

A TWO-BALL ELLSBERG PARADOX: AN EXPERIMENT

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Abstract

We conduct an incentivized experiment on a nationally representative US sample (N=708) to test whether people prefer to avoid ambiguity even when it means choosing dominated options. In contrast to the literature, we find that subjects prefer risky acts to ambiguous acts even when the latter always provides larger probabilities of winning. Such preferences violate core rational principles of decision theory under risk and ambiguity elaborated by economic theory. Our experimental design shows that such a violation is not mainly due to a lack of understanding and is, to a large extent, deliberate. In addition, we show that a similar behavior governs the choice between complex and simple options. We conclude that subjects avoid ambiguity *per se* rather than avoiding ambiguity because it may yield a worse outcome.

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¹This is Brian Jabarian's job market paper.

1 Introduction

1.1 Motivation of the Paper

A Two-Ball Ellsberg Paradox. Consider the following thought experiment proposed by ?. There are two urns, **R** and **A**, and two types of balls: red and blue. In urn **R**, there are 100 balls: 50 red and 50 blue balls. In urn **A**, there are 100 balls, but you do not know their composition. You draw two balls from one of the two urns and win if the balls match in color. Suppose you are offered the following gambles. *RR*: drawing twice from **R** and *AA*: drawing twice from **A**. Which gamble do you prefer: *RR* or *AA*?

Although the gamble *RR* may seem more attractive than *AA*, since its content is merely *risky*), *AA* has an unambiguously *larger* win probability than *RR*. The more *unevenly* distributed urn **A**'s contents, the higher the win probability of *AA*. Urn **A** having 50% red balls and 50% blue balls is the *worst case*: it yields a probability of winning equal to $\frac{1}{2}$. Any other distribution gives a probability of winning that is higher. If the distribution were, say, $(\frac{1}{3}, \frac{2}{3})$, the probability of winning would be $\frac{5}{9} > \frac{1}{2}$.

We call the preference for the *RR*-gamble over the *AA*-gamble the *Two-Ball Ellsberg Paradox*. Economic theory for decision-making under risk and ambiguity cannot explain the Two-Ball Ellsberg Paradox. When it comes to models for decision-making under risk, the easiest way to see this violation is to consider their representation theorem. When it comes to models for decision-making under ambiguity, the easiest way to see this violation is to consider the monotonicity axiom on which all standard models are based.

Economic Models Under Ambiguity cannot explain the Two-Ball Ellsberg Paradox. Since [Ellsberg \(1961\)](#)'s seminal paper, many axiomatized models have been developed for making decisions under ambiguity. Amid the most standard ones, [Schmeidler \(1989\)](#) proposed Choquet expected utility (CEU), [Gilboa and Schmeidler \(1989\)](#) designed Maximin expected utility (MEU), [Ghirardato et al. \(2004\)](#) suggested the alpha-maximin expected utility (α -MEU). Other important models to cite are: [Klibanoff et al. \(2005\)](#), [Maccheroni et al. \(2006\)](#), and [Strzalecki \(2011\)](#).

All these classes of models are based on a core axiom of decision-making under ambiguity: monotonicity ([Anscombe and Aumann \(1963\)](#)). Accordingly, if, in each state of the world, act f grants a weakly preferred lottery over act g , then the decision-maker must weakly prefer act f to act g . Formally, Given two acts F, G mapping a state space S to outcomes, if in each state $s \in S$ we have $F(s) \succeq G(s)$ then we must also have $F \succeq G$.

The Two-Ball Ellsberg Paradox violates monotonicity as defined above. Define $S = \{0, 1, \dots, 100\}$, where a state $s \in S$ is the number of red balls in urn **A**. Betting on urn **R** always has win probability $\frac{1}{2}$, while betting on urn **A** in state s has win probability $\left(\frac{s}{100}\right)^2 + \left(1 - \frac{s}{100}\right)^2 \geq \frac{1}{2}$. So assuming individuals care only about the win probability, in each state s we have that $\mathbf{A}(s) \succeq \mathbf{R}(s)$. Monotonicity implies they cannot strictly prefer **R** to **A**.

This violation persists even if we consider the weaker monotonicity axiom of ?. Given two acts F and G , if it is the case that for each prize x and each state s we have $\mathbb{P}(F(s) \geq x) \geq \mathbb{P}(G(s) \geq x)$, then $F \succeq G$. In gambles **A** and **R**, the only prizes that can be given are \$0 and \$3, so checking that the hypothesis " $\mathbb{P}(\mathbf{A}(s) \geq x) \geq \mathbb{P}(\mathbf{R}(s) \geq x)$ holds for each prize x and in each state s " holds means checking that in each state s , the win probability of act **A** is at least as large as the win probability of act **R**. This was demonstrated above. Hence, a strict preference for **R** over **A** would violate this axiom.

1.2 Aims and Methods of the Paper

Aims of the experiment. In this paper, we report the results of an incentivized experiment on a nationally representative US sample to test whether people show Two-Ball Ellsberg preferences and, if so, to understand whether it is simply due to irrationality and lack of understanding. Our experiment aims to answer two main questions. First, do subjects occasionally avoid an ambiguous act by choosing an unambiguous lottery worse than any lottery the ambiguous act could produce? Second, how are subjects' choices in this Two-Ball Ellsberg Paradox related to other modes of behavior, such as failing to reduce compound lotteries?

Overview of the experimental method. We examine subjects' choices in the novel Two-Ball Ellsberg gamble and determine how these relate to their choices in other scenarios, most notably the "classic" Ellsberg paradox and various other elicitation. Elicitations in our experiment are divided into *blocks*, with four treatments consisting of specific blocks randomized in a certain order. All subjects' choices were elicited through their CEs (CEs) using a multiple price list (MPL) to determine their preferences over various gambles. Laboratory experiments eliciting subjects' CEs for gambles are often subject to significant measurement error, i.e., biases in estimating coefficients and correlations. We rely on the *Obviously Related Instrumental Variables* (ORIV) approach to correct these errors [Gillen et al. \(2019\)](#).

1.3 Main Results, Discussions And Implications

Main results of the experiment. Overall, we determined that subjects exhibited a distaste for ambiguity *per se* as opposed to avoiding it simply because it may have yielded a worse outcome.

The two most important findings supporting this idea of ambiguity aversion *per se* are the following ones from our core treatment, labelled **NUDGING**. First, this treatment revealed that the lack of understanding does not entirely explain the preference for avoiding ambiguity. Subjects "correctly" select the act with a larger win probability when comparing two similar acts that are *both* ambiguous. Second, the treatment revealed that such preferences are deliberate. Subjects in this treatment who compared similar ambiguous acts "learned" nothing from this experience. They continued to prefer the lower-win probability, unambiguous acts as other subjects not involved in this treatment. This lack of "nudging" suggests subjects' preference for avoiding ambiguity – even when it can only improve their odds of receiving a prize – is *deliberate*.

Main discussions of the results. First, this distaste could be explained as an instance of complexity [Halevy \(2007\)](#) and the fact of not choosing the ambiguous option, evidence of cognitive failure in complex enough environments. If this is the case, then we have identified the presence of ambiguity as a driver of change in people's behavior, perhaps through complexity or other means. Second, as we elaborate in our discussion, correlation neglect (?) does not seem to explain our results. Third, unlike in the original Ellsberg paradox (?), a subject cannot eliminate the ambiguity in the ambiguous gamble by introducing randomization in her choice of color.

In the case where ambiguity would be an instance of complexity, contingent reasoning, as in ? seems a good candidate to explain our results. In general, this distaste for ambiguity suggests the existence of a *cognitive cost* to exposure to ambiguity, that should be formalized to completely capture ambiguity aversion.

Main implications of the results. Whether explained or not as an instance of complexity, people harboring a distaste for ambiguity has potentially widespread implications for economics. Subjects may prefer to gamble *R* to *A* in the classic Ellsberg paradox, primarily because they dislike the presence of ambiguity, but not, for instance, because they hold concern for worst-case scenarios, as [Gilboa and Schmeidler \(1989\)](#) would suggest. New models may be required to explain people's behavior adequately.

1.4 Literature Review

The recent experimental literature has produced several experimental tests and thought experiments that challenge these models of decision-making under risk and ambiguity. We may classify them into two main categories. The first demonstrates the limited cases of such models in specifically plausible test settings. The second questions the fundamental axioms underlying these models in generally plausible test settings. The main difference between the two approaches lies in the fact that the first category develops examples that involve inconsistencies between *multiple* choices facing the decision-maker. For example, they are of the form “If you prefer A to B, then you cannot also prefer C to D.” Furthermore, a variety of somewhat contrived examples may be required to refute various models.

Related to the first category, [Machina \(2009\)](#) presents thought experiments that demonstrate plausible violations of the CEU model. [Baillon et al. \(2011\)](#) employ variations on [Machina \(2009\)](#) to propose plausible violations of several of the decision-making models mentioned above. [L’Haridon and Placido \(2010\)](#) test one of these examples, the so-called “reflection example” of [Machina \(2009\)](#), in an experimental setting and reject the MEU and VP models and the smooth ambiguity model of [Klibanoff et al. \(2005\)](#). [Blavatsky \(2013\)](#) proposes a variant of Machina’s reflection example, casting doubt on more recent decision-making models under ambiguity, such as [Siniscalchi \(2009\)](#)’s *Vector Expected Utility* (VEU). These thought-experiment examples and the experimental tests by [L’Haridon and Placido \(2010\)](#) cast doubt on the models mentioned above.

Related to the second category, [Halevy \(2007\)](#) demonstrates that individuals’ preferences may be inconsistent with the proper reduction of compound lotteries, an assumption that is implicitly a part of any model built on the framework of [Anscombe and Aumann \(1963\)](#). He further shows that ambiguity aversion in the classic experiment of [Ellsberg \(1961\)](#) is closely correlated with an adverse reaction to compound lotteries. [Gillen et al. \(2019\)](#) replicate [Halevy \(2007\)](#)’s experiment with a correction for measurement error, revealing that this correlation may be close to 1. [Schneider and Schonger \(2019\)](#) examine whether subjects’ preferences satisfy a weak form of the monotonicity axiom (*weak separability*) and find that nearly half of the subjects violate it. They find no evidence that complexity aversion or failure to reduce compound lotteries explains these violations. Furthermore, subjects violating the monotonicity axiom generally make choices consistent with first-order stochastic dominance when choosing under risk, demonstrating that these violations are likely unrelated to a lack of understanding of their choices.

Our experiment falls into the second category of general challenges. Our experiment distinguishes itself from these experiments by proposing a new class of decision problems, namely, Two-Ball Ellsberg drawings. As they feature ambiguity but guarantee a minimum win probability that is at least as large as that of some other gambles, they enable us to test whether a subject avoids ambiguity *per se* as opposed to avoiding ambiguity because it may yield a worse outcome.

1.5 Structure of the Paper

Apart from this introduction, our paper contains three main sections and concludes.

In Section 2.1 we describe our elicitations. In Section ?? we describe our four treatments. In Section 2.6 we provide details. In Section 2.7, we elaborate on ORIV and how we implement it in our experiment.

In Section 3.1, we present the data sample details and the summary statistics. In Section 3.2, we present our first key result, the fact that participants show Two-Ball Ellsberg Paradox. In Section 3.3, we show our second key result: such preferences are not due to a lack of understanding and rather, are deliberate and as such, they relate to a distaste for ambiguity *per se*. In Section 3.4, we explore additional questions to further confirm this second result.

In Section 4, we focus on the discussion on this “ambiguity distaste *per se*”: ambiguity is already complex enough to drive participants away from gambles that have consistently higher win probabilities.

Section 5 concludes by summarizing the main results and providing some potential avenues for future research.

2 Experimental Design

2.1 Experimental Overview

Each treatment is divided into *blocks* consisting of one or multiple gambles for which the subject must report their CEs.

Below, we summarize each block’s contents that appear in at least one treatment. In each question, “winning” the gamble means a payoff of 300 tokens (= \$3), and “losing” means a payoff of 0 tokens. The notation “[x red, y blue]” means an urn that contains exactly x red balls, y blue balls, and no other balls. Similarly, “[Unknown red, Unknown blue]” means the urn contains an unknown number of red and blue balls and

no other balls. For notational convenience, \mathbf{R} = [50 red, 50 blue] and \mathbf{A} = [Unknown red, Unknown blue].

Subjects were informed that the contents of urn \mathbf{A} would vary from question² to question (i.e., the contents of ambiguous urns are re-determined between questions). In practice, the contents of each urn \mathbf{A} were determined by drawing an integer X uniformly at random between 0 and 100. A virtual urn containing X red balls and $100 - X$ blue balls was created. Subjects were not informed of this procedure to determine the contents of ambiguous urns.

To perform ORIV, we double-elicited subjects' CEs for all gambles of central importance to our analysis; however, due to time constraints and concerns that subjects may "zone out" and provide especially noisy answers if asked too many repeated similar questions, we could not double-elicit CEs for all gambles. We focused on double eliciting the most relevant gambles to our paper. We will attach the symbol \mathbf{D} to the name of an elicitation when we refer to a duplicate of this later.

As mentioned in the introduction, our experiment contains four treatments comprising a specific number of blocks randomized in a certain order, as we elaborate here.

A block contains either one or several similar elicitations. Before each block, subjects view the relevant instructions. Each elicitation within a given block contains (1) a reiteration of the block's instructions, (2) the new details of that particular elicitation, highlighted in yellow, and (3) a report of the subjects' CE for that elicitation.³ Subjects must report their CE before moving on to the next elicitation screen. Elicitations are uniformly, independently, and randomly ordered between the subjects within a given block. Each treatment may only contain 11 or 12 elicitations to accommodate online cognitive fatigue and prevent attention deficits.

Table 1 summarizes the structure of each treatment. Each item in bold is one of the blocks described in Section 2.1. Multiple items within parenthesis () mean that the order of these items is determined uniformly at random, independently for each subject. Items within brackets [] are not randomized; they always appear in the order listed within the brackets.

In each treatment, we double-elicited subjects' CEs for the two classic **Ellsberg** gambles as well as the two Two-Ball gambles in the **2BallShort** block (which also appear within its longer version **2Ball**). Thus, using data from all four treatments, we can

²In the remaining of our paper, we will use the words "elicitations" and "questions" as synonyms.

³Certain elicitations require the subject to choose a color (i.e., red or blue) to place a bet. For these elicitations, the subject must select a color before they can report their CE, which appears on the screen.

robustly determine if subjects prefer RR (or R) over AA , even though the latter is more likely to win. Furthermore, by comparing a subject’s responses to these Two-Ball gambles with their responses to the classic **Ellsberg** gambles, we can determine the relationship between ambiguity aversion, risk aversion, and “falling for” the Two-Ball Ellsberg paradox.

Treatment	Contents of Treatment
PARADOX	[(Ellsberg, 2Ball), (EllsbergD, 2BallD)]
COMPLEXITY	[(Ellsberg, 2BallShort, Compound), (EllsbergD, 2BallShortD, CompoundD)]
NUDGING	(BoundedU, [(Ellsberg, 2BallShort), (EllsbergD, 2BallShortD)])
ROBUSTNESS	((Ellsberg, 2BallShort), (3Ball, Independent), (EllsbergD, 2BallShortD))

Table 1: TREATMENTS

Each of the four treatments also contains additional questions specific to that treatment, summarized below.

2.2 Treatment PARADOX

2.2.1 Purpose

The purpose of Treatment **PARADOX** is to determine the relationship between subjects’ CEs for these four gambles. In particular, if subjects report higher CEs for RR than AR (despite each winning with 50% probability), this suggests that subjects are “scared away” from gambles involving ambiguous urns. Additionally, suppose subjects report lower CEs for RA than AR . In that case, this perhaps suggests that subjects fear that the contents of urn **A** may only be determined *after* the first ball has been drawn from urn **R**, even though the instructions explain this not to be the case.

2.2.2 Structure and Elicitations

(Ellsberg, 2Ball), (EllsbergD, 2BallD)

Ellsberg This block replicates the classic Ellsberg experiment, in which subjects provide their CEs for two gambles. In each gamble, they choose a color (red or blue) and win if a single ball drawn randomly matches their selection. The gambles are as follows:

(R) The urn is [50 red, 50 blue].

(A) The urn is [Unknown red, Unknown blue].

EllsbergD This block is a duplicate of the **Ellsberg** block where all instances of the urn [50 red, 50 blue] are replaced with [25 red, 25 blue].

2Ball This block contains this experiment's central questions. Subjects provide their CEs for four gambles, each containing a "1st urn" and a "2nd urn," where these two urns may be the same urn. A ball is drawn randomly from the 1st urn and returned to the same urn. Then a ball is drawn randomly from the 2nd urn. Subjects win if the two balls are the *same color*. The gambles are as follows:

(RR) 1st urn = [50 red, 50 blue], 2nd urn = 1st urn (i.e., the "2nd urn" is the same urn as the 1st urn.)

(AA) 1st urn = [Unknown red, Unknown blue], 2nd urn = 1st urn.

(RA) 1st urn = [50 red, 50 blue], 2nd urn = [Unknown red, Unknown blue].

(AR) 1st urn = [Unknown red, Unknown blue], 2nd urn = [50 red, 50 blue].

2BallD This block is a duplicate of **2Ball** where all instances of the urn [50 red, 50 blue] are replaced by [40 red, 40 blue].

2.3 Treatment NUDGING

2.3.1 Structure and Elicitations

2BallShort This block contains questions *RR* and *AA* from the **2Ball** block.⁴

2BallShortD This block is a duplicate of **2BallShort** where all instances of the urn [50 red, 50 blue] are replaced by [40 red, 40 blue].

⁴Due to time constraints, three of four treatments use **2BallShort** instead of **2Ball**; subjects' CEs for *RR* and *AA* have more central importance than *RA* and *AR*.

BoundedA This block is similar to **2Ball**, except that balls are drawn from ambiguous urns with "bounds" on the number of balls of certain types contained. Subjects provide their CEs for three gambles. In each gamble, there is an urn **A** = [Unknown red, Unknown blue] from which two balls are drawn with replacement. Subjects win if the two balls are the *same color*. The gambles are as follows:

(BB^{40-60}) Urn **A** is known to contain between 40 and 60 red balls (but its contents are otherwise unknown).

(BB^{60-100}) Urn **A** is known to contain between 60 and 100 red balls (but its contents are otherwise unknown).

(BB^{95-100}) Urn **A** is known to contain between 95 and 100 red balls (but its contents are otherwise unknown).

2.3.2 Purpose

The purpose of Treatment **NUDGING** is threefold.

First, it allows us to determine the relationship between "falling for" the Two-Ball Ellsberg paradox and preferring BB^{40-60} to the other gambles in **BoundedA**; that is, making a choice that is even worse than the wrong choice in **2BallShort**.

Second, by comparing the responses to **2BallShort** across subjects who either (i) completed block **BoundedA** *before* **2BallShort** or (ii) completed **BoundedA** *after* **2BallShort**, we can determine if the process of answering the questions in **BoundedA** has a "nudging" effect, i.e., if completing **BoundedA** before **2BallShort** decreases the likelihood or strength of a subject falling for the Two-Ball Ellsberg paradox.⁵

Third, Treatment **NUDGING** may allow us to rule out certain explanations for subjects falling for the Two-Ball Ellsberg paradox. Specifically, if a subject prefers BB^{40-60} to BB^{60-100} , this suggests that either

- (a) they prefer avoiding the "larger amount of ambiguity" in BB^{60-100} , even if this means sacrificing some probability of winning, or
- (b) they prefer more "evenly-distributed" (i.e., closer to 50-50) urns for this type of gamble, perhaps because they do not realize that a more unevenly distributed urn has a higher win probability.

⁵One might suspect that a subject completing **BoundedA** could learn to prefer more unevenly distributed urns to more evenly distributed ones when considering a Two-Ball gamble, as (among other things) **BoundedA** asks the subject to consider how likely they are to win a Two-Ball gamble when the urn is at least 95% red balls.

If (b) is true but (a) is false, then the subject should prefer BB^{40-60} to BB^{60-100} and also prefer BB^{60-100} to BB^{95-100} . If they do not, this suggests their preference for BB^{40-60} over BB^{60-100} is not from simply failing to calculate win probabilities correctly but instead is a deliberate sacrifice of win probability to avoid the increased ambiguity of BB^{60-100} .

2.4 Treatment COMPLEXITY

2.4.1 Structure and Blocks

Compound This block contains questions about compound lotteries. Subjects provide their CEs for two gambles involving a new urn **N**. They are informed that urn **N** = [X red, $100 - X$ blue] where X is an integer drawn uniformly at random between 0 and 100. The gambles are as follows:

- (C) Subjects pick a color (either red or blue), and a ball is randomly drawn from urn **N**. Subjects win if the ball matches the selected color.
- (CC) A ball is drawn randomly from urn **N**, then put back. A second ball is drawn randomly from urn **N**. Subjects win if both balls are the same color.

2.4.2 Purpose

Recall that the **Compound** block consists of two gambles: [Halevy \(2007\)](#)'s compound lottery *C* and a "Two-Ball Halevy" gamble *CC*. Gamble *CC* is the same as the ambiguous gamble *AA* from **2Ball**, except its urns' contents are determined by a known lottery rather than an unknown, ambiguous procedure.

The purpose of Treatment **COMPLEXITY** is threefold. First, question *C* replicates [Halevy \(2007\)](#)'s experiment; it allows us to determine which subjects have CEs for gamble *C* that are not the same as those for a simple 50% lottery, such as gamble *R* from the **Ellsberg** block. Thus, we can re-test [Halevy \(2007\)](#) and [Gillen et al. \(2019\)](#)'s conclusions that ambiguity aversion in the classic Ellsberg paradox is closely linked to such failure to reduce compound lotteries. Second, Treatment **COMPLEXITY** may allow us to extend these results by determining how these two modes of "irrational" behavior are linked to the "irrational" preference for *RR* over *AA* in block **2Ball**.

Third, question *CC* allows us to test if the "irrational" preference for *RR* over *AA* in block **2Ball** is either

- due to a preference to avoid the *ambiguity* present in *AA* or

- due to a preference to avoid the *complexity* in both *AA* and *CC* (or, perhaps, due to a *lack of understanding* of both of these gambles).

A subject preferring *RR* over *AA* and *CC* to *AA* would suggest that they try to avoid ambiguity more than they seek to avoid complexity. Similarly, a subject preferring *RR* to both *AA* and *CC* would suggest that the "irrational" choice of *RR* is primarily explained by an aversion to complexity or a lack of understanding.

2.5 Treatment **ROBUSTNESS**

2.5.1 Structure and Blocks

3Ball This block contains questions similar to **2Ball**, except with three urns instead of two. Subjects provide their CEs for three gambles. In each gamble, there is a "1st urn," "2nd urn," and "3rd urn," and any of these three urns may be the same urn. A ball is drawn randomly from the 1st urn and returned to the same urn. Another ball is drawn randomly from the 2nd urn and returned to the same urn. Finally, a ball is drawn at random from the 3rd urn. Subjects win if the three balls are all the *same color*. The gambles are as follows:

(R3) 1st urn = [50 red, 50 blue], 2nd urn = 1st urn, 3rd urn = 1st urn.

(A3) 1st urn = [Unknown red, Unknown blue], 2nd urn = 1st urn, 3rd urn = 1st urn.

(RAA) 1st urn = [50 red, 50 blue], 2nd urn = [Unknown red, Unknown blue], 3rd urn = 2nd urn.

Independent This block contains a single question:

(IA) There are two urns, A1 = [Unknown red, Unknown blue] and AA = [Unknown red, Unknown blue], whose contents are determined independently. One ball is drawn at random from each of A1 and AA. Subjects win if the two drawn balls are the same color.

2.5.2 Purpose

Treatment **ROBUSTNESS** contains two blocks not appearing in other treatments: **3Ball** and **Independent**.

In **3Ball**, subjects report their CEs for the 3-Ball gambles R3, A3, and RAA. These questions are designed with two purposes in mind. First, the combination of questions

$R3$ and $A3$ allows us to compare the "ambiguity premium" (positive or negative) of a Three-Ball gamble to the ambiguity premium of a Two-Ball gamble determined in **2Ball**.⁶

Second, question RAA provides two useful comparisons. Comparing the RAA and $A3$ answers indicate how a subject's ambiguity premium changes as the "amount" of ambiguity increases. Similarly, comparing RAA to AA from block **2Ball** allows us to determine if a subject's CE for RAA is above, below, or equal to half the CE of AA , as RAA has precisely half the win probability of AA .

In **Independent**, subjects report their CEs for a 2-stage gamble, IA , where the two balls are drawn from separate ambiguous urns whose contents are determined independently. This block is designed for two reasons. First, comparing subjects' CEs for IA and AA allows us to determine if they mistakenly interpret the two draws from the *same* ambiguous urn to be the same as the two draws from *independent* ambiguous urns. Second, since (as long as the subject believes the ambiguity is color-neutral) the gamble IA is equivalent to the "1-Ball" ambiguous gamble, A , from **Ellsberg**⁷, comparing CEs for these two gambles allows us to test if subjects are indeed indifferent. We can then determine how a preference between these two gambles explains choosing RR over AA in **2Ball**.

2.6 Incentive Mechanism and Measurement Procedure

As mentioned in the introduction, we elicit the subjects' CEs using MPLs to determine their preferences over various acts. Each question introduces a gamble as detailed above. When agents do not make choices that correspond to the expected utility theory predictions, using the MPL mechanism may be problematic. For example, **Karni and Safra (1987)** demonstrated that incentive-compatible mechanisms could not elicit CEs if the independence axiom does not hold. Despite this concern, the MPL mechanism has been used extensively in experiments where agents face risk or ambiguity when making choices, many of which included the possibility of their choices over lotteries not satisfying the predictions of expected utility theory. This is perhaps because the MPL offers several advantages over other mechanisms. **Andreoni and Kuhn (2019)**

⁶The Three-Ball gamble where all balls are drawn from urn **R** has only half the win probability of the analogous Two-Ball gamble; hence, comparisons of ambiguity premia must be adjusted accordingly. See Sections 3.4.1 and 3.4.2 for further details.

⁷To see that these gambles are equivalent, fix the first ball drawn (from $A1$) in **Independent**. If the first ball is red, the subject wins if one ball drawn from an ambiguous urn (AA) is red. If the first ball is blue, the subject wins if one ball drawn from an ambiguous urn is blue. Thus, as long as the subject believes that the ambiguity is color-neutral, the gamble in **Independent** is the same as gamble (2) of **Ellsberg**, regardless of which color ball is drawn from $A1$.

argue that the MPL mechanism is extremely easy for subjects to understand and yields more consistent choices than other standard mechanisms for eliciting risk preferences. Furthermore, it provides externally valid predictions once adjusted for measurement error.

Our experiment's MPL table contains 31 rows corresponding to fixed prize values between 0 and 300 tokens, in increments of 10 tokens. There are 32 possible locations where a subject can place their "cutoff" (below which they prefer the gamble and after which they prefer the fixed prize). If a value $x \in \{0, 10, \dots, 290\}$ exists such that the subject prefers the gamble to receive x tokens but prefers receiving $x + 10$ tokens to the gamble, then this was recorded numerically as "the subject's CE is $x + 5$." If the subject preferred 0 tokens to the gamble, the CE was 0. Finally, if the subject preferred the gamble to 300 tokens, the CE was 300.

In each row, subjects select either the left column ("Receive fixed payment") or the right column ("Play the gamble"). To make the process less time-consuming and enforce the consistency of choices, the subject's selection in each row is automatically completed based on a limited number of clicks. For example, if a subject clicks to indicate a preference for 150 tokens instead of the gamble, the JavaScript algorithm automatically completes rows 160 through 300 to indicate that the subject also prefers receiving tokens to the gamble. Similarly, if the subject prefers the gamble instead of receiving 140 tokens, the software automatically completes rows 0 through 130 to indicate a preference for playing the gamble over receiving tokens. Subjects can revise their choices (consistent with the autocompletion rules above) before moving on to the next question.

Each question contains, at most, one row in which the subject's preference switches from preferring the gamble to preferring a specific amount of tokens. The subject's CE for the gamble must lie between the token amounts listed in this row and the previous row. We then record the subject's CE as the *midpoint* between the two rows, i.e., a number ending in 5. If the subject prefers the gamble over 300 tokens or prefers 0 tokens to the gamble, then no such "switching" row exists. Nonetheless, if the subject prefers the gamble over a fixed payment of 300 tokens, their CE may be considered as 300 tokens, as the gamble cannot pay more than 300 tokens. Similarly, if the subject prefers 0 tokens to the gamble, their CE is 0. In these cases, we record the subject's CE as 300 or 0, respectively.

Fourteen questions are selected uniformly at random for payment from among all the questions in a given treatment to make this mechanism incentive compatible. Some experiments eliciting risk attitudes select only a single question for payment, avoiding

the possibility of subjects using their choices in different questions to hedge their payoffs; however, doing so creates a significant variance in the monetary payments that different subjects receive, which was undesirable for this experiment. If a question is selected for payment, then one row of that question's MPL table is selected at random, and the subject is given whatever their preference is in that row. For example, if row 120 was selected and the subject preferred the gamble to 120 tokens, then the gamble is simulated, and the subject wins the prize (usually 300 tokens) or receives 0 tokens if they lose. If the subject preferred 120 tokens to the gamble, they would receive 120 tokens.

To eliminate the possibility of wealth effects and ensure that subjects did not "learn" the distribution used to resolve ambiguity, the payoffs for each question (as well as which questions were selected for payment) were not determined until after the subject completed the entire experiment. Subjects were invited to practice with the MPL mechanism (before the experiment) and observe a summary of the results; they were informed that these practice questions would not be selected for payment. Furthermore, none of these questions involved ambiguity; hence, none presented an opportunity to learn how this experiment resolved ambiguity.

At the end of the experiment, subjects were presented with a table summarizing the questions selected for payment, the row selected in that question's MPL, the subject preference in that row, and (if they preferred the gamble) whether they won the gamble. Moreover, the subject's total payment was \$1 for every 100 tokens earned, in addition to a fixed payment of \$2 for participation.

2.7 Double Elicitations, Measurement Error and Attention Screeners

As mentioned in the introduction, laboratory experiments eliciting subjects' CEs for gambles are often subject to significant measurement errors. If not considered, such errors can create significant bias in estimated correlations and regression coefficients. Methods to correct for such measurement error involve eliciting subjects' CEs *twice* for each gamble of interest.

Although many techniques can then be used to eliminate the bias in estimating coefficients and correlations; the ORIV proposed in [Gillen et al. \(2019\)](#) generally estimates these parameters with lower standard errors. Hence, we rely on the latter. Essentially, this estimation entails using multiple instrumentation strategies simultaneously, then combining the results.

Due to the complex nature of some of the questions, it is concerning that some subjects may not comprehend the questions or may simply give random responses to complete the experiment quickly. Although most of the financial reward comes from incentivized MPL questions, there is a small fixed reward for merely completing the experiment. To avoid this concern, subjects were screened based on three criteria:

- (1) After receiving general instructions concerning the experiment, subjects were given a basic comprehension quiz with three questions regarding those instructions. Subjects unable to correctly answer the three questions were removed from the experiment. They received a small fixed amount for their two-minute participation and were made aware of this scenario when they offered their consent.
- (2) Between each of the experiment's major sections, subjects were given a standard attention-screening question.
- (3) If, in the course of our double elicitation of a subject's preferences, two reported CEs for the same question differed by more than 100 tokens—that is, one third the size of the 300-token table—then the subject was deemed to be paying insufficient attention to the experiment.⁸

Subjects failing criterion (1) were immediately removed from the experiment and received a minimum payment.⁹ Subjects failing at least one of the attention-screening questions in (2) were subsequently removed. Finally, subjects deemed to be paying insufficient attention according to (3) were removed. As a result, out of an initial 880 subjects, 172 were excluded from our data set.

3 The Data

3.1 Data Sample Details and Summary Statistics

We used Prolific to run our experiment and collect our data. Prolific is an online survey platform that, due to its participant pool's quality, is increasingly used in economics to conduct surveys and incentivized experiments due to its qualitative participant pool. Our sample comprised 880 participants, selected to be nationally representative in age and gender. Of these initial 880 participants, 708 passed the basic attention-screening

⁸Other thresholds for exclusion, such as "differed by more than 150 tokens," yield qualitatively similar results to those below. See Appendix.

⁹See section 3.1 for details.

questions and criteria described in Section 2.7. All 708 received a \$2 fixed participation payment, and they averaged an additional \$3.50 in bonus payments from the incentivized parts of the experiment.¹⁰

Table 2 summarizes the naming conventions for the various CEs. Variables with a superscript j were elicited twice; others were elicited only once. The variable R_i^j is the j th elicitation of subject i 's CE for a simple 50-50 gamble. For convenience, we will let

$$R_i = \frac{R_i^1 + R_i^2}{2}$$

denote the *average* CE R reported by subject i across the two elicitations. Similarly, when we mention any variable that was double-elicited but exclude the superscript, we refer to the *average* value of that variable across the two elicitations.

Name	Description
R^j	j th elicitation of CE for 50-50 urn of Ellsberg
A^j	j th elicitation of CE for ambiguous urn of Ellsberg
RR^j	j th elicitation of CE for 50-50 urn in 2Ball
AA^j	j th elicitation of CE for ambiguous urn in 2Ball
AR^j	j th elicitation of CE for "1st urn= A , 2nd= R " gamble of 2Ball
RA^j	j th elicitation of CE for "1st urn= R , 2nd= A " gamble of 2Ball
$R3$	CE for 3Ball with all three urns = R
$A3$	CE for 3Ball with all three urns = A
RAA	CE for 3Ball with 1st urn = R , latter two urns = A
IA	CE for Independent (Two-Ball gamble with independent ambiguous urns)
C^j	j th elicitation of CE for single-urn gamble of Compound
CC^j	j th elicitation of CE for Two-Ball gamble of Compound
BB^{40-60}	CE for BoundedA with ambiguous urn containing 40-60 red balls
BB^{60-100}	CE for BoundedA with ambiguous urn containing 60-100 red balls
BB^{95-100}	CE for BoundedA with ambiguous urn containing 95-100 red balls

Table 2: **RAW VARIABLE NAMES**

We move to the summary statistics of all of the variables that were double-elicited in the experiment: R , A , C , RR , AA , CC , RA , and AR .¹¹ The mean and 95% con-

¹⁰See the Appendix for a detailed presentation of our screening for quality process.

¹¹The reader may consult Table 7 in the appendix for a more detailed overview.

fidence interval for each of the two elicitations of that variable are presented below each variable. The correlation between the two elicitations (and its standard error) is presented below the confidence intervals. These correlations range between .855 and .883, suggesting that subjects are fairly consistent in their answers when asked the same question twice.¹²

We turn now to the summary statistics for the derived variables, such as $R - A$, that measure how much subjects prefer a simple 50-50 gamble over other gambles that are at least as good. We find that the classic Ellsberg paradox is replicated in this experiment; subjects prefer the 50-50 gamble R to the ambiguous gamble A . Averaging across elicitations, $R - A$ takes an average value of 12.31 cents ($t = 10.03$). Similarly, Halevy (2007)'s experiment is replicated; subjects prefer the simple 50-50 gamble R to the compound 50-50 gamble C by an average of 6.82 cents ($t = 3.26$).¹³

3.2 Two-Ball Ellsberg Paradox

The variable $R - AA$ measures how subjects prefer the simple 50-50 gamble R to the Two-Ball ambiguous gamble AA . As shown in Figure 1 below, the complete distribution of $R - AA$ for each elicitation is always positive and statistically significant. On average across subjects, $R - AA$ is positive (mean = 16.41) and statistically significant ($t = 10.66$). This means that subjects are typically willing to pay about 16 cents more for R than AA , even though the latter is more likely to win.

This difference is not merely statistically significant but also of noticeable size. All of the derived variables have standard deviations between 55.00 (namely, AR) and 60.15 (namely, AA). Therefore, a 16.41 difference represents a change of more than 0.27 standard deviations, or just over a 10 percentile change from the center of a Normal distribution. Although this change is not enormous, it is quite noticeable.

¹²As mentioned in Section 2.7, answers for the same question that differed by more than 100 tokens were removed from the data set because the subjects seemed to be paying less attention. See the online appendix for analysis that includes these subjects.

¹³The reader may consult Table 8 in the appendix for a comprehensive report overview.

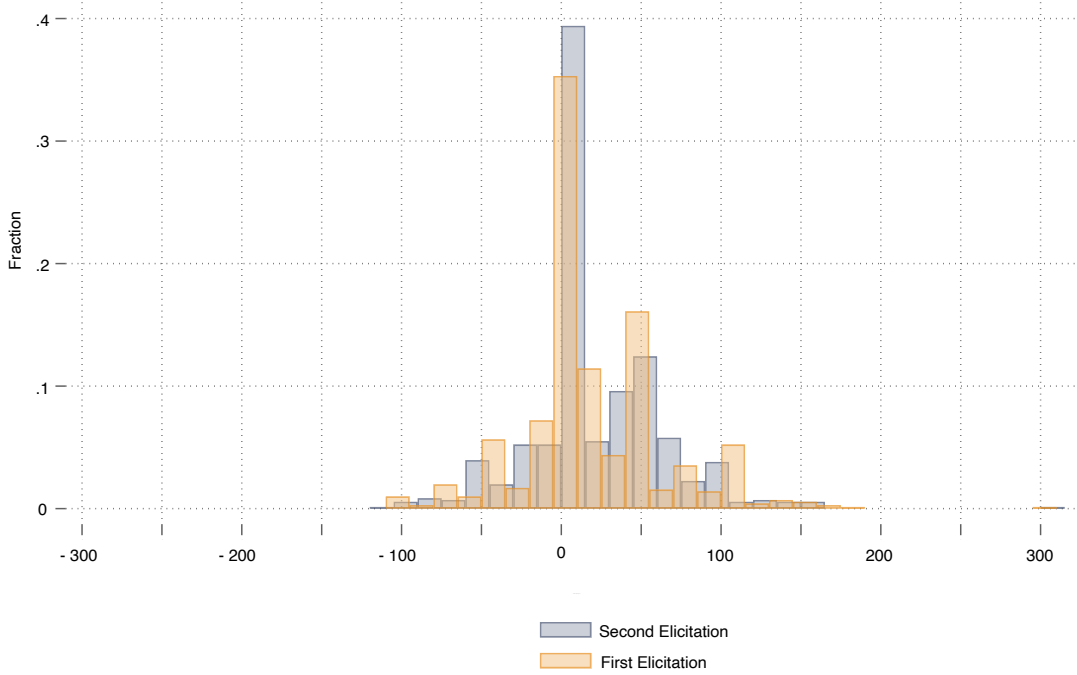


Figure 1: **HISTOGRAM OF $R - AA$, BY ELICITATION**

At present, we analyze the relationship between the preference for R over AA , (a) a general preference for "simplicity," and (b) ambiguity aversion in the classic Ellsberg paradox.

Dependent Variable: $R - AA$				
Indep. Variable:	$R - A$	$R - RR$	$R - C$	$R - CC$
ORIV ρ	0.892 (0.017)	0.952 (0.012)	0.954 (0.024)	0.917 (0.032)
N	708	708	158	158

Table 3: **RELATIONSHIPS BETWEEN CE DIFFERENCES**

The variable $R - A$ measures subjects' ambiguity aversion in the classic Ellsberg paradox, while $R - C$ measures their preference for a simple 50-50 gamble over a compound 50-50 gamble. $R - RR$ measures subjects' preference for a 1-Ball 50-50 gamble

to a Two-Ball 50-50 gamble. The variables $R - C$ and $R - RR$ are not statistically different ($t = .614$), suggesting that they both measure subjects' aversion to complexity; the first measures aversion to compound lotteries, while the second measures aversion to multi-draw gambles.¹⁴

$R - CC$ measures subjects' preference for a simple 50-50 gamble over a gamble that is both compound and Two-Ball (CC). $R - CC$ is similar to $R - AA$, except the urn in AA has ambiguous contents.

Table 3 shows that the ORIV-corrected correlations between $R - AA$ and each of $R - A$, $R - RR$, $R - C$, and $R - CC$ are quite high; however, $R - AA$ is larger than all of $R - A$, $R - RR$, and $R - C$ ($t > 4$ in all cases), but is only larger than $R - CC$ by a statistically insignificant amount ($t = 1.05$).

This insignificant difference suggests that subjects view CC and AA as somewhat similar, paying only a slightly larger premium to avoid AA than its non-ambiguous analog CC ; however, subjects' preference for simplicity in choosing R over the Two-Ball gamble RR cannot explain the choice of R over AA . Similarly, the choice of R over the compound gamble C and subjects' ambiguity-averse choice of R over A are insufficient. The strength of subjects' preference for R over AA can seemingly be explained by combining the compound nature, the Two-Ball feature, and possibly the ambiguity in AA .

One conceivable explanation for these aversions (compound nature, Two-Ball feature, ambiguity, or any combination thereof) is that subjects do not understand the presented gambles. Gamble AA is one of the most complicated gambles in the experiment, so the preference for R over AA may ultimately be entirely due to a lack of understanding that AA must have at least as high of a winning probability as R . Perhaps subjects prefer simpler gambles or gambles involving urns whose contents are known to be 50-50 due to a lack of understanding. There are three possible hypotheses to explain the preference for R over AA :

- (A) Subjects do not understand that a Two-Ball gamble with an urn whose contents are not 50-50 is more likely to win than a simple 50-50.
- (B) Subjects do not understand that in a Two-Ball gamble, a more "unevenly" distributed urn increases the win probability.
- (C) Subjects at least partially understand both (A) and (B), but they prefer R to AA , perhaps because R is simpler and less ambiguous.

¹⁴Although the Two-Ball lottery RR can itself be thought of as a compound lottery, it has many fewer possibilities to consider than [Halevy \(2007\)](#)'s compound lottery C .

The **BoundedA** and **Independent** blocks were designed to test these hypotheses. The data from **BoundedA** suggest that (A) and (B) are implausible, making (C) the most plausible hypothesis. In contrast, the data from **Independent** questions whether subjects’ understanding of the gambles is complete and universal.

The **BoundedA** block consists of gambles identical to the Two-Ball ambiguous gamble, *AA*, except the subject is given a particular range for the ambiguous urn’s percentage of red balls. Gamble BB^{40-60} ’s ambiguous urn contains 40 to 60 red balls, BB^{60-100} has 60 to 100 red balls, and BB^{95-100} has 95 to 100 (in all cases, there are 100 balls total). Table 4 summarizes subjects’ CEs for these gambles.

	BB^{40-60}	BB^{60-100}	BB^{95-100}
Mean	98.603	132.235	207.654
SD	(52.113)	(63.887)	(90.784)
<i>N</i>	179	179	179

Table 4: **BOUNDED-AMBIGUITY TWO-BALL GAMBLES**

If hypothesis (B) is true, subjects should prefer BB^{40-60} to BB^{60-100} , as the former has an ambiguous urn whose contents are closer to 50-50; however, the opposite is the case. Subjects prefer BB^{60-100} to BB^{40-60} by an average of 33.6 cents ($t > 9$). Similarly, they prefer BB^{95-100} to BB^{60-100} by an average of 75.4 cents ($t > 13$).

Indeed, even those 22 subjects who reported a larger CE for BB^{40-60} than BB^{60-100} showed a preference for BB^{95-100} over BB^{60-100} (mean = 68.64, $t = 3.36$). This indicates that the former preference cannot be entirely explained by failing to understand the gambles or having a universal preference for urns closer to 50-50.

These significant differences suggest that subjects understand that having a more “unevenly” distributed urn is advantageous in Two-Ball gambles. This makes hypothesis (B) implausible. Similarly, hypothesis (A) seems implausible, as subjects strongly prefer BB^{60-100} or BB^{95-100} to the simple 50-50 gamble *R* ($t > 3.9$ in both cases). This suggests that hypothesis (C) is the most plausible; subjects at least partially understand that *AA* is more likely to win than *R*, but they prefer to avoid its complexity and ambiguity.

Interestingly, subjects generally prefer *R* to BB^{40-60} (mean = 16.47, $t = 5.62$) even though the latter has a larger win probability. Since a total lack of understanding cannot explain this difference, it seems more plausible that it comes from a preference to avoid the complexity and ambiguity in BB^{40-60} . This preference to avoid complex-

ity/ambiguity is not sufficiently strong to cause a preference for R over BB^{60-100} (which has a winning probability somewhere between 52% and 100%); however, it *is* strong enough to cause a preference for R over BB^{40-60} (which has a winning probability only between 50% and 52%).

The **Independent** block consists of the single gamble IA , which is identical to AA except that the two draws in gamble IA are from *separate ambiguous urns* whose contents are determined *independently*. For this gamble, the mean of subjects' CEs is 107.839, and its standard deviation is 68.733.

Suppose subjects fully understand both gambles AA and IA . In that case, they must realize that IA is (in terms of ultimate win probabilities) equivalent to the 1-Ball ambiguous gamble A .¹⁵ For any given realization of the contents of urn A , AA has a winning probability at least that of A . If subjects only care about win probabilities and fully understand all the gambles, they should value IA and A identically and value AA the most.

In reality, among the 192 subjects in Treatment **ROBUSTNESS** (those asked about IA), A is slightly preferred to AA ; however, the figure is not statistically significant (mean = 2.63, $t = 1.18$). Similarly, these subjects slightly prefer AA to IA , but the preference is not significant (mean = 1.73, $t = .60$). Furthermore, when combining these two preferences, A is not significantly larger than IA (mean = 4.36, $t = 1.36$).

Interestingly, among the entire pool of 708 subjects across all four treatments, subjects slightly prefer A to AA in a way that *is* statistically significant (mean = 4.79, $t = 4.03$). This result suggests that inadequate sample size may cause the lack of statistical significance between A and AA (perhaps also between A and IA) in Treatment **ROBUSTNESS**. Altogether, this sample fails to disprove that subjects treat gamble IA differently from either A or AA , questioning whether subjects fully understand all the gambles.

3.3 Distaste for the Presence of Ambiguity

Recall that RA is a Two-Ball gamble in which subjects win if matching balls are drawn first from a 50-50 urn and second from an ambiguous urn. AR is the same gamble, but the order of the urns is reversed; RR is the same gamble, except both draws are from a 50-50 urn. Both RA and AR have a 50% win probability, so if subjects understand these gambles and care only about win probability, their CEs should be indistinguishable from those for the simple 50-50 gamble R .

¹⁵Assuming the subject chooses red or blue at random in gamble A

Subjects' average CEs for the Two-Ball gambles RA , AR , and AA are not statistically different. The largest of these differences is between AR and RA and is not significant (mean = 1.80, $t = 1.39$); however, RR is significantly larger than RA (mean = 11.33, $t = 5.89$), and A is also significantly larger than RA (mean = 4.27, $t = 2.10$).¹⁶

Notice that gambles RR and RA have a similar level of complexity, both being Two-Ball gambles; the only difference between them is that RA involves a draw from an ambiguous urn. Furthermore, both gambles have the same 50% win probability. This means that subjects' preference for RR over RA can only be explained as a *distaste for ambiguity*¹⁷, as the presence of an ambiguous urn is the only difference.

Subjects exhibit a statistically significant preference for RR over AA (which can only have a larger win probability); however, they do not exhibit a significant preference for AA over RA . This result suggests that win probabilities have little effect on subjects' preferences in these cases, at least relative to the other forces at play. Furthermore, from Section 3.2 we know that subjects do not entirely fail to understand that two draws from a single ambiguous urn have a higher chance of winning than two draws from a 50-50 urn. Thus, a distaste for the mere presence of ambiguity, or the complexity created by the mere presence of ambiguity, seems to be the only adequate explanation for the subjects' preferences.

Our claim that subjects' preference to avoid ambiguity (even when it can only improve their odds of winning) is *deliberate* is reinforced because subjects did not seem to "learn" to choose AA over R . This result held even when subjects were prompted with questions in the **BoundedA** block that demonstrated the principle that more "unevenly" distributed urns yield larger win probabilities in Two-Ball gambles.

Recall from Section 3.2 that subjects strongly preferred gamble BB^{95-100} to BB^{60-100} to BB^{40-60} . This preference shows that, by the time they had completed this block, subjects had at least some understanding that more unevenly distributed urns yield higher win probabilities in Two-Ball gambles. It stands to reason that if a subject *did not* understand this point before completing block **BoundedA**, they may have come to understand it during that block. Thus, if subjects exhibit a preference for R over AA because of a lack of understanding (such that, if subjects understood them, then they would prefer AA to R), then we may expect that completing block **BoundedA** could have a "nudging" effect. This effect might cause subjects to report a more negative CE

¹⁶From Section 3.1, this implies that the average difference between R and RA is even larger than that between A and RA , by about 12.3 cents.

¹⁷We do not use the term "ambiguity aversion" since none of the classical ambiguity aversion models permit an agent to strictly prefer X over Y , even though both yield a winning probability of 50% in all states of the world.

difference $R - AA$ than if they had not already completed the **BoundedA** block.

Only subjects in Treatment **NUDGING** completed the **BoundedA** block. Since subjects were randomly assigned to one of the four treatments, if such a nudging effect exists, it should manifest as a statistically significant difference between the $R - AA$ values in Treatment **NUDGING** versus those in the other treatments.

With this in mind, if we let I^{T3} be the indicator variable for Treatment **NUDGING** participation, then in a regression of $Z := R - AA$ on I^{T3} , the slope coefficient should represent the causal effect of being in Treatment **NUDGING** on how subjects prefer R over AA despite the latter being more likely to win. A statistically significant *negative* slope coefficient would indicate that Treatment **NUDGING** has a nudging effect, causing subjects to manifest less preference for R over AA .

	Z^1	Z^2	Z^{avg}
I^{T3}	2.615 (3.659)	-0.418 (3.917)	1.098 (3.366)
Const.	16.994*** (1.840)	16.786*** (1.969)	16.890*** (1.692)
N	708	708	708

Table 5: **NUDGING EFFECTS**

Table 5 shows the results of such a regression, first using individual elicitations and then the averages across elicitations. As shown, the slope coefficient is not statistically significant, and it is *positive* in the case using averages. Thus, we fail to reject the hypothesis that there is no nudging effect ($p = .63$).

There are two possible explanations for the lack of a nudging effect despite subjects successfully identifying that more unevenly distributed urns are more likely to win in the **BoundedA** block:

- (I) Subjects cannot see the similarity between gamble AA and the "bounded" versions of this gamble in **BoundedA**, or upon arriving at gamble AA , they forget what they might have learned from **BoundedA** and fail to realize that AA is more likely to win than R .
- (II) In **BoundedA** and in comparing gambles R and AA , subjects understand that a more unevenly distributed urn is more likely to win. Their preference for R over AA is deliberate and due to a distaste for the ambiguity or complexity in AA .

Although hypothesis (I) is conceivably correct, it seems implausible that it can entirely explain the lack of a nudging effect. Hence, a distaste for ambiguity or complexity must partially explain that subjects generally prefer R to AA .

3.4 Additional Results

3.4.1 Three-Ball Gambles and Overweighting

Recall that the block **3Ball** consists of 3-Ball gambles; the subject wins the gamble if all three balls drawn have the same color. Subjects were asked about three gambles, $R3$, $A3$, and RAA , and the summary statistics for their CEs appear in Table 6.

	$R3$	$A3$	RAA
Mean	97.708	91.120	92.552
SD	(67.310)	(69.264)	(68.172)
N	192	192	192

Table 6: **3-BALL GAMBLES**

These reported CEs are too large for a classical risk-averse or risk-neutral agent who correctly calculates the probabilities of winning. Notice that $R3$ has a winning probability of exactly $\frac{1}{4}$. Therefore if subjects based their CEs only on correct calculations of win probabilities (or only on this plus a distaste for complexity), then any risk-neutral or risk-averse subject would report a CE for $R3$ that is *at most* $\frac{1}{4}$ times 300, i.e., at most 75; however, subjects report an average CE of 97.71 for $R3$, significantly larger than 75 ($t = 4.67$). Thus, subjects cannot be correctly calculating the win probability of the 3-Ball gamble $R3$; they *overweight* this win probability and choose a CE that is larger than the actual win probabilities would suggest.

Still, subjects report smaller CEs for $R3$ than for RR (mean = 17.92, $t = 5.38$); however, the average CE for $R3$ is massively larger than *half* the average CE for RR (mean = 39.90, $t = 11.14$), even though $R3$ has exactly half the win probability of RR . Similarly, subjects report an average CE for RAA that is smaller than AA (mean = 17.02, $t = 5.52$) but massively larger than half that of AA (mean = 37.77, $t = 11.03$), even though RAA has exactly half the win probability of AA . Similar findings apply to $A3$ versus AA . The relationship between the win probabilities of $A3$ and AA is not obvious. For any model for resolving ambiguity, $A3$ has *at least* half the win probability of AA . Under any model other than "the ambiguous urn always contains exactly 50% red balls," $A3$

has a winning probability strictly larger than half that of AA . The exact ratio of win probabilities depends on the model.; however, the statistical results mentioned for the other 3-Ball versus Two-Ball comparison remain qualitatively true and are of similar numerical magnitude.

Despite the general overweighting of win probabilities, comparisons between CEs for these 3-Ball gambles remain qualitatively similar to the comparisons between the CEs for Two-Ball gambles discussed in Section 3.3. Similar to how subjects were indifferent between RA and AA , we find no statistically significant difference between RAA and $A3$ (mean = 1.43, $t = .56$). Likewise, just as subjects on average preferred RR to AA , we find that subjects generally prefer $R3$ to $A3$ (mean = 6.59, $t = 2.16$), even though $A3$ can only have a higher win probability than $R3$. As before, this suggests subjects' distaste for ambiguity.

3.4.2 Does the "amount" of ambiguity matter?

On average, subjects report a larger CE for the 1-Ball ambiguous gamble A than the Two-Ball ambiguous gamble AA (mean = 4.79, $t = 4.03$), even though the latter has a higher win probability. One possible explanation for this difference is that AA is more complex than A , causing subjects to prefer A ; however, the preference for A over AA also suggests the subjects' dislike for gambles with more ambiguity, as measured by the number or proportion of ambiguous draws.

Recall from Section 3.3 that the difference between subjects' average CEs for gambles RA and AA was statistically insignificant. Similarly, in Section 3.4.1 we found that RAA and $A3$ were not statistically different. Unfortunately, these results do not imply that an increased number/proportion of ambiguous draws affects CEs. For example, when comparing AA to RA , the CE for AA may fall below that of RA due to AA having "more" ambiguity. Simultaneously, the CE for AA also grows *larger* than that of RA because AA has a higher win probability than RA . These two effects could precisely cancel each other out on average.

Therefore, we compare RAA to AA to control for win probability differences. AA has a larger *proportion* of ambiguous draws than RAA ; however, RAA has precisely half the win probability of AA , making win probability comparisons easier.

As discussed in Section 3.4.1, subjects seem to overweight the win probabilities of *all* 3-Ball gambles relative to analogous Two-Ball gambles. For example, averaging across subjects (and across elicitations for RR), we find that

$$\overline{RR/R3} = 1.122$$

even though this ratio should be precisely two if subjects were risk-neutral and based their CEs only on win probabilities. It should be even more significant if subjects are also averse to the additional complexity of the 3-Ball gamble $R3$ compared to the Two-Ball gamble RR .

Thus, when comparing RAA to AA , instead of using a correction factor of 2 for each subject's win probability differences, we use a subject-specific correction factor of $RR/R3$ to account for the combination of *perceived* win probability differences and possible complexity differences between Two-Ball and 3-Ball gambles. Hence, we test whether

$$RAA \cdot \frac{RR}{R3} - AA$$

is statistically greater than 0. If so, this implies that subjects *do* prefer gambles with a smaller proportion of draws from ambiguous urns (after correcting for perceived win probability and complexity differences). Running this test, we find a t -statistic of 1.577, with a p -value of .058 for a 1-sided test.

At a significance level of .05, we (barely) fail to disprove the hypothesis that a larger proportion of ambiguous draws is associated with a lower CE after correcting for perceived win probability differences and possible complexity differences. Thus, similar to the comparisons between RA and AA or between A and AA , it is unclear whether subjects care about the *amount* of ambiguity. Further experiments may be necessary to resolve this question more precisely.

4 Discussion

The results in Section 3.3 show that subjects generally prefer RR to RA . The two gambles have equal win probability and are of similar complexity. Hence, we must explain the preference for RR over RA as a *distaste for the presence of ambiguity*. Some might argue that this phenomenon could be explained otherwise. In what follows, we overview potential explanations and rule out some others; we then turn to potential theoretical implications and venues that could be worth it to explore in another project.

4.1 Potential explanations

Failures under complexity. Qualitatively, this preference for RR over RA is somewhat similar to that of R over C in Halevy (2007)'s experiment. Substituting a more complex urn for a 50-50 urn in a way that does not affect the ultimate win probability causes subjects to report lower CEs. In RR versus RA , replacing one urn draw (previ-

ously from a known 50-50 urn) with a draw from an ambiguous urn is associated with a lower CE for the gamble, even though the win probability is unchanged. Thus, one might argue that our supposed distaste for ambiguity is simply another instance of a distaste for complexity. Gambles involving ambiguous urns are less appealing than similar non-ambiguous gambles, but only because the ambiguity involved constitutes a type of complexity.

We could explain our results by relying on the following hypothesis that "people struggle to rationally calculate 'correct' decisions when the environment is sufficiently complex." This hypothesis is plausible if we identify the mere presence of ambiguity, as exemplified by the two-ball Ellsberg paradox, as a particular type of complexity: "the presence of ambiguity changes people's decisions merely because it introduces a compound lottery".

This interpretation seems plausible; however, our experiment has discovered new terrain, even if it is correct. We show that ambiguity can drive people away from otherwise-attractive gambles: perhaps through complexity or other means. Subjects may prefer a non-ambiguous gamble to an analogous ambiguous gamble in which the ambiguity can only make the subject *better off* under the non-ambiguous gamble.

Correlation neglect. Can our results be explained by subjects neglecting the correlation (in fact, equivalence) between the probability of getting a red ball on the first draw and the probability of getting a red ball on the second? What if subjects imagine that our "two draws with replacement from the same ambiguous urn" are actually "two draws from two ambiguous urns whose contents were determined independently"? Our experiment can't fully rule out this explanation, but it suggests how further experiments might do so.

First, on average, subjects preferred gamble *AA* over gamble *IA*, although the difference in average certainty equivalents was not statistically significant. If a future experiment replicated block **Independent** with larger sample size and found a statistically significant preference for *AA* over *IA*, this would suggest that people understand that these gambles are different and that gamble *AA* has a higher average win probability.

Second, a variation on block **BoundedA** may be sufficient to show that correlation neglect cannot fully explain our results. Consider a version of gamble *BB*⁹⁵⁻¹⁰⁰ wherein instead of the gamble specifying that the urn contains between 95 and 100 *red* balls, it merely specifies that *at least 95 of the 100 balls in the urn are of the same color*. Suppose subjects imagined the two draws from the specified urn as "one draw from each of two distinct urns, whose contents were determined in a specified manner but

were determined independently”. Then, we should not find a strong preference for this version of gamble BB^{95-100} over gamble AA . Indeed, suppose subjects exhibited correlation neglect in this manner. In that case, they might easily imagine this version of gamble BB^{95-100} to have a win probability close to 50%. Although it is possible in their minds that “both urns” contain at least 95 red balls (or that both contain at least 95 blue balls), it is equally possible to them that “one urn contains at least 95 red balls while the other contains at least 95 blue balls”. In other words, their CEs for this version of gamble BB^{95-100} should certainly *not* be radically larger than their CEs for gamble AA . If such a radical difference in CEs as we found between the original version of gamble BB^{95-100} and gamble AA were still found under this modified version of BB^{95-100} , this would suggest that correlation neglect is not the primary factor generating our results.

Raiffa Critique. Unlike in the original Ellsberg paradox, a subject cannot eliminate the ambiguity present in gamble AA by introducing randomization in her choice of color. Indeed, gamble AA does not ask subjects to choose a color. Even if we presented subjects with a modified version of gamble AA wherein they choose either red or blue and win if and only if both balls drawn were of the chosen color (and compared this to a similarly modified version of gamble RR), it is still the case that randomizing one’s color choice does not eliminate the ambiguity in the payoff of gamble AA . If p is the (ambiguous) proportion of red balls in urn A , then this modified version of gamble AA has win probability p^2 when you bet on red and win probability $(1 - p)^2$ when you bet on blue. Randomizing your choice of color 50-50 would thus mean that the gamble’s win probability is $.5p^2 + .5(1 - p)^2 \geq .25$. In contrast, the modified version of gamble RR has a probability of winning .25 regardless of the color you bet (or whether you randomized your choice of color). It is still the case that gamble AA has an ambiguous win probability and that this win probability is at least as large as (and in all but one case, strictly larger than) that of RR .

4.2 Theoretical Implications

Before elaborating on the potential theoretical solutions, it is worth reminding that this paradox, the fact that people harbor a distaste for ambiguity because of its mere presence cannot be explained by models for decision-making under risk (?) and ambiguity (Gilboa and Schmeidler (1989)), as detailed in our introduction.

New models may be required to explain people’s behavior adequately. In the case where ambiguity would be an instance of complexity, contingent reasoning, as in ?

seems a good candidate to explain our results. In general, this distaste for ambiguity suggests the existence of a *cognitive cost* to exposure to the ambiguity that might need to be formalized to capture ambiguity aversion completely.

5 Conclusion

Two-Ball gambles are a rich class of decision problems. Because they can involve ambiguity but guarantee a minimum win probability that is at least as large as that of some other gamble, they allow us to test whether subjects avoid ambiguity *per se* as opposed to avoiding ambiguity because it may yield a worse outcome.

The most striking case of preferring a gamble with lower win probability is that subjects preferred the 50-50 gamble, R , to the Two-Ball ambiguous gamble, AA . This preference is closely correlated with the traditional Ellsberg preference for R over a 1-Ball ambiguous gamble A , but also for R over the compound 50-50 C , and R over the Two-Ball 50-50 gamble RR . These close relationships suggest that much of the preference for R over AA is from a distaste for ambiguity and complexity.

It is implausible that subjects prefer R to AA simply due to a poor understanding of the gambles. In the **BoundedA** block, subjects correctly and strongly identified that more unevenly distributed urns are more likely to win. Moreover, the lack of a "nudging" effect from being in the treatment containing **BoundedA** suggests that subjects' preference for R over AA is *deliberate*.

Although the presence of an ambiguous draw within a gamble is associated with a significantly lower CE, it remains unclear whether having more ambiguity, as measured perhaps by the *number* or *proportion* of ambiguous draws present in a gamble, has an additional negative effect on the CE. This presents an interesting question for further research.

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Appendix

A Building Model State Spaces And Representation Theorems

A.1 Savage 1972

Although SEU ? is not the same framework as [Anscombe and Aumann \(1963\)](#)'s since acts pay out prizes rather than lotteries, so long as the decision-maker's subjective probabilities are required to match the objective probabilities when objective probabilities are given, no SEU theory can explain a strict preference for gamble **A** over gamble **R**. In the most extreme case, namely a subjective probability measure that assigns probability 1 to the set of states in which the ambiguous urn contains exactly 50 red balls, it would still be the case that gamble **A** is considered exactly as good as gamble **R**. In all other cases, gamble **A** would be strictly better.

In the ? model, an act must pay out a deterministic prize in each state. Hence, to adopt the Savage framework for our gambles, we must assume that the state consists not only of description of the contents of urn **A** but also a description of which combination of balls will be drawn from each urn. Some example states are the following:

- s_1 = "Urn **A** contains 60 red balls and 40 blue balls; we draw RR from urn **A** and RB from urn **R**."
- s_2 = "Urn **A** contains 60 red balls and 40 blue balls; we draw RR from urn **A** and BB from urn **R**."
- s_3 = "Urn **A** contains 60 red balls and 40 blue balls; we draw BR from urn **A** and RB from urn **R**."
- s_4 = "Urn **A** contains 23 red balls and 77 blue balls; we draw BR from urn **A** and RB from urn **R**."

Hence, if urn **A** can contain anywhere between 0 and 100 red balls and the rest of the 100 are blue, then there are exactly $101 \cdot 2^4 = 1616$ many different states to consider.

If a person's decisions satisfy all of ?'s assumptions, then by the results of ? that person's decisions must have a subjective expected utility (SEU) representation. That is, she must assign (i) probabilities to each state and (ii) utilities to each outcome, and then she must behave in a manner that maximizes the expectation of her utility with respect to her subjective probability distribution over states.

For example, in theory a decision maker might assign probability .00045 to state s_1 above and assign probability .0005 to state s_2 above. However, such a subjective probability assessment is inconsistent with the objectively computable odds of drawing the various outcomes from the urns. Indeed, conditional on there being exactly 60 red balls in urn **A**, the odds of drawing RR from urn **A** are exactly $.6^2 = .36$ and the odds of drawing RB from urn **R** are exactly $.5^2 = .25$, meaning (since the draws from urn **A** are independent of those from urn **R**) the odds of drawing "RR from urn **A** and RB from

urn **R**" are exactly $.36 \cdot .25 = .09$. Since the decision maker assesses the probability of state s_1 as $.00045$, this means that *if* the decision maker's subjective probabilities are to be consistent with the objectively known information, then she must assess the probability of the event "Urn **A** contains 60 red balls and 40 blue balls" as exactly $.005$ (since $.005 \cdot .09 = .00045$). However, if this is the case, then her subjective probability of state s_2 above must equal $.005 \cdot .36 \cdot .25 = .009$ as well.

We therefore make two assumptions about the decision maker's subjective probabilities and utilities:

1. Subjective probabilities must be consistent with objectively known information whenever possible. That is, conditional on the event "urn **A** contains exactly a p proportion of red balls", the decision maker must assess the odds of outcome "we draw XY from urn **A** and ZW from urn **R**" to equal $.25 \cdot a \cdot b$, where

$$a = \begin{cases} p & \text{if } X = R \\ 1 - p & \text{if } X = B \end{cases}$$

and

$$b = \begin{cases} p & \text{if } Y = R \\ 1 - p & \text{if } Y = B \end{cases}$$

regardless of whether Z, W equal R or B .

2. Utilities must be a function only of the amount of money earned and must not depend on the way in which the money was earned. Furthermore, earning strictly more money must yield a strictly higher utility.

For example, winning \$3 from a bet on urn **A** must have the same utility value as winning \$3 from a bet on urn **R**, and both of these outcomes must be better than earning no money. Similarly, winning \$3 from a bet on urn **A** when urn **A** turns out to contain exactly 47 red balls must yield the same utility as earning \$3 from a bet on urn **A** when urn **A** turns out to contain exactly 84 red balls.

If a decision maker satisfies these two assumptions, then she cannot exhibit a strict preference for gamble **R** (or, for gamble RR) over gamble AA . Indeed, let $u(\cdot)$ denote the decision maker's subjective utility function and let $q(x)$ denote her subjective probability that urn **A** contains exactly an x proportion of red balls. Then by the assumptions above, the expected payoff of gamble **R** (or gamble RR) is

$$U(R) := .5 \cdot u(\$3) + .5 \cdot u(\$0)$$

(since both win with 50% probability) and the expected payoff of gamble AA is

$$U(AA) := \sum_x q(x) \left[(x^2 + (1-x)^2) \cdot u(\$3) + 2x(1-x) \cdot u(\$0) \right]$$

since the gamble pays \$3 if and only if the two drawn balls have the same color, which occurs with probability $x^2 + (1-x)^2$ (either both are red or both are blue). Notice that

if $x = .5$ then $x^2 + (1 - x)^2 = .5$, and if $x \neq .5$ then $x^2 + (1 - x)^2 > .5$. Hence, $U(AA)$ consists of a weighted average of numbers of the form

$$(x^2 + (1 - x)^2) \cdot u(\$3) + 2x(1 - x) \cdot u(\$0),$$

where in each case the weight on $u(\$3)$ is at least .5 and the weight on $u(\$0)$ is at most .5. By assumption 2 above, we know $u(\$3) > u(\$0)$; hence we know that $U(AA) \geq U(R)$ (with strict inequality if $q(.5) \neq 1$). This means that the decision maker cannot exhibit a strict preference for gamble \mathbf{R} (or gamble RR) over gamble AA .

A.2 Is Savage violated?

Here we'll show that the results of our experiment are technically not inconsistent with ?'s framework, but we'll show that any SEU decision-maker who exhibits a preference for gamble RR (or for gamble \mathbf{R}) over gamble AA must be assessing probabilities "incorrectly" in some way. We'll also show what would be a sufficient experimental finding to definitively refute the Savage framework as a possible explanation for our results.

A.2.1 This example is compatible with Savage in 2-ball but not in 1-ball

Suppose that rather than including in the "state" a description of how many balls will be in Urn \mathbf{A} , we simply let the states include a description of which balls will be drawn from which urns.¹⁸ For example, a state might be "RB from urn \mathbf{R} ; BB from urn \mathbf{A} " and another might be "RR from urn \mathbf{R} ; BR from urn \mathbf{A} ." In fact, the following example works in the even simpler setting where there are just 4 states, including "win in urn \mathbf{R} ; lose in urn \mathbf{A} " and "lose in urn \mathbf{A} ; win in urn \mathbf{R} " and the two other possible combinations. But to illustrate how our game differs from the classic Ellsberg paradox (and why Savage can theoretically explain our results but not the classic Ellsberg paradox), let's at least include a description of the color of the ball that wins. So we will let there be 9 states in total, such as "win in urn \mathbf{R} with two red balls; lose in urn \mathbf{A} " and "lose in urn \mathbf{R} ; win in urn \mathbf{A} with two blue balls."

Consider a Savage SEU decision-maker who assesses the probabilities of the 9 possible states as follows:

- The probability of winning with two red balls in urn \mathbf{R} is .25.
- The probability of winning with two blue balls in urn \mathbf{R} is .25.
- The probability of losing in urn \mathbf{R} is .5.
- The probability of winning with two red balls in urn \mathbf{A} is .2.
- The probability of winning with two blue balls in urn \mathbf{R} is .2.
- The probability of losing in urn \mathbf{A} is .6.

¹⁸We are grateful to Jean-Marc Tallon who made us this suggestion.

- What happens in urn **A** is independent of what happens in urn **R**. So for example, the probability of the state "lose in urn **R**; win in urn **A** with two blue balls" is $.5 \cdot .2 = .1$.

We assume that the only "outcomes" are Win and Lose. This rules out e.g. preferring the outcome "win after drawing two red balls" to "win after drawing two blue balls." We assume that the decision maker prefers Win to Lose (i.e., she prefers an act that gives Win in all states to an act that gives Lose in all states).

It is easy to see that this decision maker has the following preferences over the following acts:

1. Indifferent between "Win if two red balls are drawn from urn **R**" and "Win if two blue balls are drawn from urn **R**"
2. Indifferent between "Win if two red balls are drawn from urn **A**" and "Win if two blue balls are drawn from urn **A**"
3. Strictly prefers "Win if two red balls are drawn from urn **R**" to "Win if two red balls are drawn from urn **A**"
4. Strictly prefers "Win if two blue balls are drawn from urn **R**" to "Win if two blue balls are drawn from urn **A**"

This decision maker has a well-defined Savage SEU preference representation and hence her preferences cannot violate any of ?'s axioms.

The act preferences in items 1-4 above resemble those in the classic [Ellsberg \(1961\)](#) paradox: indeed, when we replace the expression "two blue balls" with "a blue ball" and replace "two red balls" with "a red ball," the acts and preferences above become identical to those in [Ellsberg \(1961\)](#)'s thought experiment. So why is it that the "two-ball" version of these preferences can fit within ?'s SEU framework while the "one-ball" version cannot?

This is because in the "one-ball" version, there are only two possible outcomes within each urn: either Red Wins or Blue Wins. Hence, in the "one-ball" case, whenever a decision maker exhibits preferences like items 1 and 2 above, Savage's framework forces her to assign probability .5 to each of the four events "Win with a red ball in urn **R**," "Win with a blue ball in urn **R**," "Win with a red ball in urn **A**," and "Win with a blue ball in urn **A**." But such a probability assignment is not consistent with preferences like those in items 3 and 4 above.

Meanwhile, in the "two-ball" version, there are *three* possible outcomes: Red Wins, Blue Wins, and Lose. Preference items 1 and 2 above require the decision maker to assign equal probability to "Red Wins in urn **R**" as to "Blue Wins in urn **R**", and it similarly requires her to assign equal probability to "Red Wins in urn **A**" as to "Blue Wins in urn **A**." However it does *not* require her to assign the same probability to "Red Wins in urn **R**" as to "Red Wins in urn **A**," etc. Hence, in particular it allows the decision maker to believe that *it is strictly more likely to win in urn **R** than to win in urn **A***.

Such a belief is not consistent with the *objective* probabilities implied by the gambles AA and RR , but no component of ?'s theory is formally violated by an individual who chooses to disregard the "objective" facts when creating her subjective beliefs.

A.2.2 What kind of experimental findings would be a counterexample to Savage?

In order to show that individuals' behavior in our "two-ball" gambles is not consistent with Savage's framework, we would have to allow states to include a description of the contents of urn **A**, and we would also have to obtain certain further experimental findings. Indeed, suppose we construct a state space where each state contains a description of (i) how many red/blue balls are in urn **A**, (ii) whether the decision maker would Win or Lose if she chose to play the gamble with urn **A**, and (iii) whether the decision maker would Win or Lose if she chose to play the gamble with urn **R**. So for example, a typical state might be "Urn **A** contains 73 red balls and 27 blue balls; urn **A** Wins; urn **R** Loses." Assuming urn **A** can contain anywhere between 0 and 100 red balls, there will be a total of $2^2 \cdot 101 = 404$ such states.

In this example, if a decision maker has preferences satisfying ?'s axioms, then she must assign a consistent set of subjective probabilities \mathbb{P} to the 404 states. Given any set $S \subseteq \{0, 1, \dots, 100\}$, let

$$p_A(S) = \sum_{x \in S} \mathbb{P}[\text{Urn A wins} \mid \text{Urn A contains exactly } x \text{ red balls}]$$

be her subjective probability that urn **A** wins conditional on urn **A** having some number of red balls that is in the set S . Similarly, let

$$p_R(S) = \sum_{x \in S} \mathbb{P}[\text{Urn R wins} \mid \text{Urn A contains exactly } x \text{ red balls}]$$

be her subjective probability that urn **R** wins conditional on urn **A** having some number of red balls that is in the set S . Finally, given $S \subseteq \{0, 1, \dots, 100\}$, let A_S and G_S denote the following gamble:

- $A_S =$ "Urn **A** contains a number of red balls x for some $x \in S$; the rest of the 100 total balls are blue. We draw two balls with replacement from urn **A**; you win if and only if the two balls have the same color."
- $R_S =$ "Urn **A** contains a number of red balls x for some $x \in S$; the rest of the 100 total balls are blue. We draw two balls with replacement from urn **R**; you win if and only if the two balls have the same color."

Notice that the second of these gambles specifies details about urn **A** even though its ball draws come from urn **R**.

In order to show that ?'s theory cannot explain individuals' preferences, the following would suffice. Suppose there exist disjoint sets $S_1, \dots, S_n \subseteq \{0, 1, \dots, 100\}$ whose union is $\{0, 1, \dots, 100\}$ such that a certain individual's preferences are as follows (in the following, you can substitute "gamble **R**" wherever you see "gamble RR " and the same would hold):

1. Gamble RR is strictly preferred to gamble AA .
2. For each $i = 1, \dots, n$, gamble A_{S_i} is weakly preferred to gamble R_{S_i} .

In item 2 above, each preference $A_{S_i} \succeq R_{S_i}$ entails a subjective probability assessment $p_A(S_i) \geq p_R(S_i)$; that is, the conditional probability of urn **A** winning given ball composition S_i is larger than the conditional probability of **R** winning given S_i . Since the events S_1, \dots, S_n are mutually exclusive and exhaustive, this entails that

$$p_A(\{0, 1, \dots, 100\}) \geq p_R(\{0, 1, \dots, 100\}),$$

which is inconsistent with a strict preference for gamble RR over gamble AA .

A.2.3 Does our experiment contain such a counterexample?

Our experiment comes close to having a "counterexample to Savage" fitting the form above, but it does not quite contain it. Indeed, consider the gambles BB^{40-60} and BB^{60-100} in our experiment. In the notation introduced two paragraphs ago, these gambles are just other names for the gambles $A_{\{40,41,\dots,60\}}$ and $A_{\{60,61,\dots,100\}}$. If we make a few relatively innocuous assumptions, then our data come close to providing a counterexample to Savage:

- (I) Individuals' preferences over acts are color-symmetric. That is, if you change the descriptions of various gambles by merely switching the roles of Red and Blue, then the preferences remain the same.
- (II) Individuals' CEs for gamble $A_{\{60,61,\dots,100\}}$ are very close to their CEs for gamble $A_{\{61,62,\dots,100\}}$. That is, the possibility of the urn containing exactly 60 balls doesn't carry too much weight.
- (III) Individuals' CEs for gambles of the form "You win if two balls drawn with replacement from urn **R** are of the same color" do not depend on any information given about the contents of urn **A**.

This third assumption allows us to merely compare a gamble of the form A_S to the gamble RR instead of having to compare it to the corresponding gamble R_S that contains information about the contents of urn **A**. Hence, under this assumption, to have a "counterexample to Savage" like the above it would suffice to find that the following four preferences hold:

$$RR > AA, \quad A_{\{0,1,\dots,39\}} \succeq RR, \quad A_{\{40,41,\dots,60\}} \succeq RR, \quad \text{and} \quad A_{\{61,62,\dots,100\}} \succeq RR.$$

Our data show that on average $RR > AA$. They also show that $A_{\{60,61,\dots,100\}} > RR$; by assumption (II) above this should imply that $A_{\{61,62,\dots,100\}} \succeq RR$. Using our color symmetry assumption (I) above, this implies that $A_{\{0,1,\dots,39\}} \succeq RR$ holds as well. Finally, our data show no statistically significant difference between subjects' CEs for gambles $A_{\{40,41,\dots,60\}}$ and RR (**CHECK THIS**), which suggests that perhaps $A_{\{40,41,\dots,60\}} \sim RR$ holds. However, although we did not find a statistically significant difference,

the average CE for gamble RR was about 109 cents while the average CE for gamble $BB^{40-60} = A_{\{40,41,\dots,60\}}$ was only about 99 cents. This suggests that perhaps in reality on average $RR > A_{\{40,41,\dots,60\}}$ and we failed to find a statistically significant difference simply because we lacked a large enough sample size. If so, then such data would not constitute a counterexample to ?'s theory.

A.2.4 A future experiment where we might find such a counterexample

I suggest running an experiment analogous to ours but with urns that contain a total of 6 balls. In this case, urn **R** should contain 3 red balls and 3 blue balls while urn **A** should contain a total of 6 balls, all either red or blue, but in amounts that may or may not be specified (depending on the gamble). We should present individuals with a series of 7 screens, where each contains the following text and asks the subject to report her CEs for two gambles. The only difference between these 7 screens is that the number n ranges over the set $\{0, 1, \dots, 6\}$ in a random order.

- "Urn **R** contains 3 red balls and 3 blue balls. Urn **A** contains exactly n red balls and $6 - n$ blue balls."
- How much would you pay for the following gamble? "We draw two balls with replacement from urn **A**; you win if they match in color."
- How much would you pay for the following gamble? "We draw two balls with replacement from urn **R**; you win if they match in color."

I conjecture that on each screen $n = 0, 1, \dots, 6$ we would find that the average reported CE for the **A**-gamble is at least as large as that reported for the **R**-gamble. Assuming individuals still preferred gamble RR to gamble AA in this 6-ball environment, together this would constitute a counterexample to Savage of the form mentioned in Section A.2.2.

In this version of the experiment, it would also be interesting to randomize whether individuals answer this block of 7 screens before or after answering the questions about AA versus RR and to see if there is a "nudging" or "learning" effect, as we did with the block **BoundedA** in our experiment.

A.3 Two approaches to what the state must include

Any attempt to model our 2-ball gambles as "acts" (i.e. maps from states to outcomes, or from states to lotteries) must include in the "states" a description of the contents of Urn **A**.¹⁹ The state may also include any other quantity over which there would be residual uncertainty even after the contents of Urn **A** are known. For example, to fit our gambles into the framework of ?, we must also include a description of what would happen if the subject chose to play the gamble using Urn **A** as well as a description of

¹⁹See Section A.4 for an argument as to why this must be so.

what would happen if the subject chose to play the gamble using Urn **R**.²⁰ We *must* include this additional description since ?'s model does not allow there to be any residual uncertainty of the outcome once the state is known. For if the state merely included a description of the contents of Urn **A**, there would still be residual uncertainty about the balls to be drawn from each possible urn.

In models based on Anscombe-Aumann acts rather than Savage acts, like [Anscombe and Aumann \(1963\)](#), [Schmeidler \(1989\)](#), [Gilboa and Schmeidler \(1989\)](#), and others, there *can* be residual uncertainty (in the form of an objective "roulette" lottery) after the state is known. In models like these, there are two possible approaches to how we should model the "states." In the first approach, we assume that when it is known that Urn **A** contains exactly an x proportion of red balls, the decision maker must believe that the probability of winning a 2-ball gamble drawn from Urn **A** is exactly $x^2 + (1-x)^2$ (since this win probability can be computed objectively). Hence, in this first approach, the state does not need to include any information other than the contents of Urn **A**.

In the second approach, even when the ball composition of Urn **A** is known, we allow the decision maker to consider a 2-ball gamble drawn from Urn **A** (or, from urn **R**) to contain ambiguity. In this case, we must allow each state to contain not only a description of the contents of Urn **A**, but also a description of whether the decision maker would win or lose if she chose to play the 2-ball gamble drawing from Urn **A** as well as a description of whether she would win or lose if she chose to play the 2-ball gamble drawing from Urn **R**. Including these more detailed states allows the decision maker to subjectively assess the probabilities of each of these win/loss outcomes even when the ball composition of the urn is known.

If one considers a model of decision-making that uses Anscombe-Aumann acts, and if one takes the first approach mentioned above, then a subject strictly preferring gamble RR to gamble AA is inconsistent with a Monotonicity axiom (provided the subject prefers winning \$3 for sure to winning \$0 for sure), since in each state gamble AA has at least as high of a win probability as gamble RR .

If one instead uses the second approach mentioned above, then Anscombe-Aumann acts are modeled in the same way as Savage acts. Hence, if one either (i) uses an Anscombe-Aumann model and takes the second modeling approach above or (ii) uses a Savage model, experimental results like those hypothesized in [Section A.2.4](#) would be sufficient to falsify one's model.

A.4 Why must the state include a description of the contents of Urn **A?**

The contents of Urn **A** are relevant to subjects' decisions. As we can see from [Block BoundedA](#), when we change gamble AA only in ways that involve different specifications about the contents of Urn **A**, subjects report very different CEs for that gamble. If subjects were assessing our 2-ball gambles in a way that did not depend on the contents of Urn **A**, this behavior could not occur.

²⁰See [Section A.2.1](#) for an example.

Since the contents of Urn **A** affect subjects' decisions, and since subjects are told that Urn **A** can contain anywhere between 0 and 100 red balls (the rest of the 100 being blue) but are not given any probability distribution over this number of red balls, in any model of subjects' behavior in our gambles we must allow the "state" to include a description of the contents of Urn **A**.

In order to better understand this point, suppose we attempted to describe our 2-ball gambles as Savage acts. As mentioned in Section **A.3**, such a model would require us to include in the state a description, for each of urns **A** and **R**, of whether one would win or lose the 2-ball gamble if one plays it drawing from that urn. But why is a description of merely whether each urn would "win" or "lose" sufficient? Why don't we need to include in the state a complete description of the *order* in which the different colors of balls would be drawn from each urn? For instance, perhaps an example state should be "Urn **A** contains exactly 58 red balls and 42 blue balls; playing the 2-ball gamble in Urn **A** would result in us drawing *a red ball followed by a blue ball*; and playing the gamble in Urn **R** would result in us drawing *a blue ball followed by a red ball*" rather than "Urn **A** contains exactly 58 red balls and 42 blue balls; playing the 2-ball gamble in Urn **A** would result in losing; and playing the gamble in Urn **R** would result in losing."

We don't need to include such details about the order of the balls in our description of the state because we are assuming subjects understand that the order of the balls does not play a role in determining whether a 2-ball gamble wins or loses - only whether the balls have the *same color* makes any difference. Our experimental results give us no reason to suppose subjects fail to understand that the order of the balls does not matter. On the other hand, if we did not include a description of the contents of Urn **A** as a part of the state, then we would effectively be assuming that *subjects believe the contents of Urn A do not play a role in determining whether a 2-ball gamble from Urn A wins or loses*. This assumption is falsified by our data from Block **BoundedA**.

A.5 Anscombe & Aumann 1961

A.6 Schmeidler 1989

A.7 Gilboa & Schmeidler 1989

	R		A		C		RA	
Mean	118.55	117.72	105.42	106.22	108.67	111.55	95.67	93.72
95% Conf. Interval	[114.43, 122.66]	[113.48, 121.96]	[101.10, 109.74]	[101.81, 110.63]	[100.15, 117.19]	[102.31, 120.79]	[87.64, 103.70]	[85.54, 101.89]
ρ	0.875 (0.018)		0.871 (0.018)		0.878 (0.038)		0.855 (0.039)	
N	708	708	708	708	158	158	179	179
	RR		AA		CC		AR	
Mean	110.55	108.64	100.95	101.12	102.53	104.97	97.21	95.78
95% Conf. Interval	[106.25, 114.85]	[104.44, 112.85]	[96.59, 105.30]	[96.60, 105.64]	[93.51, 111.56]	[95.49, 114.45]	[89.15, 105.26]	[87.61, 103.95]
ρ	0.866 (0.019)		0.876 (0.018)		0.855 (0.042)		0.883 (0.035)	
N	708	708	708	708	158	158	179	179

Table 7: RAW VARIABLES: DECOMPOSED SUMMARY STATISTICS

	R - A		R - C		R - AA		R - CC	
Mean	13.15	11.54	7.91	5.70	17.66	16.68	14.11	12.34
95% Conf. Interval	[10.46 ,]	[8.64 , 14.44]	[3.37 , 12.45]	[0.23 , 11.16]	[14.53 , 20.78]	[13.34 , 20.02]	[6.91 , 21.32]	[, 19.82]
ρ	0.489 (0.033)		0.364 (0.075)		0.578 (0.031)		0.561 (0.066)	
N	708		158		708		158	
	R - RR		RA - AR		RA - AA		RA - RR	
Mean	8.02	9.08	-1.51	-2.07	0.84	-2.85	-11.68	-11.01
95% Conf. Interval	[5.33 ,]	[6.40 , 11.77]	[-4.85 , 1.84]	[-5.48 , 1.35]	[-4.76 , 6.44]	[-7.58 , 1.87]	[-16.81 , -6.55]	[-15.47 , -6.54]
ρ	0.428 (0.034)		0.151 (0.074)		0.368 (0.070)		0.259 (0.073)	
N	708		179		179		179	

Table 8: DERIVED VARIABLES: DECOMPOSED SUMMARY STATISTICS

Online Appendix

B Main Appendix

- Re-do analysis without removing attention screeners, 150, etc.
- Cognitive Uncertainty.
-

Name	Definition	Description
E^j	$K^j - U^j$	CE difference in j -th elicitation of Ellsberg
Z^j	$K^j - UU^j$	CE difference in j -th elicitation of 2Stage
H^j	$K^j - C^j$	CE difference in j -th elicitation of 50-50 vs. Halevy compound 50-50
L^j	$K^j - CC^j$	CE difference in j -th elicitation of 2-Stage simple 50-50 vs. compound 50-50
I^E	$\mathbb{1}\{E^1 + E^2 > 0\}$	Indicator for falling for classic Ellsberg paradox
I^T	$\mathbb{1}\{T^1 + T^2 > 0\}$	Indicator for falling for 2-Stage Ellsberg paradox
I^H	$\mathbb{1}\{H^1 + H^2 > 0\}$	Indicator for falling for Halevy paradox
I^L	$\mathbb{1}\{L^1 + L^2 > 0\}$	Indicator for falling for unambiguous 2-Stage paradox
F^{0-2}	$.5(UU^1/KK^1) + .5(UU^2/KK^2)$	Ratio of certainty equivalents for UU and KK (averaged across 2 elicitations)
F^{0-3}	$UUU/3K$	Ratio of certainty equivalents for UUU and KKK
F^{1-3}	$KUU/3K$	Ratio of certainty equivalents for KUU and KKK
I^B	Treatment = C & did "Bounded U" first	Indicator variable for having the "learning" section first
I^R	$R^2 = 1$ and $R^3 = 0$	Indicator variable for choosing the correct color in both practice questions
I^A	all $A^j = 1$	Indicator variable for get all 3 attention screeners correct

Table 9: CONTINGENT VARIABLE NAMES

	T^1	T^2	E^1	E^2	H^1	H^2	L^1	L^2
Mean	9.92	6.90	13.49	10.79	1.21	6.74	11.31	3.13
95% Conf. Interval	[6.39, 13.44]	[3.43, 10.38]	[9.99, 17.00]	[7.22, 14.36]	[-7.10, 9.52]	[-1.28, 14.76]	[2.73, 19.89]	[-5.37, 11.64]
ρ		0.152		0.287		0.134		0.221
$1 - \rho$		0.848		0.713		0.866		0.779
se $1 - \rho$		0.033		0.032		0.067		0.066
N	880		880		220		220	

Table 10: DECOMPOSED SUMMARY STATISTICS

C Prolific Data Collection Details

Fair attention check. We did not use captcha for this reason ??? Instead we used attention checks. This has been developing these last years. However, amid those attention checks some are valid, some are not valid. Those not valid are.;Those valid, called “fair attention checks” are... We used these latter ones, following Prolific standards.

Preventing duplicates. Submissions to studies on Prolific are guaranteed to be unique by the firm²¹. Our system is set up such that each participant can have only one submission per study on Prolific. That is, each participant will be listed in your dashboard only once, and can only be paid once. On our side, we also prevent participants to take up several times our experiment in two steps. First, we enable the functionality “Prevent Ballot Box Stuffing” which permits to... Second we check participant ID and delete the second submission from the data set of the same ID if we find any.

Drop-out rates. Here put the drop out (or in the main text).

High vs low-quality submissions. Participants joining the Prolific pool receive a rate based on the quality of their engagement with the studies. If they are rejected from a study then they receive a malus. If they receive too much malus, then they are removed by the pool from the company²². Based on this long term contract, participants are incentivized to pay attention and follow the expectations of each study. Hence, a good research behavior has emerged on Prolific according to which, participants themselves can voluntarily withdraw their submissions if they feel they did a mistake such as rushing too much, letting the survey opened for a long period of time without engaging with it, and so on²³. According to these standards, we kept submissions rejections as low as possible, following standard in online experimental economics. Participants who fail at least one fair attention check are rejected and not paid. Following Prolific standards, participants who are statistical outliers (3 standard deviations below the mean) are excluded from the good complete data set.

Payments and communication. . We make sure to review participants’ submissions within within 24-48 hours after they have completed the study. This means that within this time frame, if we accept their submission, they receive their fixed and bonus payment. Otherwise, we reject their submissions and send to them a personalized e-mail(²⁴), detailing the reason of the rejection, leaving participants the opportunity to contact us afterwards if they firmly believe the decision to be unfair (motivate their

²¹See Prolific unique submission guarantee policy [here](#).

²²See Prolific pool removal Policy [here](#).

²³See Prolific update regarding this behavior [here](#).

²⁴Partially-anonymized through Prolific messaging app which put the researcher’s name visible to the participants and only the participantsID visible to the researcher.

perspective). Participants can also contact us at any time if they encounter problems with our study or just have questions about it.

D Variables Dictionary

D.1 Independent Variables

Stata/Paper	Data File	Elicitation Description
K^1	Balc1a	1st elicitation of risk preferences in one-stage Ellsberg
K^2	Final1a	2nd elicitation of risk preferences in one-stage Ellsberg
\bar{U}^1	Balc1d	1st elicitation of ambiguous preferences in one-stage Ellsberg
U^2	Final1c	2nd elicitation of ambiguous preferences in one-stage Ellsberg
KK^1	Balu1a	1st elicitation of risk preferences in two-stage Ellsberg
KK^2	Matu1a	2nd elicitation of risk preferences in two-stage Ellsberg
$\bar{U}\bar{U}^1$	Balu1b	1st elicitation of ambiguous preferences in two-stage Ellsberg
$\bar{U}\bar{U}^2$	Matu1b	2nd elicitation of ambiguous preferences in two-stage Ellsberg
$\bar{U}K^1$	Balu1c	
$\bar{U}K^2$	Matu1c	
KU^1	Balu1d	
KU^2	Matu1d	
$\bar{K}\bar{K}\bar{K}$	Balu2a	elicitation of risk preferences in 3-stage Ellsberg
$\bar{U}\bar{U}\bar{U}$	Balu2b	elicitation of ambiguous preferences in 3-stage Ellsberg
$K\bar{U}\bar{U}$	Balu2c	
\bar{H}	Balu4	2-Stage gamble with independent ambiguous urns
C^1	Lotte1	1st Halevy compound 50-50 lottery
C^2	Final2a	
$\bar{C}\bar{C}^1$	Lotte2	1st 2-stage Halevy
$\bar{C}\bar{C}^2$	Final2b	
$\bar{B}\bar{B}^{40-60}$	Cmu1b	2-stage Ellsberg with bounded U ($40 \leq R \leq 60$)
$\bar{B}\bar{B}^{60-100}$	Cmu2b	2-stage Ellsberg with bounded U ($60 \leq R \leq 100$)
$\bar{B}\bar{B}^{95-100}$	Cmu4b	2-stage Ellsberg with bounded U ($95 \leq R \leq 100$)
R^1	Answered "red" on Mp1	
R^2	Answered "red" on Mp2	Picked the CORRECT color in practice question 2
R^3	Answered "red" on Mp3	Picked the WRONG color in practice question 3
P^1	Q78	Indicator variable for get $P^1 = 1$, i.e., correct := "32 Blue balls and 95 Red balls"
P^2	Q1777	Indicator variable for get $P^2 = 1$, i.e., correct := "2"
P^3	Q80	Indicator variable for get $P^3 = 1$, i.e., correct := "\$1"
A^1	Q13	Indicator variable for get $A^1 = 1$, i.e., correct := "orange"
A^2	Q22	Indicator variable for get $A^2 = 1$, i.e., correct := "11"
A^3	Q30	Indicator variable for get $A^3 = 1$, i.e., correct := "blue"

INDEPENDENT VARIABLE NAMES

D.2 Dependent Variables

Note on the naming convention for first few items: E =Ellsberg, T =Two-stage, H =Halevy, L = compound Lottery

Stata/Paper	Definition	Description
E^j	$K^j - U^j$	Certain equivalent difference in j -th elicitation of 1-stage Ellsberg
T^j	$KK^j - UU^j$	Certain equivalent difference in j -th elicitation of 2-stage Ellsberg
H^j	$K^j - C^j$	Certain equivalent difference in j -th elicitation of 50-50 vs. Halevy compound 50-50
L^j	$KK^j - CC^j$	Certain equivalent difference in j -th elicitation of KK vs. CC
F^{0-2}	$.5(UU^1/KK^1) + .5(UU^2/KK^2)$	Ratio of certainty equivalents for UU and KK (averaged across 2 elicitations)
F^{0-3}	UUU/KKK	Ratio of certainty equivalents for UUU and KKK
F^{1-3}	KUU/KKK	Ratio of certainty equivalents for KUU and KKK
I^E	$E^1 + E^2 > 0$	Indicator variable for having a larger Certain equivalent for K than U
I^T	$T^1 + T^2 > 0$	Indicator variable for having a larger Certain equivalent for KK than UU
I^H	$H^1 + H^2 > 0$	Indicator variable for having a larger Certain equivalent for K than C
I^L	$L^1 + L^2 > 0$	Indicator variable for having a larger Certain equivalent for KK than CC
I^B	Treatment = C & did "Bounded U" first	Indicator variable for having the "learning" section first
I^R	$R^2 = 1$ and $R^3 = 0$	Indicator variable for choosing the correct color in both practice questions
I^A	all $A^j = 1$	Indicator variable for get all 3 attention screeners correct

DEPENDENT VARIABLE NAMES

MPL Example

Complete experimental instructions available online

In this section, you will be presented with an urn. The gamble is as follows: you get to choose a color (either red or blue), then we will draw a ball at random from the urn. You win 300 tokens if the ball we drew was the COLOR YOU CHOSE.

Suppose the urn is [25 Red, 25 Blue]. Which do you prefer?

RED BLUE

	Receive fixed payment	Play the gamble
Fixed payment: 0 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 10 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 20 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 30 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 40 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 50 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 60 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 70 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 80 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 90 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 100 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 110 tokens	<input type="radio"/>	<input type="radio"/>
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Fixed payment: 260 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 270 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 280 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 290 tokens	<input type="radio"/>	<input type="radio"/>
Fixed payment: 300 tokens	<input type="radio"/>	<input type="radio"/>