al. (2020).

⁵See Penberthy (2022) for a non-technical discussion on thoughts of regret leading to chronic stress.

(2017), and references therein). The stress-response system potentially contributes to the equity premium being countercyclical as recessions have many more stressors (job insecurity, financial loss etc.) when compared with economic booms. In other words, the higher allostatic load during recessions potentially contributes to the countercyclical equity premia.

This article is organized as follows. Section 2 provides a non-technical summary of the stress-response costs on the brain and the body. Section 3 shows that the inclusion of anticipated stress-response costs potentially resolves both the Allais paradox and the Ellsberg paradox. Section 4 shows that the stress-response costs potentially contribute to the equity-premium being high and countercyclical. Section 5 concludes.

2. The Stress-Response System and Its Costs

The two major components involved in the human stress response system are Sympathetic-Adreno-Medullar (SAM) axis and Hypothalamus-Pituitary-Adrenal (HPA) axis.⁶ These components create a chemical bath for the brain and the body in response to a stressor in which several hormones, enzymes, and other substances are released. Notably, the stress hormone, cortisol, is released from adrenal glands. These hormones give the brain and the body a burst of energy needed to better deal with negative situations. However, too much of these hormones or repeated exposure to these hormones exacts a cost on the brain and the body.⁷

The key costs on the brain and the body are summarized as follows⁸:

1) **(Brain-Cost I, BRC1)** Elevated cortisol levels can cause neurons in the brain to take in too much calcium through their membranes, which can make neurons fire too quickly and die. In particular, this loss of neurons happens in the prefrontal cortex (PFC) and the hippocampus, which are the brain regions associated with judgment/decision making and learning new concepts respectively. We call this cost the Brain-Cost I and refer to it as BRC1 in what follows.

2) **(Brain-Cost II, BRC2)** Elevated cortisol levels decrease serotonin, which is the hormone that makes one happy. Serotonin reduction is a factor in the mental health issue of depression. We refer to this cost as the Brain-Cost II and denote it by BRC2 in the rest of this article.

3) **(Body Costs, BOC)** Elevated cortisol levels are implicated in type 2 diabetes, high blood pressure, suppressed immune system, problems with metabolism, loss in bone density & muscles, and cardiovascular issues among others. We denote such “Body Costs” by BOC in what follows.

In addition to the substantial costs summarized above, research has established the following two key properties of the stress-response system:

1) **(Cumulative-Stress Property, CS)** Stress-response costs depend on the cu-

⁶For an extensive overview of stress neurobiology, see [Godoy et al. \(2018\)](#) and references therein.

⁷For a nontechnical summary/discussion of research on how stress effects the body and the brain for general audience, see chapter 4 in [Thompson, F. L.](#)

⁸See [Mariotti and McEwen](#) (and references therein).

mulative level of stress at a given point in time. That is, a decision-maker (DM) already facing multiple stressors suffers higher costs from an additional stressor.⁹ This is the cumulative-stress property and we refer to it as CS in this article.

2) **(Internal-Stressor Property, IS)** Stress-response system may get switched on if an internal stressor is present such as one's own thoughts. Bad news from an external source may initially activate the stress-response system; however, one's own thoughts, by becoming an internal stressor, may keep the stress-response system switched on long after the first arrival of bad news. In fact, such internal stressors are considered the leading cause of chronic stress in the literature.¹⁰ We refer to this internal-stressor property as IS in what follows.

Overall, given substantial stress-response costs on the brain and the body, it is implausible to keep on assuming that the brain, which ultimately is the seat of all decision making, completely ignores these costs. In particular, as discussed in this section, a large body of research on the stress-response system has not only elaborated the nature of these costs but has also clarified the key properties of the stress-response system. In other words, stress is not a black-box anymore. It is a phenomenon with real physiological effects that exact a cost on both the brain and the body. Armed with established findings, one can develop a more nuanced view of decision making where anticipated stress-response costs are explicitly considered. Such a nuanced view adds explanatory and predictive power to the study of how people make decisions. This is demonstrated with the Allais paradox and the Ellsberg paradox in the next section.

3. The Allais Paradox and the Ellsberg Paradox

In this section, we consider how the established findings in the literature regarding the stress-response system (summarized in Section 2) enrich our understanding of the Allais paradox and the Ellsberg paradox by adding both explanatory and predictive power.

3.1 The Allais Paradox

The original "Allais questions" consist of two pairwise lottery choices. A subject is first asked to choose between lotteries A and B where

$$A = \text{Certainty of \$1 million} \quad \text{and} \quad B = \begin{cases} 1\% \text{ chance of \$0} \\ 89\% \text{ chance of \$1 million} \\ 10\% \text{ chance of \$5 million} \end{cases}$$

Then, a subject is asked to choose between lotteries A' and B' where

$$A' = \begin{cases} 89\% \text{ chance of \$0} \\ 11\% \text{ chance of \$1 million} \end{cases} \quad \text{and} \quad B' = \begin{cases} 90\% \text{ chance of \$0} \\ 10\% \text{ chance of \$5 million} \end{cases}$$

The four possible pairs of choices are AA' , BB' , AB' , and BA' . Out of these four possibilities, only the first two are apparently consistent with expected utility

⁹See Guidi et al. (2021) and references therein.

¹⁰See Seiler et al. (2020).

theory and the last two are not.¹¹ In practice, most subjects choose AB' .¹²

In this article, we argue that the brain also considers anticipated stress-response costs in these choices. Consider option A . As this is a risk-free option, there are no associated stress-response costs; hence, utility from option A is simply $u(A)$. In option B , there is a chance of getting nothing, which has anticipated stress-response costs associated with it as it may activate the stress-response system. These costs include BRC1, BRC2, and BOC, and are influenced by the properties CS and IS (see the discussion in Section 2). Denoting the probability of the stress-response system getting activated in response to the bad outcome of \$0 by γ , the anticipated/expected stress-response costs can be written as:

$$\bar{C}(CS, IS) = \gamma * C(CS, IS) + (1 - \gamma) * 0$$

Such that:

$$\frac{\partial C(CS, IS)}{\partial IS} > 0 \quad (IS \text{ Property}) \quad (3.1)$$

$$\frac{\partial C(CS, IS)}{\partial CS} > 0 \quad (CS \text{ Property}) \quad (3.2)$$

(3.1) captures the finding that if a bad outcome generates further stressors such as thoughts that become internal stressors in their own right (keep the stress-response system switched on long after the initial arrival of bad news), then the stress-response costs are higher. (3.2) captures the finding that higher the cumulative stress on the DM, higher are the stress-response costs of an additional stressor.

With the inclusion of the stress-response costs, the expected utility from lottery B is:

$$u(B) = 0.89 * u(\$1M) + 0.10 * u(\$5M) + 0.01 * u(\$0) - 0.01 * \bar{C}_B(CS, IS) \quad (3.3)$$

where $\bar{C}_B(CS, IS)$ captures the anticipated stress-response costs, which are associated with the bad outcome in lottery B .

With the original "Allais questions", $\bar{C}_B(CS, IS)$ is expected to be quite high. The reason is that the bad outcome of nothing is expected to generate the emotion of regret for not choosing the certain \$1M earlier.¹³ The associated thoughts of self-blame for giving up such a large sum of money (for a chance at winning \$5M) would keep the stress-response system switched on long after learning the bad outcome. By becoming an internal stressor, such thoughts would keep the stress-response system switched on for a long time substantially adding to the stress-

¹¹Here is why: Adding $0.89 * u(\$0) - 0.89 * u(\$1M)$ to both sides of the inequality

$u(A) = u(\$1M) > 0.01 * u(\$0) + 0.89 * u(\$1M) + 0.10 * u(\$5M) = u(B)$ implies

$u(A') = 0.89 * u(\$0) + 0.11 * u(\$1M) > 0.90 * u(\$0) + 0.10 * u(\$5M) = u(B')$.

¹²See the discussion in Huck and Muller (2012).

¹³Thoughts of self-blame are critical for generating regret and one does not feel regret without it (Penberthy, 2022). As discussed in the introduction, there is a large literature on the role of anticipated regret in decision making (see Bleichrodt and Wakker (2015) and references therein). In the stress-response framework developed here, regret is a special case that arises due to thoughts of self-blame becoming an internal stressor.

response costs (BRC1, BRC2, and BOC).¹⁴ With $\bar{C}_B(CS, IS)$ sufficiently large, A is preferred to B even if one has low risk-aversion or even if one is risk neutral.

With the inclusion of anticipated stress-response costs, the utility from lotteries A' and B' are:

$$u(A') = 0.11 * u(\$1M) + 0.89 * u(\$0) - 0.89 * \bar{C}_{A'}(CS, IS) \quad (3.4)$$

$$u(B') = 0.10 * u(\$5M) + 0.90 * u(\$0) - 0.90 * \bar{C}_{B'}(CS, IS) \quad (3.5)$$

where:

$$\bar{C}_{A'}(CS, IS) = \gamma * C_{A'}(CS, IS) + (1 - \gamma) * 0 \quad (3.5a)$$

$$\bar{C}_{B'}(CS, IS) = \gamma * C_{B'}(CS, IS) + (1 - \gamma) * 0 \quad (3.5b)$$

The stress-response costs in lotteries A' and B' , which are $C_{A'}(CS, IS)$ and $C_{B'}(CS, IS)$ respectively, are likely to be much smaller than $\bar{C}_B(CS, IS)$ due to the absence of the internal stressor of self-blame in these lotteries. In both A' and B' , the odds are that one is not going to win anything, so there is little reason for self-blame to arise from not picking the other option. Indicating this by writing '-' in the place-holder for IS in $C_{A'}(CS, IS)$ and $C_{B'}(CS, IS)$:

$$C_B(CS, IS) \gg C_{A'}(CS, -) \quad (3.5c)$$

$$C_B(CS, IS) \gg C_{B'}(CS, -) \quad (3.5d)$$

The typical response of preferring B' to A' implies:

$$\begin{aligned} &0.10 * u(\$5M) + 0.90 * u(\$0) - 0.90 * \bar{C}_{B'}(CS, -) \\ &> 0.11 * u(\$1M) + 0.89 * u(\$0) - 0.89 * \bar{C}_{A'}(CS, -) \end{aligned} \quad (3.6)$$

With $\bar{C}_{B'}(CS, -) \sim \bar{C}_{A'}(CS, -) = \bar{C}(CS, -)$ and setting $u(\$0) = 0$, the condition for preferring B' to A' is:

$$0.10 * u(\$5M) > 0.11 * u(\$1M) + 0.01 * \bar{C}(CS, -) \quad (3.7)$$

It follows that, unless $\bar{C}(CS, -)$ is very large, B' would continue to be preferred over A' .

The above discussion shows that even though the observed outcome of AB' is considered inconsistent with the expected utility theory (without the stress-response costs), including the stress-response makes it consistent.

Previous analysis gives rise to testable predictions regarding the observed behavior in Allais type questions. The predictions follow from the properties of IS and CS, which are factors in determining the magnitude of the stress-response costs.

Predictions Regarding Allais Type Violations

The anticipated stress-response costs associated with the bad outcome in lottery

¹⁴To see how high these costs could be, consider the true story of a man who would pick the same lottery numbers each time; however, he forgot to buy the ticket one time and at that time, his numbers won the jackpot. Heart-broken, that man committed suicide (see Oldfield, S., "The Tragedy of the Lottery Loser", *Daily Mail*, April, 11, page 1).

B , $\bar{C}_B(CS, IS)$, play a key role in giving rise to observed violations from expected utility theory without stress-response costs (EUT). In particular, it is the self-blame thoughts for passing up on a life-changing amount of \$1M for a small chance of winning an additional \$4M that become internal stressors. Such internal stressors keep the stress-response system switched on long after realization of the bad outcome. It immediately follows that reducing the large payoffs to smaller ones would reduce $\bar{C}_B(CS, IS)$. For example, if the original payoffs in Allais questions are proportionately reduced such that the sure outcome in A is \$5 and the payoffs in B are 89% chance of \$5, 10% chance of \$25, and 1% chance of \$0, then the thoughts of self-blame from choosing B and ending up with \$0 are expected to be much milder or none at all. This is because, unlike \$1M, \$5 is not a life-changing amount of money. It immediately follows that the anticipated stress-response costs without the IS factor, $\bar{C}_B(CS, -)$ are much smaller: $\bar{C}_B(CS, -) \ll \bar{C}_B(CS, IS)$. Proposition 1 immediately follows.

Proposition 1 (Payoff Size Matters): *The observed violations of EUT in Allais type questions fall as payoff size falls.*

Another prediction follows from manipulating the Allais questions in accordance with the CS property. Recall that the CS property refers to the finding that higher the level of cumulative stress, higher is the stress-response cost (see Section 2). That is, the stress-response costs without any cumulative stress, $\bar{C}_B(-, IS)$, are lower: $\bar{C}_B(-, IS) < \bar{C}_B(CS, IS)$. It follows that for subjects which are facing a lower level of cumulative stress, the observed violations should be lower. People with steady jobs, financial assets, and high level of education are likely to have fewer pre-existing stressors when compared with people without jobs, financial assets, and education.

Proposition 2 (Cumulative-Stress Correlates Matter): *The observed violations of EUT in Allais type questions are lower if subject characteristics (such as education, steady job, financial assets) correspond to a lower level of cumulative stress when compared with subject characteristics (such as lack of education, unemployment, no financial assets) that correspond to a higher level of cumulative stress.*

Both the predictions above regarding payoff size and cumulative-stress correlates hold up well in both lab and field experiments. Huck and Muller (2012) conduct field experiments with Allais type questions with a large representative sample of general population as well as with students in the lab. Consistent with the predictions here, they report fewer violations with lower payoffs and with subject characteristics such as incomes, financial assets, and education.

3.2. The Ellsberg Paradox

The original demonstration of “Ellsberg paradox” involves an urn containing 90 balls, 30 are red while the remaining 60 are either black or yellow in unknown proportions. The balls are well mixed so each ball is as likely to be drawn as any other. A subject is first asked to choose between the following scenarios:

$A = \$100$ if a red ball is drawn and

$B = \$100$ if a black ball is drawn

Then, the subject makes a choice between the following scenarios with the same situational parameters given earlier:

$A' = \$100$ if a red or a yellow ball is drawn and

$B' = \$100$ if a black or a yellow ball is drawn

Out of the 4 possible outcomes, AA' , BB' , AB' , and BA' , only the first two are consistent with expected utility theory (without stress-response costs) (EUT). However, typically subjects choose AB' , apparently in violation of EUT.¹⁵ However, as shown in this section, the typical outcome AB' is not inconsistent with EUT inclusive of the stress-response costs.

In scenario A , if the anticipated stress-response costs are also considered, then the expected utility is:

$$u(A) = \frac{1}{3} * u(\$100) + \frac{2}{3} * u(\$0) - \frac{2}{3} * \bar{C}_0(CS, IS) \quad (3.8)$$

where $\bar{C}_0(CS, IS)$ is the anticipated stress-response cost associated with the \$0 outcome:

$$\bar{C}_0(CS, IS) = \gamma * C_0(CS, IS) + (1 - \gamma) * 0 \quad (3.8a)$$

Compared to scenario A , in scenario B , in the absence of objectively known odds of drawing a black ball, a subject assigns a subjective probability; however, she is aware that there is missing information which could be adverse. In this case, the missing information may reveal that the objective probability is less than the assumed subjective probability. Such adverse information may trigger a stress-response. If the subject assigns a (subjective) probability of π to the missing information being adverse (the objective probability of drawing a black ball is less than assumed subjective probability), then the expected utility is:

$$u(B) = P_B * u(\$100) + \left(1 - \frac{1}{3} - P_B\right) * u(\$0) - \left(1 - \frac{1}{3} - P_B\right) * \bar{C}_0(CS, IS) - \pi * \bar{C}_B(CS, IS) \quad (3.9)$$

where $\bar{C}_B(CS, IS)$ is the anticipated stress-response cost associated with the missing information being adverse. If the missing information turns out to be adverse, which has a probability, π , then the stress-response system may be triggered with a probability, γ , creating the anticipated stress-response costs of $\bar{C}_B(CS, IS) = \gamma * C(CS, IS) + (1 - \gamma) * 0$.

A comparison of (3.9) and (3.8) indicates that even if the subject assigns a subjective probability which is higher than 1/3 to the drawn ball being black, that is

¹⁵Note that $u(A) = \frac{1}{3} * u(\$100) + \frac{2}{3} * u(\$0) > p_b * u(\$100) + (1 - p_b) * u(\$0) = u(B)$ implies that

$p_b < 1/3$, and $u(A) = \frac{1}{3} * u(\$100) + \frac{2}{3} * u(\$0) < p_b * u(\$100) + (1 - p_b) * u(\$0) = u(B)$ implies that $p_b > 1/3$. This makes AA' and BB' as the only two options that are consistent with EUT.

$P_B > 1/3$, a subject may still choose A over B . This is because the subject knows that the true probability can be different and such missing information could be adverse, which may trigger the stress-response system with the anticipated stress-response costs of $\bar{C}_B(CS, IS)$.

It is illustrative to consider the case when the assumed subjective probability of drawing a black ball, P_B , is $1/3$:

$$u(B) = \frac{1}{3} * u(\$100) + \frac{2}{3} * u(\$0) - \frac{1}{3} * \bar{C}_0(CS, IS) - \pi * \bar{C}_B(CS, IS) \quad (3.10)$$

Note that $u(B)$ in (3.10) is less than $u(A)$ in (3.8) due to an additional term, $\pi * \bar{C}_B(CS, IS)$. This term is a product of the subjective probability of missing information being adverse, π , and the associated expected stress-response costs, $\bar{C}_B(CS, IS)$.

Extending the above discussion to scenarios A' and B' :

$$u(A') = \left(\frac{1}{3} + P_Y\right) * u(\$100) + \left(1 - \frac{1}{3} - P_Y\right) * u(\$0) - \left(1 - \frac{1}{3} - P_Y\right) * \bar{C}_0(CS, IS) - \pi * \bar{C}_{A'}(CS, IS) \quad (3.11)$$

where the subjective probability of drawing a yellow ball is P_Y .

$$u(B') = \frac{2}{3} * u(\$100) + \frac{1}{3} * u(\$0) - \frac{1}{3} * \bar{C}_0(CS, IS) \quad (3.12)$$

Even if the subjective probability of drawing a yellow ball, P_Y , is more than $1/3$, a subject may still choose B' over A' , because of the awareness that missing information about probabilities could be adverse (objective probability of drawing a yellow ball is less than the assumed subjective probability). This introduces an additional stress-response cost term in (3.11) of $\bar{C}_{A'}(CS, IS)$. There is no corresponding term in (3.12) as there is no missing information about probabilities in lottery B' .

Considering the illustrative case, $P_Y = 1/3$, it follows that:

$$u(A') = \frac{2}{3} * u(\$100) + \frac{1}{3} * u(\$0) - \frac{1}{3} * \bar{C}_0(CS, IS) - \pi * \bar{C}_{A'}(CS, IS) < \frac{2}{3} * u(\$100) + \frac{1}{3} * u(\$0) - \frac{1}{3} * \bar{C}_0(CS, IS) = u(B') \quad (3.13)$$

Hence, the typical outcome in Ellsberg type scenarios, AB' , which is not consistent with EUT without stress-response costs, is consistent with EUT inclusive of stress-response costs. It is intriguing that both the Allais paradox and the Ellsberg paradox, which generally serve as exhibit 1 and exhibit 2 against EUT in the literature, are reconcilable with EUT inclusive of the stress-response costs.

A Prediction Regarding Ellsberg Type Violations

Previous analysis is based on the idea that the anticipated stress-response costs cannot be ignored in a comparison of a scenario where objective probabilities are known with a scenarios where objective probabilities are unknown. When objective probabilities are unknown, subjective probabilities are assigned; however, a

subject is aware that they could be wrong. That is, missing information about probabilities may be adverse with the objective probability of good outcomes turning out to be less than the assumed subjective probability. Such adverse information may trigger the stress-response system. The subjective probability of missing information being adverse, π , and the anticipated stress-response costs arising from such adverse information, $\bar{C}(CS, IS)$, are jointly considered in the expected utility calculation: $\pi * \bar{C}(CS, IS)$. Ignoring this term is the source of Ellsberg type violations from EUT.

From the above discussion, it immediately follows that the subjective probability of missing information being adverse is a critical factor in determining whether a subject displays Ellsberg type violations or not. Where does the subjective probability of the missing information being adverse, π , comes from? We assert that they come from a subject's past experiences with missing information. Every subject carries with her an inventory of prior experiences with missing information. In some cases, the missing information might have turned out to be positive whereas in some others it might have been negative. It makes sense to think of π as some function of the frequency of prior negative experiences with missing information. Proposition 3 follows.

Proposition 3 (Prior Experiences Matter): *The observed violations of EUT in Ellsberg type questions is higher if the frequency of prior negative experiences with missing information is higher.*

Malmendier and Nagel (2011) present evidence that people who have lived through the depression years exhibit much lower stock market and bond market participation rates when compared with the general population. In the stress-response decision framework developed here, buying a financial asset such as a stock requires assigning subjective probabilities to various outcomes while being aware that further information may reveal these probabilities to be different than what has been assumed. Exposure to pre-dominantly adverse missing information during the depression years implies assigning a higher probability to the missing information being negative in the new gambles (financial assets) that one faces. Akin to higher violations of EUT in Ellsberg type scenarios, this implies not accepting the gambles offered by financial assets resulting in the observed low participation rates.

Ellsberg paradox has spawned a large literature on ambiguity aversion (see Machina and Siniscalchi (2014) and references therein). However, as discussed here, what appears as ambiguity aversion may be arising from ignoring the anticipated stress-response costs associated with missing information.

4. High and Countercyclical Equity Premium

Under EUT, a decision is made if the associated marginal costs are smaller than its marginal benefits. In particular, if a stock has a price, p_t , and the DM has a utility of consumption, $u(c_t)$, then the marginal cost of purchasing the stock is $p_t u'(c_t)$ where $u'(c_t)$ is the marginal utility of consumption at t . The utility

benefit (expected, discounted) of stock's payoffs, x_{t+1} , in the future is $E_t[\beta u'(c_{t+1})x_{t+1}]$ where β is the time-discount factor, and $u'(c_{t+1})$ is the marginal utility of consumption at $t+1$.

The decision to purchase the stock is made if:

$$p_t u'(c_t) < E_t[\beta u'(c_{t+1})x_{t+1}]$$

In market equilibrium, the price of the stock, p_t , rises till:

$$p_t u'(c_t) = E_t[\beta u'(c_{t+1})x_{t+1}] \tag{4.1}$$

In this article, we argue that the brain does not just make a comparison between the utility cost of the purchase with the utility (expected, discounted) benefit of the payoffs, but also includes the anticipated stress-response costs on the brain and the body. Using $\bar{C}_S(CS, IS)$ to denote the anticipated stress-response costs associated with the risky payoffs (including the anticipated stress-response costs associated with new information adversely changing the payoffs and/or bad outcomes being realized), it follows in equilibrium that:

$$p_t u'(c_t) = E_t[\beta u'(c_{t+1})x_{t+1}] - \bar{C}_S(CS, IS) \tag{4.2}$$

$$\Rightarrow p_t = E_t\left[\beta \frac{u'(c_{t+1})}{u'(c_t)} x_{t+1}\right] - \frac{\bar{C}_S(CS, IS)}{u'(c_t)} \tag{4.3}$$

Defining $m_{t+1} = \beta \frac{u'(c_{t+1})}{u'(c_t)}$, it follows that:

$$p_t = E_t[m_{t+1}x_{t+1}] \left\{1 - \frac{\bar{C}_S(CS, IS)}{u'(c_t)E_t[m_{t+1}x_{t+1}]}\right\} \tag{4.4}$$

$$\Rightarrow p_t = \alpha_t E_t[m_{t+1}x_{t+1}] \tag{4.5}$$

where $\alpha_t = \left\{1 - \frac{\bar{C}_S(CS, IS)}{u'(c_t)E_t[m_{t+1}x_{t+1}]}\right\} < 1$

If there is an asset with genuinely risk-free payoff, $x_{F(t+1)}$, then for such an asset $\bar{C}_S(CS, IS) = 0$ implying that $\alpha_t = 1$. Hence, the price of the risk-free asset, p_{Ft} , is:

$$\begin{aligned} p_{Ft} &= E_t[m_{t+1}]x_{F(t+1)} \\ \Rightarrow \frac{1}{E_t[m_{t+1}]} &= R_{F(t+1)} \end{aligned} \tag{4.6}$$

where $R_{F(t+1)} = \frac{x_{F(t+1)}}{p_{Ft}}$ is the risk-free return between t and $t+1$.

The R.H.S in (4.5) can be expanded to yield:

$$\begin{aligned} p_t &= \alpha_t \{E_t[m_{t+1}]E_t[x_{t+1}] + Cov[m_{t+1}, x_{t+1}]\} \\ \Rightarrow p_t &= \alpha_t E_t[m_{t+1}] \left\{E_t[x_{t+1}] + Cov\left[\frac{m_{t+1}}{E_t[m_{t+1}]}, x_{t+1}\right]\right\} \end{aligned} \tag{4.7}$$

Substituting from (4.6) in (4.7):

$$p_t = \alpha_t \frac{1}{R_{F(t+1)}} \left\{ E_t[x_{t+1}] + Cov \left[\frac{m_{t+1}}{E[m_{t+1}]}, x_{t+1} \right] \right\} \quad (4.8)$$

Dividing both sides in (4.8) by p_t yields:

$$1 = \alpha_t \frac{1}{R_{F(t+1)}} \left\{ E_t[R_{t+1}] + Cov \left[\frac{m_{t+1}}{E[m_{t+1}]}, R_{t+1} \right] \right\} \quad (4.9)$$

where $R_{t+1} = \frac{x_{t+1}}{p_t}$

Re-arranging (4.9) leads to:

$$E[R_{t+1}] - \frac{R_F}{\alpha_t} = -Cov \left[\frac{m_{t+1}}{E[m_{t+1}]}, R_{t+1} \right] \quad (4.10)$$

$$\begin{aligned} \Rightarrow E[R_{t+1}] - R_F &= -\rho \frac{\sigma(m_{t+1})}{E[m_{t+1}]} \sigma(R_{t+1}) + \frac{1-\alpha_t}{\alpha_t} \cdot R_F \\ \Rightarrow \frac{E[R_{t+1}] - R_F}{\sigma(R_{t+1})} &= -\rho \frac{\sigma(m_{t+1})}{E[m_{t+1}]} + \frac{1-\alpha_t}{\alpha_t} \cdot g_t \end{aligned} \quad (4.11)$$

where ρ is the correlation between m_{t+1} and R_{t+1} (which is generally negative), $\sigma(R_{t+1})$ is the standard deviation of stock returns, $g_t = \frac{1}{\sigma(R_{t+1})E[m_{t+1}]}$,

and we have made the substitution $Cov \left[\frac{m_{t+1}}{E[m_{t+1}]}, R_{t+1} \right] = \rho \frac{\sigma(m_{t+1})}{E[m_{t+1}]} \sigma(R_{t+1})$.

Note that the L.H.S in (4.11) is the ratio of equity-premium (excess return on the stock over the risk-free rate) to the standard-deviation of stock return, which is called the Sharpe-ratio of the stock. Without stress-response costs, $\alpha_t = 1$, so the Sharpe-ratio is lower. Proposition 4 follows.

Proposition 4 (High Equity Premium) Consideration of anticipated stress-response costs increases the equity risk-premium. Specifically, the Sharpe-ratio rises by $\frac{1-\alpha_t}{\alpha_t} \cdot g_t$.

A common observation in the literature is that the observed equity premium is much higher than expected. This is known as the equity premium puzzle. See [Cochrane \(2017\)](#) for a review of the large literature on the puzzle. Proposition 4 shows that anticipated stress-response costs may be contributing to the puzzle. Supporting evidence for proposition 4 can be found in the literature ([Siddiqi, 2024a, 2024b](#)).

As discussed in Section 2, the CS property of stress-response costs shows that the stress-response costs of a stressor are higher if the cumulative stress on the DM is higher at a given point in time. Recessions are times where several stressors are simultaneously present such as related to work (potential layoffs) and financial loss. Hence, it follows that the cumulative stress and consequently the stress-response costs of an individual stressor are higher in recessions when compared

with booms. This means that α_t is lower in recessions when compared with booms. Proposition 5 follows.

Proposition 5 (Countercyclical Equity Premium): *Consideration of anticipated stress-response costs contributes to the countercyclicity of the equity premium. That is, the equity-premium is higher at the bottom of recessions when compared with the top of the booms.*

The countercyclicity of the equity premium is a robust empirical finding in the literature.¹⁶

5. Conclusion

Incoming information can be neutral, good, or bad. Research shows that the brain and the body's response to bad news is much stronger and sustained than their response to other types of news. Specifically, bad news may trigger the human stress-response system, which creates a chemical bath for the brain and the body. In particular, the stress hormone, cortisol, is released, which makes the brain and the body ready to deal with the adverse situation. However, research has demonstrated that the repeated or continuous exposure to elevated cortisol exacts a substantial cost on both the brain and the body. In this article, we argue that it is implausible to assume that the brain (which ultimately is the seat of all decisions) completely ignores these costs in choosing among alternatives. We show that incorporating such costs enriches our understanding of decision making by adding both explanatory and predictive power. We show that Allais paradox and the Ellsberg paradox are both explained in the same framework with a number of key predictions having empirical support. We also show that the anticipated stress-response costs potentially contribute to the high equity-premium and its countercyclicity, both of which are empirically robust phenomena.¹⁷

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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¹⁶See Cochrane (2017), Siddiqi and Murphy (2023) and references therein.

¹⁷Some of the experimental findings such as in Siddiqi (2009) and Siddiqi (2011) can also be understood with this new approach. This is a subject for further research.

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