Ambiguity Preferences and Beliefs in Strategic Interactions

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Abstract

Based on a within-subjects laboratory experiment, we examine decisions made under uncertainty within strategic and non-strategic environments. This paper uses the matching probabilities method to elicit perception of ambiguity and ambiguity attitudes in three strategic interactions, a modified Tullock contest, a minimum-effort coordination game, and a classic zero-sum Rock-Paper-Scissors game, and a standard three-color Ellsberg setup. We find remarkable stability of attitudes to ambiguity across all four environments. In contrast, subjects perceived a significantly greater amount of ambiguity in the minimum-effort coordination game, which has multiple equilibria and entails considerably more strategic uncertainty than the other games. Our findings suggest that ambiguity is ubiquitous in strategic interactions and its role is closely tied to the amount of strategic uncertainty.

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1 Introduction

Many strategic and non-strategic choices are made under ambiguity (Knight (1921), Ellsberg (1961)), where decision-makers lack information about the underlying uncertain phenomenon to form beliefs characterized by a unique probability distribution. Ellsberg's seminal contribution and subsequent axiomatization of a number of models of decision-making under ambiguity (e.g., Bewley (2002), Schmeidler (1989), Gilboa and Schmeidler (2004), Klibanoff, Marinacci and Mukerji (2005), Maccheroni, Marinacci and Rustichini (2006), Cerreia-Vioglio, Dillenberger and Ortoleva (2015)) lead to a plethora of experimental papers on individual decision-making under ambiguity.[1] There has also been a significant growth in trying to explore the role of ambiguity in strategic settings, especially during the last decade.[2] These studies provide numerous novel insights, but many gaps in our understanding of preferences and behavior under ambiguity remain. The main objective of the present paper is to address one of these unresolved questions by investigating whether individuals' attitudes and perceptions of ambiguity are stable across different environments. To accomplish that, we design an experiment to elicit these behavioral traits across both strategic and non-strategic environments and then compare them.

We examine ambiguity preferences across three strategic environments (a modified Tullock contest, a minimum-effort coordination game, and a Rock-Paper-Scissors game) and one non-strategic environment (a three-color Ellsberg urn task). We hypothesize that ambiguity perceptions about opponents' possible choices depend on the strategic uncertainty surrounding an interaction. Our three games entail varying degrees of strategic uncertainty and were selected to explore this relationship. The modified Tullock contest has a unique equilibrium in dominant strategies and was chosen to represent situations with a minimal degree of strategic uncertainty about an opponent's play. The minimum-effort coordination game represents the other end of the range of strategic uncertainty. The game has three pure strategy equilibria and mixed strategy equilibria, where each of the strategies has favorable features from a player's perspective. If ambiguity perceptions

[1] For a review of the experimental literature, see, e.g., Trautmann and van de Kuilen (2015)

[2] See Di Mauro and Castro (2011), Eichberger and Kelsey (2011), Ivanov (2011), Kelsey and Le Roux (2013), Chark and Chew (2015), Kelsey and Le Roux (2015), Kelsey and Le Roux (2018) Dominiak and Duersch (2019), Li, Turmunkh and Wakker (2019), Calford (2020), Li, Turmunkh and Wakker (2020), or Aoyagi, Masuda and Nishimura (2021)

are indeed related to the strategic uncertainty surrounding strategic interactions, then one would expect the coordination game to entail considerably more revealed ambiguity than the Tullock contest. The Rock-Paper-Scissors with its unique mixed strategy equilibrium falls between these two extremes. Additionally, since the Rock-Paper-Scissors game can be interpreted as a strategic analog of the three-color Ellsberg urn task, a comparison of the two environments will shed light on the role of the human factor in attitudes and perceptions of ambiguity.

We use the matching probabilities method (see, e.g., Raiffa (1968), Dimmock, Kouwenberg and Wakker (2016), and Baillon et al. (2018)) to elicit model-free indexes of ambiguity aversion b and ambiguity-generated insensitivity a.[3] The main benefits of these indices include: i) they correct for subjective likelihoods, ii) they apply to both non-strategic and strategic settings, iii) they are directly observable, and iv) they are valid under most ambiguity theories. The ambiguity aversion index measures an individual's attitude towards ambiguity, free of any model or statistical assumptions. The ambiguity-generated insensitivity index captures an individual's ability to differentiate between high and low probability events. As it pertains to our analysis, higher values of insensitivity indicate a decision-maker who has greater difficulty distinguishing between likelihoods for their opponent's single and composite strategy play. Thus, this decision-maker perceives more ambiguity about their opponent's choice.

To provide further support for the analysis based on the model-free indices (b and a), we use the α-maxmin model with a neo-additive capacity to estimate two more indices associated with ambiguity attitudes and perception of ambiguity (Chateauneuf, Eichberger and Grant (2007)). This set of preferences were selected for their ability to provide a clear separation between the two components of interest and for having a unique parameter characterizing each of the two behavioral traits (ambiguity attitude and perception of ambiguity). Making further use of the matching probabilities, we estimate ambiguity attitude α and a single parameter δ characterizing perception of ambiguity.

Our four indices, two for ambiguity aversion (b and α) and two for the perception of ambiguity (a and δ), give us two pairs of comparisons. We can directly compare the results between the ambiguity aversion index (b) and the ambiguity attitude index (α) and between the ambiguity-

[3] Fox and Tversky (1995), Abdellaoui et al. (2011), Webb and Zank (2011), and Baillon et al. (2018).

generated insensitivity index (a) and the perception of ambiguity index (δ). By construction, each pair of indices relays the same information for an individual. One index for the pair is model-free, and the other is estimated using α-maxmin preferences with a neo-additive capacity. Our first finding supports the noteworthy result that individuals have stable ambiguity-seeking attitudes across all of our settings, both strategic and non-strategic. This result is congruent with the construction of the ambiguity aversion indices, which are designed to capture a general characteristic of a decision-maker. Our second finding offers evidence that individuals perceive the greatest amount of ambiguity in the minimum-effort coordination game compared to all of the other settings (Tullock, Rock-Paper-Scissors, Ellsberg). Additionally, we would expect the dominant strategy Tullock contest to have the smallest amounts of perceived ambiguity. Still, we only found nominally smaller averages for a and δ, which were not significantly different than the corresponding indexes for the Rock-Paper-Scissors and Ellsberg tasks. We also found that the perceived levels of ambiguity the Tullock, Rock-Paper-Scissors, and Ellsberg tasks are all statistically similar.

The remainder of the paper is organized as follows. Section 2 defines the four indices and takes the reader through the matching probability procedure to illustrate how the method can be applied to our environment. It also introduces the α-maxmin model with beliefs given by a neo-additive capacity. Section 3 describes our experimental design. Section 4 presents our results and discusses their implications. Finally, Section 5 concludes.

2 Elicitation Method and Procedure

2.1 The Choice Setup

We examine two types of settings; strategic and non-strategic. The strategic interactions studied in the paper involve two players, 1 and 2, where each player has three strategies. Player 1 and player 2's payoffs when the former chooses strategy $i \in \{A, B, C\}$ while the latter chooses strategy $j \in \{X, Y, Z\}$ are denoted u_{ij} and v_{ij}, respectively (see Table 1).

Table 1: General Normal Form Table

		Player 2		
		X	Y	Z
Player 1	A	u_{AX}, v_{AX}	u_{AY}, v_{AY}	u_{AZ}, v_{AZ}
	B	u_{BX}, v_{BX}	u_{BY}, v_{BY}	u_{BZ}, v_{BZ}
	C	u_{CX}, v_{CX}	u_{CY}, v_{CY}	u_{CZ}, v_{CZ}

From the perspective of player 1, one can interpret the set of player 2's pure strategies as the state space: $S \equiv \{X, Y, Z\}$. Correspondingly, the set of possible events is given by the set 2^S of all subsets of S. Acts are mappings from the set of states to the real line with a generic act given by $f : S \longrightarrow \mathbb{R}$. The set of all acts include player 1's pure strategies A, B, and, C, which we denote by f_A, f_B, and f_C, respectively. From Table 1, we have $f_i(s) = u_{is}$, where $i \in \{A, B, C\}$ and $s \in \{X, Y, Z\}$. The decision-maker's (player 1, in our case) preferences are given by a monotonic weak order over acts.

The non-strategic setting examined in the paper involves an Ellsberg urn with three colors. Slightly abusing our notation, the state space in this case is given by $S \equiv \{X, Y, Z\}$, where individual elements of S correspond to a different color of the urn. As in the strategic case, acts are mappings from S to $\mathbb{R}$. They correspond to bets on a color of the ball randomly drawn from the urn.

2.2 Elicitation Procedure

Our objective is to use experimental data to elicit subjects' preferences, including their aversion to ambiguity and insensitivity to beliefs about their opponent's strategy choice as well as those same traits in non-strategic settings. We utilize a matching probability procedure that is rooted in the source method to analyze uncertainty (Tversky and Kahneman (1992), Fox and Tversky (1995), Kilka and Weber (2001), Chew and Sagi (2006), Chew and Sagi (2008), Abdellaoui et al. (2011)). The source method distinguishes between different collections of events where each group arises from a distinct and common uncertainty-generating mechanism. For example, one source of uncertainty may pertain to the outcome of the US presidential election in 2024, while the other source of uncertainty may apply to the result of the UEFA champions league soccer competition in 2023. As another set of examples, one source of uncertainty may be associated with an urn that has unknown proportions of balls of different colors while the other may be related to an urn that has known proportions of balls of different colors.

Building on Chew and Sagi (2006) and Chew and Sagi (2008), Dimmock, Kouwenberg and Wakker (2016) demonstrate that the method of eliciting matching probabilities for ambiguous events allows to estimate model-free measures of ambiguity aversion and perception of ambiguity without eliciting Bernoulli utilities or probability weighting. The procedure requires that a decision-maker evaluates binary acts that pay V under event E and 0 otherwise, using product $w(E) * u(V)$, where $w(E)$ is the weight assigned to event E while $u(V)$ is the utility of outcome V.[4]

The procedure to elicit the matching probability function m (Raiffa (1968), Dimmock, Kouwenberg and Wakker (2016), and Baillon et al. (2018)) asks a decision-maker to choose between an ambiguous prospect and a sequence of risky prospects. For the strategic setting, a decision-maker is asked to choose between:

Option AS: You win \$20 if the other person makes a choice E and \$0 otherwise.

and

Option R Option R: You win \$20 with $p\%$ probability and \$0 otherwise.

For the non-strategic setting, a decision-maker is asked to choose between:

Option ANS: You win \$20 if a ball randomly drawn from the urn is ____ and \$0 otherwise.

and

[4]The set of preferences that allows for such representation is extensive. It includes biseparable preferences (Ghirardato and Marinacci (2002)) and several classes of non-biseparable preferences (for more on this, see, e.g., Dimmock, Kouwenberg and Wakker (2016), Baillon et al. (2018), and Baillon et al. (2020)).

Option R: You win \$20 with $p\%$ probability and \$0 otherwise.

The sequence of risky prospects is formed by gradually increasing $p\%$ from 0% to 100%: For the three strategic tasks in our experiment, the events considered for Option AS contain individual strategies X, Y, and Z and strategy pairs XY, XZ, and YZ. For the non-strategic Ellsberg task, the events correspond to draws of individual colors and two color pairs. The matching probability m_E of event $E \in \{X, Y, Z, XY, XZ, YZ\}$ is the value $p\%$ such that the decision-maker is indifferent between ambiguous and risky options. In our experiment, this indifference point is determined by taking the midpoint of the range of probabilities where the switch occurs. Specifically, a subject is only permitted to switch from the ambiguous option to the risky option once for some $p\%$ probability. For example, m_{XZ} is the matching probability of the event that player 2 chooses strategy X or strategy Z. The act that corresponds to Option AS in this case is given by $f(\text{X}) = f(\text{Z}) = \$20$ and $f(\text{Y}) = \$0$.

2.3 Ambiguity aversion and a-insensitivity indices

Define the averages of the matching probabilities for singleton strategies and for their pairs by

$$\bar{m}_s = \frac{m_X+m_Y+m_Z}{3} \text{ and } \bar{m}_c = \frac{m_{XZ}+m_{YZ}+m_{XY}}{3},$$

respectively. The *ambiguity aversion* index (Abdellaoui et al. (2011), Baillon et al. (2018)) is defined as

$$b = 1 - \bar{m}_s - \bar{m}_c. \tag{1}$$

The index measures how much success probability a decision-maker is willing to give up on average to avoid ambiguity. A more ambiguity-averse decision-maker will tend to have smaller matching probabilities and will be willing to sacrifice more in terms of the likelihood of winning to obtain the risky option. A decision-maker is *ambiguity neutral* if the collection of the matching probabilities m_E for events $E \in \{X, Y, Z, XY, XZ, YZ\}$ forms a probability distribution over the algebra of sets $\{\emptyset, X, Y, Z, XY, XZ, YZ\}$ so that

$$m_{XY} = m_X + m_Y, \;\; m_{XZ} = m_X + m_Z, \;\; m_{ZY} = m_Z + m_Y, \;\; m_X + m_Y + m_Z = 1. \tag{2}$$

In this case, $\bar{m}_s = \frac{2}{3}$, $\bar{m}_c = \frac{1}{3}$ and the ambiguity aversion index $b = 0$. Note also that the ambiguity aversion index is maximal ($b = 1$) when the matching probabilities for all six events $\{X, Y, Z, XY, XZ, YZ\}$ are equal to 0. In contrast, the ambiguity aversion is minimal ($b = -1$) when all matching probabilities are equal to 1. A decision-maker with a maximal ambiguity aversion index will choose Option R over Option Am for any strictly positive probability $p\%$. Thus, a maximally ambiguity averse decision-maker treats the ambiguous option similar to a risky option where the preferred outcome of \$20 has a zero probability. Conversely, a decision-maker with a minimal ambiguity aversion index will choose Option Am over Option R for any probability $p\%$ strictly less than 100%.

We now turn to the second index of interest. Recent empirical evidence on behavior under ambiguity reveals ambiguity aversion for likely events and ambiguity seeking for unlikely events. Moreover, as one moves toward the middle of the range from very likely events on one end of the spectrum, and improbable events, on the other end, decision-makers tend to become more non-responsive to ambiguity (see, e.g., Baillon and Bleichrodt (2015), Trautmann and van de Kuilen (2015) and Kocher, Lahno and Trautmann (2018)). As Baillon et al. (2020) put it, a decision-maker "takes ambiguous events (too much) as one blur" (p. 10). An individual's inability to differentiate between different ambiguous situations is sometimes interpreted as a reflection of irrationality (see, e.g., Li (2017) and Baillon et al. (2020)). The *ambiguity-generated insensitivity* (a-insensitivity) index (Fox and Tversky (1995), Abdellaoui et al. (2011), Webb and Zank (2011), Baillon et al. (2018)), defined as

$$a = 3 * (\frac{1}{3} - (\bar{m}_c - \bar{m}_s)), \tag{3}$$

characterizes this behavioral trait. An individual who is relatively insensitive to ambiguity will have a low tendency to discern the ambiguity associated with a single event from the ambiguity associated with a composite event containing the former. Note that under ambiguity neutrality, we have $\bar{m}_s = \frac{1}{3}$ and $\bar{m}_c = \frac{2}{3}$, implying $a = 0$; but the latter condition is not sufficient for ambiguity neutrality. At the other end of the insensitivity spectrum is a "completely insensitive" decision-maker who assigns a 0.5 probability to all single and composite events, resulting in $a = 1$.

2.4 α-maxmin Expected Utility Model

In addition to estimating the model-free indexes of ambiguity aversion and a-insensitivity, we explore similar measures within a subclass of α-maxmin expected utility preferences. Appendix D contains a comparison of different models of ambiguity-sensitive preferences in terms of their ability to explain the observed behavioral patterns. There, we reach a conclusion that the α-maxmin expected utility is one of the leading contenders in achieving this objective.

To introduce these preferences, consider an arbitrary finite set of states S and the set of possible events 2^S. Recall that acts are mappings from the set of states to the real line with a generic act given by $f : S \longrightarrow \mathbb{R}$. A decision-maker with α-maxmin expected utility preferences has beliefs given by set $P \subseteq \Delta$ of priors over 2^S, where Δ is the probability simplex over 2^S. The decision-maker's evaluation of act f is given by

$$\alpha \min_{p \in P}(E_p u(f)) + (1-\alpha) \max_{p \in P}(E_p u(f)). \tag{4}$$

Within the α-maxmin model, the scenario where a decision-maker is ambiguity neutral corresponds to the case where the set P is a singleton. The parameter α is often interpreted as a measure of ambiguity aversion or pessimism. When $\alpha > 0.5$, a decision-maker places more weight on the most pessimistic scenario than the most optimistic. For this reason, a decision-maker with $\alpha > 0.5$ is said to be ambiguity averse. Conversely, the values of α smaller than 0.5 correspond to ambiguity-loving decision-makers.

Consider a decision-maker with α-maxmin expected utility preferences who evaluates a binary act with outcomes \$0 and \$20.[5] Suppose, for simplicity, there are two events of interest: event E and its complement E^c. The matching probability m_E for the ambiguous prospect with outcome

[5] See Baillon et al. (2018) and Baillon et al. (2020) for more on the form of the ambiguity aversion index and a-insensitivity index under α-maxmin expected utility and its various special cases.

\$20 under event E and outcome \$0 under event E^c is given by

$$\alpha \min_{p\in[\underline{p},\bar{p}]}(pu(20)+(1-p)u(0))+(1-\alpha)\max_{p\in[\underline{p},\bar{p}]}(pu(20)+(1-p)u(0))$$
$$=m_E u(20)+(1-m_E)u(0), \quad (5)$$

where $[\underline{p},\bar{p}]$ is the range of probabilities entertained by the decision-maker about the likelihood of event E. This expression can be re-written as

$$m_E=\alpha\underline{p}+(1-\alpha)\bar{p}. \quad (6)$$

With a similar ambiguous prospect for E^c, we can obtain

$$m_{E^c}=\alpha(1-\bar{p})+(1-\alpha)(1-\underline{p}). \quad (7)$$

Thus, the matching probabilities depend on the measure of ambiguity aversion α and the amount of perceived ambiguity as measured by $\bar{p}-\underline{p}$.

We focus our attention on the case where the decision-maker's beliefs P are given by the core of a neo-additive capacity. To introduce these beliefs, let N denote the set of null events (see, e.g., Chateauneuf, Eichberger and Grant (2007)). Suppose the decision-maker has a reference probability distribution $\pi\in\Delta$ and let $\delta\in[0,1]$ characterizes her degree of confidence in that probability distribution. The decision-maker's beliefs are given by

$$P=\{p\in P:p(E)=0 \text{ for all } E\in N, p(E)\geq(1-\delta)\pi(E) \text{ for all } E\notin N\}. \quad (8)$$

A decision-maker with α-maxmin expected utility preferences and beliefs given by (8) evaluates act f according to

$$(1-\delta)E_\pi u(f)+\delta(\alpha\min_{s\in S}(u(f_s))+(1-\alpha)\max_{s\in S}(u(f_s))). \quad (9)$$

Let π = (π_X, π_Y, 1-π_X-π_Y) $\in\Delta$ characterize the anchor probability. The general matching probability formula between a known probability and unknown probability can be written as $m = (1-\delta)\pi + (1-\alpha)\delta$ (see also Dimmock, Kouwenberg and Wakker (2016)). Using our six matching probabilities, we estimate the parameters α, δ, π_X, and π_Y for each experimental subject by minimizing the function

$$\textstyle\sum_{E \notin N}(m_E - ((1-\delta)\pi_E + (1-\alpha)\delta))^2$$

under the constraints $0 \leq \alpha \leq 1$, $0 \leq \delta \leq 1$, $0 \leq \pi_X \leq 1$, $0 \leq \pi_Y \leq 1$, and $0 \leq (1 - \pi_X - \pi_Y) \leq 1$.

3 Experimental Design and Procedures

3.1 Experimental Design

The experiment has a within-subject design consisting of four main tasks. The first three tasks include a modified Tullock contest, a minimum-effort coordination game, and a classic zero-sum Rock-Paper-Scissors game. These games represent the strategic component of the study. The order of these first three tasks was randomized in each session. The last fourth task was non-strategic. It was a version of a standard three-color Ellsberg urn task (Ellsberg (1961)). This task was always the last task seen by the subjects to prevent any contamination in behavior from the non-strategic onto the strategic settings, a procedure that is fairly standard in the literature.

One of the three games used in our experiment is a Tullock contest (Tullock (1980)) with two participants. Each player's probability of winning a prize, V, is affected by the amount of effort both her and the other player invest in the game. The payoff function for player i is given by

$$E[\pi_i] = \frac{e_i}{e_i + e_{-i}}V - e_i, \tag{10}$$

where e_i and e_{-i} denote player i's and her opponent's efforts, respectively.[6]

In the experiment, we used a discrete version of the game with three "effort" levels: \$0, \$10 and \$20. The value of the prize is set to \$40 and it is also assumed that neither player receives the

[6] For all tasks, the subjects did not receive any instructions on how the payoff functions looked or what game they were playing outside of the payoff tables.

prize if both players choose \$0. Table 2 displays how the normal form of the game was presented to the subjects.[7] The row players' strategies and payoffs were displayed in red to the subjects while the column players' strategies and payoffs were in black. The row players' strategies A, B, and C and the column players' strategies X, Y, and Z correspond to "effort" levels \$0, \$10 and \$20, respectively. Since the game has a unique Nash equilibrium in dominant strategies, where player 1 chooses strategy B while player 2 chooses strategy Y, participants in this strategic interaction are likely to face little strategic uncertainty about behavior of their opponents. Relatedly, a player may perceive little ambiguity about the action of her counterpart. This aspect of the strategic interaction is the main reason for the inclusion of this "extreme" case as one of the three strategic tasks.

Table 2: Tullock Contest

		Player 2		
		X	Y	Z
	A	\$0, \$0	\$0, \$30	\$0, \$20
Player 1	B	\$30, \$0	\$10, \$10	\$3, \$7
	C	\$20, \$0	\$7, \$3	\$0, \$0

The second strategic task in the experiment is a minimum-effort Coordination game. As will become apparent momentarily, relative to the Tullock contest this game stands at the opposing end of the spectrum of strategic uncertainty about opponent's choice. There are two players in the game who have incentives to coordinate their efforts. Player i's payoff function is given by

$$\pi_i = \min(e_i, e_{-i}) - \frac{1}{2}(e_i), \tag{11}$$

where e_i and e_{-i} denote player i's and her opponent's effort levels, respectively.

We used a discrete version of the game where each player has three possible choices \$0, \$10 and \$20. Table 3 displays the normal form table that the subjects saw within the instructions. The row players' strategies are represented by the red A, B, and C while the column players' strategies

[7] We rounded some of the payoffs obtained from (10) so that Table 2 contained only integer numbers.

are represented by the black X, Y, and Z. These choices correspond to strategies \$0, \$10 and \$20, respectively. The payoffs in Table 3 are also presented similarly to the display of the Tullock contest in Table 2.[8] It is straightforward to verify that the game has three Nash equilibria in pure strategies (A, X), (B, Y), and (C, Z), as well as equilibria in mixed strategies. Although the strategy profile (C, Z) Pareto dominates the other two pure strategy Nash equilibria, it is not at all obvious that it is a "natural" choice of play for participants in this strategic interaction. If a player chooses to play according to this equilibrium but the opponent does not, the former will end up with a payoff of \$0, which is the least attractive option in the game. In contrast, if a player chooses effort \$0, she will get \$10 irrespective of her opponent's choice. But this payoff is significantly lower than the payoff of \$20 a player would receive if she and her opponent could coordinate on contributing \$20 each. Finally, the potential advantages and strategic risks for contributing \$10 fall between choosing \$0 and \$20. Since it is not clear which of these considerations will prevail, it seems that participants in this strategic interaction may perceive significant strategic uncertainty about opponent's choice.

Table 3: Coordination Game

		Player 2		
		X	Y	Z
	A	\$10, \$10	\$10, \$5	\$10, \$0
Player 1	B	\$5, \$10	\$15, \$15	\$15, \$10
	C	\$0, \$10	\$10, \$15	\$20, \$20

The third strategic task is a standard Rock-Paper-Scissors game. Table 4 illustrates how the game was presented to the participants.[9] Given the game's payoff structure and its unique mixed strategy Nash equilibrium, where each player selects each of her three choices with probability $\frac{1}{3}$, one can interpret the Rock-Paper-Scissors game as a strategic analog of a three-color Ellsberg experiment, which we discuss next.

[8] We added \$10 to the payoffs in Table 3 so that all of the payoffs were non-negative.

[9] Note that the strategies and coloring of the strategies and payoffs are the same as for the other two games.

Table 4: Rock-Paper-Scissors Game

		Player 2		
		X	Y	Z
	A	$10, $10	$0, $20	$20, $0
Player 1	B	$20, $0	$10, $10	$0, $20
	C	$0, $20	$20, $0	$10, $10

The fourth choice task involves a three-color Ellsberg urn. A participant in this task is told that the urn contains a total of 100 balls of three colors: Red, Green, and Blue. No additional information about the composition of the urn was revealed to participants. Thus, the only available piece of information supplied to the subjects was that the sum of the balls of the three colors must add to 100.

In the beginning of the study, the subjects were informed how to read and interpret a normal form table. Then, they were shown each of the four main tasks independently. After they were shown the payoff table to be used for the respective task, they were prompted to make six decisions based on their beliefs about the other player playing strategies X, Not X, Y, Not Y, Z, and Not Z or the selection of a colored ball from an urn using choice lists. Each player functioned as a row player. The choice list for each strategic task included 20 choices between between Option AS and variants of Option R. The choice list for the Ellsberg urn included 20 choices between between Option ANS and variants of Option R. The subjects were allowed to switch from one option to another only once. There were two different lists of probabilities (see Appendix B); one list was used for singleton events while the other was used for composite events. These lists were constructed to avoid potential middle bias choice, to avoid formation of a prior that all events are equally likely, and to allow the choice lists for single and composite events to add up to probability 1 to ensure an accurate interpretation of the attitudes. In addition to eliciting the matching probabilities, the subjects chose an action that they would like to play in each of the three games. Finally, each of the choices made by a subject during the experiment could be selected for payment. If a game was selected for payment, the choices of each subject were used to determine the appropriate payoff for the pair.

3.2 Procedures

The experiment consists of 12 sessions conducted at the University of Alabama TIDE Lab in the Fall of 2021.[10] Each session had an even number of subjects between 8 and 16. At the beginning of a session, subjects were randomly seated at the computers in the lab and read the instructions individually (instructions are broken down in Appendix A). No subject appeared in more than one session and all choices and information were entered into the z-Tree program (Fischbacher (2007)). After each subject read the instructions, they were prompted with a quiz to ensure their understanding of a payoff table. Subjects were provided with the correct answers for the questions they answered incorrectly.

After all of the subjects completed the instructions, they saw four sequential tasks. For each task, the subjects made choices from six choice lists. The sequence in which these six choice lists appeared was randomized. In the case of the three strategic tasks, the subjects also chose an action that they would like to play in the corresponding game and this choice always followed the six choices lists. After completing each of the four tasks, we anonymously and randomly re-matched the subjects. The four tasks were followed by a short survey, collecting each subject's gender and their answers to the standard seven CRT (cognitive reflection test) questions.[11] They were subsequently paid for one randomly chosen choice list decision or game play. All payoffs shown to the participants were denoted in US dollars, and the average earning in the study was $17.89 (this average does not include a $5 show-up payment).

[10]Subjects were recruited from the TIDE lab's distribution list comprised of undergraduate students from across the entire university who had indicated a willingness to be paid volunteers in decision-making experiments. This pool of undergrads primarily comprises business school undergrads, and none of the participants had previously participated in any related studies. For this experiment, subjects were sent an e-mail invitation to participate in a session lasting approximately 60 minutes. Subjects were informed they would receive a $5 show-up payment plus any salient earnings made during the study.

[11]See Appendix E for the list of the seven questions

4 Results

4.1 Description of Data

We now take the first look at the data. The data contains 213 ($142 \times 3 \div 2$) one-shot games and 142 Ellsberg Urn tasks across 142 total subjects. For each environment- Rock-Paper-Scissors, Tullock, Coordination, and Ellsberg- we elicited each subject's matching probability for all singleton events (m_X, m_Y, and m_Z) and all composite events (m_{XY}, m_{XZ}, and m_{YZ}) along with their incentivized choice (A, B, or C) for each game.

Figure 1: Singleton and Composite Matching Probabilities

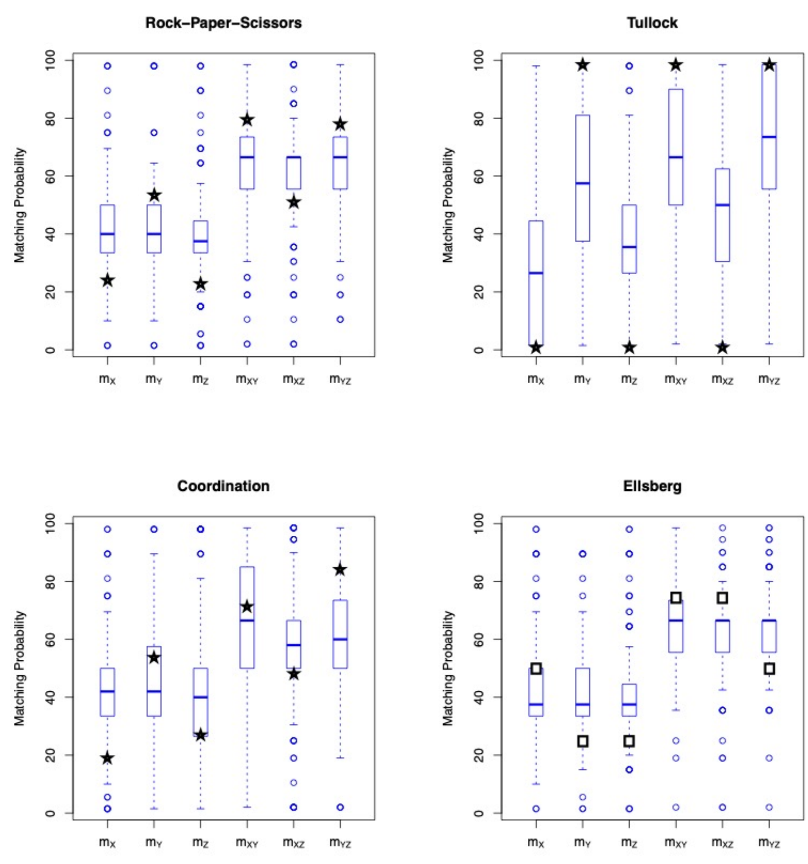


Figure 1 displays the distributions of the matching probabilities for the six events using standard box plots. The solid stars in the plots for the strategic interactions represent the actual frequency of play for the corresponding game while the squares for the Ellsberg task represent the pre-selected distribution of balls of different colors in the urn.

The Rock-Paper-Scissors task box plot is in the upper left-hand corner while the Ellsberg urn plot is in the bottom right-hand corner. The matching probabilities for these two tasks follow a probability weighting trend that is consistent with the received literature (see, e.g., Tversky and Kahneman (1992)). Taking as the benchmark the beliefs of an individual who assigns a probability of $\frac{1}{3}$ to singleton events and a probability of $\frac{2}{3}$ to composite events, the observed behavior reveals that the subjects overweight low likelihood events and underweight high likelihood events. Figure 1 illustrates this pattern; the subjects have a central tendency to place around 40% probability on the singleton events and close to 63% on the composite events.

We argued above that the Rock-Paper-Scissors game, which is symmetric in its three pure strategies, may be interpreted as a strategic counterpart of the symmetric three-color Ellsberg task. One may claim that beliefs about an opponent's possible choice in the Rock-Paper-Scissors game have less "subjectivity." This line of reasoning may be supported by relying on the fact that the game has a unique Nash equilibrium, where each strategy is played with probability $\frac{1}{3}$, and the argument that Nash is an "obvious" or "natural" mode of behavior due to its requirements of rationality and rational expectations. This view may, however, be countered. For example, one may argue that a greater presence of human factor in strategic interactions leads to more "subjectivity" in beliefs than in the Ellsberg task. Another argument supporting this position may be based on the supposition that in the Ellsberg task a decision-maker is more likely to form a second-order probability (probability distribution over probabilities of different colors) and to reduce that second-order probability to the probability distribution $(\frac{1}{3}, X; \frac{1}{3}, Z; \frac{1}{3}, Y)$. Although the matching probabilities for the two tasks are visually similar (see Figure 1), we provide a more definitive assessment of the similarity of the two environments only after conducting a statistical analysis of the empirical distributions illustrated in Figure 1, a task that we relegate to later sections of the paper. There, we also use the Rock-Paper-Scissors game as a benchmark to describe how ambiguity affects the Tullock and Coordination games.

The distributions of the matching probabilities for the Coordination game are in large part similar to those of the Rock-Paper-Scissors game and Ellsberg task. However, the frequency of strategy Y is around 0.5 in both the Coordination and Rock-Paper-Scissors games. This result is an early indication of discrepancies between beliefs about opponents' choices and frequencies of the actual choices.

The box plots for the Tullock contest and the Coordination task appear in the top right and bottom left of Figure 1, respectively. An examination of Figure 1 immediately reveals that in the Tullock contest the subjects place significantly more probabilistic weight on the event that their opponent will play the dominant strategy Y than on other singleton strategies. Consistently with this behavior, the subjects place disproportionately large weights on the composite events containing Y. However, the probability weight placed on strategies X and Z is not at all insignificant, even though 98% of the subjects opted for strategy Y when asked to make a decision within the contest itself. Thus, it is very likely that the participants realize that Y is the dominant strategy and do not hesitate to play it. But at the same time, they entertain the possibility that their opponents may not follow the dominant strategy, perhaps due to error, irrationality or some other justification.

Similarly to the Tullock contest, all of the frequencies of actual choices for the Rock-Paper-Scissors game (see the stars in the left top corner of Figure 1) fall outside the interquartile range. Finally, the pattern is mixed for the Coordination game (see the stars in the left bottom corner of Figure 1). The actual frequencies of some events fall inside the interquartile range while those of others fall outside.

Table 5 reports the mean values of the matching probabilities for the three singleton events and the three composite events, as well as the indices b, a, α, and δ for each of the four environments. Recall that the indices α and δ are bounded between [0,1], the index b is bounded between [-1,1], and the index a is bounded between [-2,4].

Table 5: Summary Statistics for Matching Probabilities and Indices

Rock-Paper-Scissors	m_X	m_Y	m_Z	m_{XY}	m_{XZ}	m_{YZ}	b	a	α	δ
Mean	41.83	41.56	40.34	61.89	60.53	62.98	-0.03	0.38	0.43	0.38
Median	40.00	40.00	37.50	66.50	66.50	66.50	-0.01	0.35	0.50	0.32
Std. Dev.	16.04	17.13	17.73	17.92	17.81	16.12	0.26	0.41	0.28	0.33
Tullock	m_X	m_Y	m_Z	m_{XY}	m_{XZ}	m_{YZ}	b	a	α	δ
Mean	26.34	57.96	37.04	67.41	46.64	72.10	-0.02	0.35	0.33	0.35
Median	26.50	57.50	35.5	66.50	50.00	73.50	-0.01	0.26	0.38	0.21
Std. Dev.	27.09	27.10	22.68	24.61	24.43	26.06	0.29	0.47	0.31	0.34
Coordination	m_X	m_Y	m_Z	m_{XY}	m_{XZ}	m_{YZ}	b	a	α	δ
Mean	42.90	45.61	41.80	64.95	57.23	60.90	-0.04	0.47	0.43	0.67
Median	42.00	42.00	40.00	66.50	58.00	60.00	-0.03	0.43	0.44	0.67
Std. Dev.	18.46	20.26	25.93	24.66	22.18	20.63	0.27	0.46	0.19	0.23
Ellsberg	m_X	m_Y	m_Z	m_{XY}	m_{XZ}	m_{YZ}	b	a	α	δ
Mean	41.84	40.65	41.33	62.90	61.70	63.03	-0.04	0.36	0.36	0.40
Median	37.50	37.50	37.50	66.50	66.50	66.50	-0.01	0.27	0.46	0.29
Std. Dev.	16.69	15.81	17.04	14.22	14.95	14.22	0.23	0.46	0.23	0.37

All four means of the estimated degree of ambiguity aversion α fall below 0.5 but well above 0 (see Table 5). Thus, on average the subjects tend to be "slightly" ambiguity-seeking and on a superficial level exhibit similar aversion to ambiguity across different environments.

The means of the estimated δ, which is a proxy for the amount of perceived ambiguity, exhibit a different pattern. First, note that all four means are significantly greater than 0, which corresponds to the scenario where a decision-maker does not perceive any ambiguity. Thus, the subjects perceive ambiguity in all four environments. While the means of δ are very close to each other for the Ellsberg task, Rock-Paper-Scissors game, and Tullock contest, the mean of δ for the Coordination game is substantially larger, revealing that on average the subjects perceive significantly more ambiguity about the behavior of their opponents in the Coordination game than in other situations. The difference between the perception of ambiguity in the Coordination game and Tullock contest reflects the significant amount of strategic uncertainty present in the former game, where each of the pure strategies can be a part of a Nash equilibrium, and its relatively minor role in the Tullock contest, where both players have a dominant strategy. Thus, these two ends of the perceived ambiguity spectrum are likely to arise from the varying degrees of strategic uncertainty. The mapping between the Nash predictions of the Coordination and Rock-Paper-Scissors games and the difference between the means of their δs also seams to stem from the difference in their strategic uncertainty. While the Rock-Paper-Scissors game has a unique Nash equilibrium, albeit in mixed strategies, the Coordination game has three pure strategy equilibria as well as equilibria in mixed strategies.

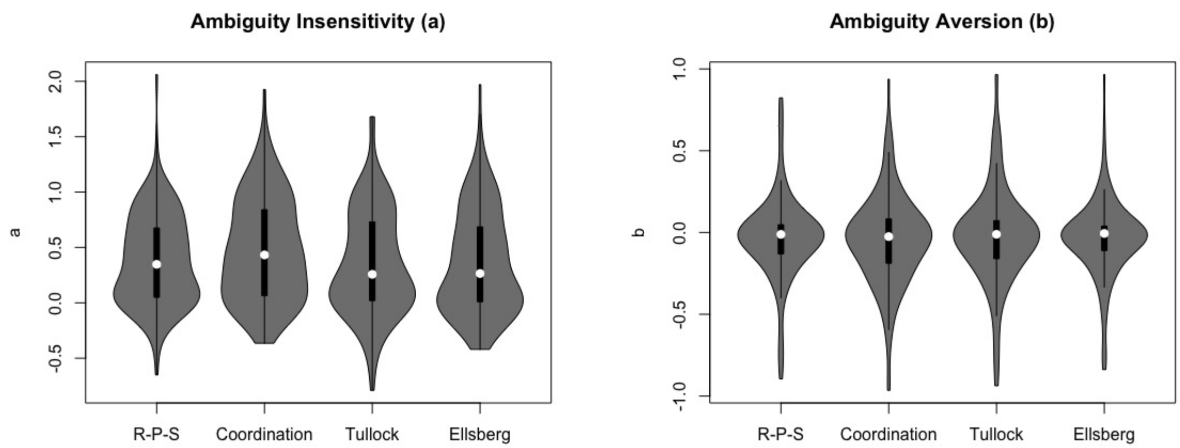
The means of the indices b and a are consistent with the pattern revealed by our estimation of the parameters α and δ. The mean of b for all four tasks is slightly below 0, indicating that the subjects tend to be slightly on the ambiguity seeking side. This is in line with our calculations that the means of the estimated αs in the four tasks fall below $\frac{1}{2}$ but are bounded away from 0.

The average tendencies of the estimated indices δ and a are also similar. Recall that larger values of δ correspond to a smaller amount of ambiguity perceived by a decision-maker. Or, all else equal, ambiguity matters little for such decision-maker. In a similar vein, larger values of a characterize an individual who is more insensitive to ambiguity. The means of both δ and a for the Coordination game are significantly larger than for the other tasks. Thus, both indices point in the same direction in terms of perception of ambiguity in the Coordination game. The means of δ for the other three tasks are very close to each other. Remarkably, the means of a for these tasks are almost identical. Thus, the two indices are very consistent with each other.

4.2 Ambiguity Aversion and Ambiguity Insensitivity

In this section, we take a much deeper look into the ambiguity aversion index, b, and the ambiguity insensitivity index, a. Figure 2 depicts standard violin plots for the distribution of the two indices for each task. The black rectangle in the middle of each "violin" pattern represents the interquartile range, where the white dot within the rectangle reflects each task's median. The left-hand panel of Figure 2 displays the distribution of the ambiguity insensitivity index, a, while the right-hand panel displays the distribution of the ambiguity aversion index, b.

Figure 2: Ambiguity Aversion and Ambiguity Insensitivity Indices



To test the hypothesis that the medians of an index (a or b) for two tasks are equal, we use a non-parametric Bonferroni adjusted Wilcoxon Signed-Rank test. A Wilcoxon Signed-Rank test compares the "central tendencies" of two paired samples by ranking the differences between the two samples into positive and negative groups. The test then compares the signed (+ and -) ranked groups under the null hypothesis that the two ranks are equal. By doing so, the Wilcoxon Signed-Rank test compares the locations of the two samples to test whether the medians are equal. These differences between the two paired samples allow us to use the Wilcoxon Signed-Rank test to make comparisons at the task level.

Subject heterogeneity is not picked up via the Wilcoxon Signed-Rank test because these differences are first aggregated by their sign (+ or -) and then compared. To examine the relationship between the two tasks at individual level, we use a non-parametric Bonferroni adjusted Spearman Correlation test. The Spearman Correlation test separately ranks two samples of paired data from the greatest to the smallest. It then takes those two lists of ranks and assesses how well the direction and magnitude between the two samples is described using a monotonic function (allowing for a non-linear relationship). The Spearman Correlation test takes into account subject heterogeneity because the relative position of each rank is preserved when comparing two paired samples. The p-values for the Wilcoxon Signed-Rank test and the Spearman Correlation test are reported in Tables 6 and 7 for each pair of tasks (six in total).

Table 6: Task and Individual Effects for Index b

b	Wilcoxon p-value	Spearman p-value
R-P-S v. Tullock	0.597	0.000
R-P-S v. Coordination	0.348	0.000
R-P-S v. Ellsberg	0.935	0.000
Coordination v. Tullock	0.345	0.000
Coordination v. Ellsberg	0.189	0.000
Tullock v. Ellsberg	0.790	0.000

The Wilcoxon Signed-Rank test results for index b reveal a clear statistical pattern. For *any* two tasks, we cannot reject the null hypothesis that the medians of index b are equal, which strongly suggests that attitude to ambiguity is stable across all four settings. This is quite noteworthy as we selected the four tasks to differ across several dimensions, including (i) the strategic versus non-strategic nature of the task and (ii) the amount of strategic uncertainty about the opponent's behavior in the three strategic interactions. One may argue that ambiguity arises more "naturally" in some strategic settings compared to the Ellsberg choice problem, where the latter may seem somewhat constructed and "non-organic" to some observers. Our findings point toward the robustness of the estimate b of the ambiguity attitude to this feature of the decision-making environment.

Table 6 also reports the results from the Spearman Correlation tests. The highly significant p-values in Table 6 provide strong support that there is a positive relationship between *all* pairings of tasks at individual level. Thus, each subject's attitude towards ambiguity is very similar between *any* two tasks. Furthermore, the results of the Spearman Correlation test together with significant individual-level heterogeneity of the estimates of b provide evidence of systematic between-subject heterogeneity. Similarly to our finding, Abdellaoui et al. (2011) found a high positive correlation for b between their sources of uncertainty in a non-strategic setting.

Our finding of stability across settings for ambiguity aversion (b) based on the Wilcoxon Signed-Rank test is strengthened via the Spearman Correlation test results. The individual analysis of the Spearman Correlation test supports the task-level stability finding because the trend of stability is generated from the entire sample of subjects, rather than an erratic behavior of a small subset.

In contrast to our finding of stability of ambiguity aversion between strategic and non-strategic settings, Li, Turmunkh and Wakker (2020)[12] report a smaller ambiguity aversion index (b) in a trust game than in an Ellsberg-type task (a card drawn from an ambiguous deck of four cards). An important distinction of Li, Turmunkh and Wakker (2020) from our paper is that the former used a between-subjects experimental design. Moreover, the trust game has a potentially significant pro-social component and a very different type of strategic uncertainty about opponent's behavior. There is, however, a notable similarly between the findings in the two studies. The measures of ambiguity aversion for the trust game in Li, Turmunkh and Wakker (2020) and the three games in our paper are very similar - a slight amount of ambiguity-seeking with estimates of b between -0.02 and -0.05.

Table 7: Task and Individual Effects for Index a

a	Wilcoxon p-value	Spearman p-value
R-P-S v. Tullock	0.359	0.000
R-P-S v. Coordination	0.016	0.000
R-P-S v. Ellsberg	0.526	0.000
Coordination v. Tullock	0.008	0.000
Coordination v. Ellsberg	0.006	0.000
Tullock v. Ellsberg	0.927	0.000

[12]Similarly to Li, Turmunkh and Wakker (2020), Bolton, Feldhaus and Ockenfels (2016) and Chark and Chew (2015) report that experimental subjects are less averse toward ambiguity under human-generated mechanisms than in non-social Ellsberg-type settings.

The analysis of the the ambiguity insensitivity index a reveals a picture that is considerably different from the pattern of index b across the four tasks. Table 7 reports the Wilcoxon and Spearman p-values for index a. The Wilcoxon Signed-Rank test yields stark findings. Compared to all other tasks, the subjects displayed more a-insensitivity in the Coordination task than all other three tasks. Recall that we argued above that the Coordination task entails more strategic uncertainty than the other two games. Our findings reveal that this translates into perceptions of more ambiguity, as reflected by index a, in the Coordination task. Moreover, the subjects also tend to exhibit higher a-insensitivity in the Coordination task than in the Ellsberg task. Turning to the remaining pairwise comparisons (between the RPS task, Tullock task, and Ellsberg task), we do not find a statistically significant difference of a-insensitivity for any pair.

The Spearman Correlation test results in Table 7 for the ambiguity insensitivity index (a) tell a story similar to the case of the ambiguity aversion index (b). There is a statistically significant positive monotonic relationship between *all* pairings of tasks at an individual level. Thus, if a subject is relatively more a-insensitive for one task then she is more likely to be more a-insensitive for another. In other words, there are systematic differences between subjects' perception of ambiguity.[13]

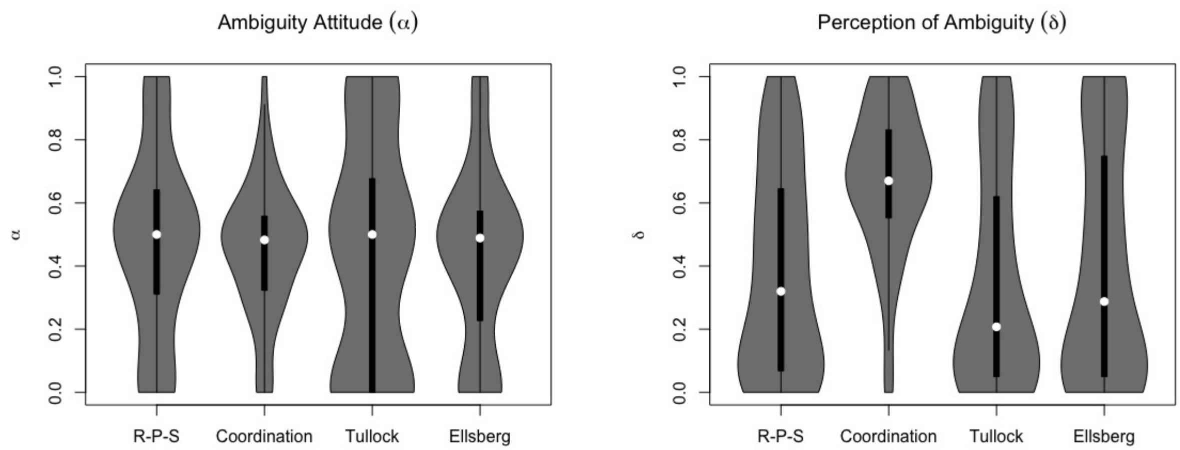
Li, Turmunkh and Wakker (2020) report a significantly higher amount of ambiguity insensitivity in their strategic setting than in the Ellsberg-type setting. Our paper sheds new light on the relationship between a-insensitivity in strategic and non-strategic settings. It reveals that the nature of strategic uncertainty present in the strategic setting is a key moderating factor of this relationship. Individuals are likely to be more a-insensitive in games with more strategic uncertainty.

[13] Abdellaoui et al. (2011) also found a substantial between-subject heterogeneity for index a across a number of non-strategic settings.

4.3 Ambiguity Attitudes and perception of ambiguity

In this section, we further examine ambiguity attitude, α, and perception of ambiguity, δ, from the α-maxmin model with a neo-additive capacity. By imposing additional structure using neo-additive capacities, we are able to separate our analysis of ambiguity into attitudes and perception, with similar interpretations to our model-free indices (b and a). The left-hand panel of Figure 3 displays the ambiguity attitude index, α, while the right-hand panel displays the ambiguity perception index, δ.

Figure 3: Ambiguity Attitudes and perception of ambiguity Indices



Along with the violin plots in Figure 3, we report the p-values for the Bonferroni adjusted Wilcoxon Signed Ranks tests and Bonferroni adjusted Spearman Correlation tests to provide both a task-level and individual-level analysis. Similar to Section 4.2, the Wilcoxon Signed Ranks test compares the medians of two tasks under the null that the two medians are equal. The Spearman Correlation test examines whether there is a signed monotonic relationship between two tasks under the null hypothesis that there is no relationship.

Table 8: Task and Individual Effects for Index α

α	Wilcoxon p-value	Spearman p-value
R-P-S v. Tullock	0.321	0.002
R-P-S v. Coordination	0.685	0.000
R-P-S v. Ellsberg	0.058	0.000
Coordination v. Tullock	0.852	0.000
Coordination v. Ellsberg	0.359	0.000
Tullock v. Ellsberg	0.845	0.000

The Wilcoxon Signed Rank p-values for the ambiguity attitude index α in Table 8 reveal a similar pattern to that of index b. For *any* two tasks, we cannot reject the null hypothesis that the medians are equal. This result provides further support to our previous finding that ambiguity aversion is stable across all four tasks. It also provide evidence in favor of the hypothesis that α is a personal characteristic of a decision-maker that is stable across different environments.

The Spearman Correlation results for index α in Table 8 show strong support for the finding that there is a highly significant positive monotonic relationship between all pairings of tasks at an individual level. Furthermore, the results of the Spearman Correlation tests together with significant individual-level heterogeneity of the estimates of α provide evidence of systematic between-subject heterogeneity.

In contrast to our findings for index α, Kelsey and Le Roux (2015) and Kelsey and Le Roux (2018) find a weak negative statistical correlation between their Ellsberg urn type task (three-color urn with one of the proportions of one of the balls as given) and that of a six-strategy coordination game (with an ambiguity-safe option) or strategic complements and substitutes games, respectively. Both studies find subjects to be ambiguity-loving in single-person decisions and ambiguity averse in game settings. There are several reasons for this difference. Our study uses a different method to elicit beliefs. Furthermore, the subjects in their studies played the same game over multiple rounds while our design had strictly one-shot games.

Table 9: Task and Individual Effects for Index δ

δ	Wilcoxon p-value	Spearman p-value
R-P-S v. Tullock	0.047	0.000
R-P-S v. Coordination	0.000	0.000
R-P-S v. Ellsberg	0.829	0.000
Coordination v. Tullock	0.000	0.000
Coordination v. Ellsberg	0.000	0.002
Tullock v. Ellsberg	0.165	0.000

Our hypothesis is that the perception of ambiguity δ is source dependent. The Wilcoxon p-values provide support for this hypothesis. We find that the Coordination task has a significantly higher amount of perceived ambiguity compared to every other task, and the remaining tasks have the same level of perceived ambiguity. Similarly to the findings for the other three indices, the Spearman Correlation p-values in Table 9 show strong support that there is a highly significant positive relationship between all pairings of tasks at individual level. This result is similar to the finding in Kelsey and Le Roux (2015) that subjects perceived a greater amount of ambiguity in a two-person six-strategy coordination game with an ambiguity safe option than in an Ellsberg urn type task.

5 Conclusion

The paper elicits attitudes and perception of ambiguity across three strategic environments and an Ellsberg task. The strategic environments differ from each other by the amount of strategic uncertainty participants may perceive about their opponents' choices. At one end of spectrum of our games in terms of their strategic uncertainty is the modified Tullock contest that has a unique

Nash equilibrium in dominant strategies. Thus, this interaction is likely to have a minimal degree of strategic uncertainty. At the other end of the spectrum is the minimum-effort coordination game with three pure strategy equilibria and mixed strategy equilibria. Moreover, playing each of the equilibrium strategies has both pros and cons. Our last strategic environment, the Rock-Paper-Scissors game, falls between these two games in terms of the degree of strategic uncertainty. Another reason why we have chosen the Rock-Paper-Scissors game is that one can view it through the lens of being a "strategic equivalent" of a three-color Ellsberg experiment.

In a series of controlled laboratory experiments, we find remarkable stability of ambiguity attitudes across the four environments. This provides support for the hypothesis that ambiguity attitude is an innate characteristic of a decision-maker that is invariables across various sources of uncertainty. In contrast, we find source dependence for perceptions of ambiguity. Subjects perceived a considerably more ambiguity in the minimum-effort coordination game than in the other three tasks. Furthermore, the perceptions of ambiguity perceived in the Tullock contest, Rock-Paper-Scissors game, and three-color Ellsberg urn task are similar.

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Appendix A (Experimental Instructions)

Note: section headings were not shown to the subjects and games were not always shown in this order.

Introduction

This is a study on economic decision-making. You will be paid at the end of the study based on your and others' decisions in this study. Thus, it is very important that you understand these instructions fully. If you have a question at any point, please raise your hand. Also, please make sure you have turned off and put away all personal electronic devices at this time.

This experiment is comprised of 4 sections. In each of the first three sections, you will see a total of 7 tasks. In the fourth section, you will see a total of 6 tasks. Thus, you will see a total of 27 different tasks in the 4 sections. Each task will have its own page on the computer screen.

You will be paid based on your decision in 1 of these 27 tasks, selected at random at the end of the experiment. Because you will not know which task will be used to determine your payoff when making your decisions, you should treat each task as though it is the one that will be used to determine your payment. This payment is in addition to the $5 show-up payment you were promised.

Before describing the first section, you will need to know how to interpret a "payoff table", as will be explained on the next page. After this explanation, a small quiz will test your knowledge of reading these tables. Your responses to the quiz will not impact your payoff as the point is to make sure you understand how to interpret payoff tables before starting the sections that could determine your payment.

For each of the first three sections, you will be randomly matched with a person in today's group. Both your and this randomly chosen person's payoffs depend on the choices that you and she/he make according to a "payoff table." You and that person will be making these choices independently and simultaneously. This simply means that you both will be making these choices privately and at the same time.

The table below is an example of a "payoff table." You and the person you are randomly matched with have three possible choices each. Your possible choices are represented by the red A, B, and C. The other person's possible choices are represented by the black X, Y, and Z.

	X	Y	Z
A	\$13, \$6	\$5, \$2	\$1, \$18
B	\$9, \$10	\$17, \$15	\$3, \$16
C	\$4, \$12	\$8, \$14	\$11, \$7

In the table above, there are 9 cells that each contain a pair of numbers. The red numbers (the first elements of the pairs) represent your payoffs, while the black numbers (the second elements of the pairs) represent the other person's payoffs. All payoffs throughout this entire study will be in terms of \$US dollars. For this example, the computer randomly selected two numbers between 1 and 18 to occupy each of the 9 cells.

Note that the payoffs in the table are based on the choices made by both participants. For example, if you chose B and the other person chose Z, then your payoff would be \$3 and her/his payoff would be \$16. If you chose C and the other person chose X, your payoff would be \$4 and her/his payoff would be \$12. If you chose A and the other person chose X, your payoff would be \$13 and her/his payoff would be \$6. If you chose B and the other person chose X, your payoff would be \$9 and her/his payoff would be \$10.

If you are having trouble reading/understanding the table, please raise your hand.

Quiz

Below is the payoff table you saw on the previous page. At the bottom of this page, you will be asked four questions about the payoff table. Again, your answers to this quiz will not affect your payment in any way. It is only for improving your understanding. The next page will show you which of your answers were correct and which were not.

	X	Y	Z
A	$13, $6	$5, $2	$1, $18
B	$9, $10	$17, $15	$3, $16
C	$4, $12	$8, $14	$11, $7

Question 1: What is your payoff if you choose B and the other person chooses Y? ANS: $17

Question 2: What is the other person's payoff if you choose C and the other person chooses Y? ANS: $14

Question 3: What is your payoff if you choose A and the other person chooses Z? ANS: $1

Question 4: What is the other person's payoff if you choose C and the other person chooses Z? ANS: $7

Option Tasks

Along with understanding payoff tables, you will need to understand how they will be used for you to make decisions based off of them. The first 6 tasks in all the sections will look similar, but not identical, and decisions within them will depend on the given section's payoff table. In each of the first 6 tasks, you will be presented with two options. **Option 1** is in relation to the other person choosing X, Y or Z. **Option 2** is in relation to a list of probabilities. Below are what the two options will look like.

Option 1: You win $20 if the other person chooses ____ and $0 otherwise.

Option 2: You win $20 with p% probability and $0 otherwise.

As described above, you have a chance to win $20 in all of the first 6 tasks. You will be asked to state which one of the two options you prefer for some set of probabilities p% between 0% to 100%. Here is a specific example of **Options 1 and 2**:

Option 1: You win $20 if the other person chooses X and $0 otherwise.

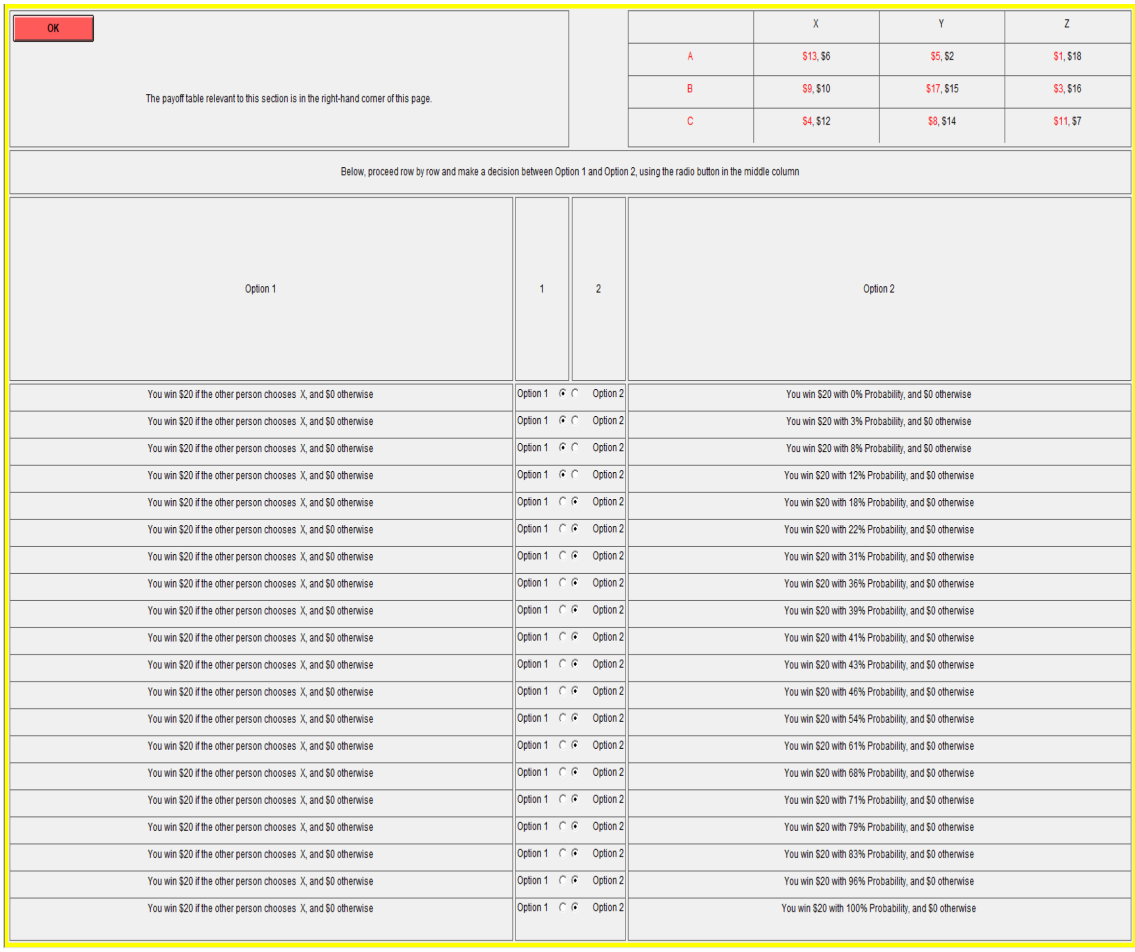
Option 2: You win $20 with 41% probability and $0 otherwise.

Furthermore,

If p = 100%, you will most likely prefer **Option 2** because you are guaranteed to win $20 under this option.

If p = 0%, you will most likely prefer **Option 1** as you might win something under this option, as opposed to **Option 2**, where there is no chance for you to win anything at all.

The first 6 tasks' screens will look similar to the image below. When prompted with this screen, you will need to make a total of 20 choices between **Option 1** and **Option 2**. To make these selections, you will have to click on either **Option 1** or **Option 2** under the title boxes labeled 1 and 2, respectively.



OK

The payoff table relevant to this section is in the right-hand corner of this page.

	X	Y	Z
A	$13, $6	$5, $2	$1, $18
B	$9, $10	$17, $15	$3, $16
C	$4, $12	$8, $14	$11, $7

Below, proceed row by row and make a decision between Option 1 and Option 2, using the radio button in the middle column

Option 1	1	2	Option 2
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 0% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 3% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 8% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 12% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 18% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 22% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 31% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 36% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 39% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 41% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 43% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 46% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 54% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 61% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 68% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 71% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 79% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 83% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 96% Probability, and $0 otherwise
You win $20 if the other person chooses X, and $0 otherwise	Option 1	Option 2	You win $20 with 100% Probability, and $0 otherwise

In the top right-hand corner of the image above, you see the payoff table from the quiz. This payoff table applies to all tasks in this section.

Under the title box labeled **Option 1**, you can see a description of **Option 1**. Note that all entries for **Option 1** (all of the cells in **Option 1** column) are identical. Under the title box labeled **Option 2**, you can see different probabilities associated with **Option 2**. The probabilities p% for **Option 2** are in ascending order as one moves towards the bottom of the image. For each stated probability p%, you will be asked to state your preference between **Option 1** and **Option 2** using the respective button in the middle column.

Note that if you prefer **Option 1** when, for instance, the probability for **Option 2** offers you 40% chance of winning, then when **Option 2** offers an even lower chance of winning, say 25%, you should find it in your own interest to choose **Option 1** over **Option 2**. Similarly, if you prefer

Option 2 over **Option 1** when the probability is 70%, then you should find it in your own interest to choose **Option 2** over **Option 1** for any values above 70%. This principle will only allow you to switch from **Option 1** to **Option 2** one time. The program will auto-fill the rest of the choices once you have made a selection. The image above illustrates a switching point that lies somewhere between 12% and 18%. Please note that this was just an illustration.

You can change your choices as many times as you would like. However, once you have made your final selection, you must click the OK button in the top left corner to confirm and submit your choices. You will not be allowed to go back to a previous task once you have clicked OK. Also note that each of the first 6 tasks may have different lists of probabilities for **Option 2** and different statements for **Option 1**.

If 1 of these first 6 tasks is selected for payment, the computer will retrieve the option you selected. If you chose **Option 1**, the computer would retrieve the other person's choice in task 7 and payout $20 if the other person made the choice indicated in **Option 1**, and $0 otherwise. If you chose **Option 2**, the computer would pick 1 ball out of a box containing 100 numbered balls from 1 to 100; if the selected ball's number is strictly less than your probability, p%, when you switched from **Option 1** to **Option 2**, then you will win the prize of $20, and $0 otherwise.

Section 1 (Contest)

This section contains 7 tasks. In the first 6 tasks, you will be asked to choose between **Option 1**, a choice related to the behavior of the person you are randomly matched with, and **Option 2**, a list of ascending probabilities. If 1 of these first 6 tasks is selected for payment, the computer will retrieve the option you selected. If you chose **Option 1**, the computer would retrieve the other person's choice in task 7 and payout $20 if the other person made the choice indicated in **Option 1**, and $0 otherwise. If you chose **Option 2**, the computer would pick 1 ball out of a box containing 100 numbered balls from 1 to 100; if the selected ball's number is strictly less than your

probability, p%, when you switched from **Option 1** to **Option 2**, then you will win the prize of $20, and $0 otherwise.

For the 7th task of this section, you will be asked to choose 1 out of the 3 choices, A, B or C, according to the payoff table seen below. The person you are randomly matched with will be choosing 1 out of the 3 choices, X, Y, or Z, according to the same payoff table. The two of you will be making these choices independently and simultaneously.

	X	Y	Z
A	$0, $0	$0, $30	$0, $20
B	$30, $0	$10, $10	$3, $7
C	$20, $0	$7, $3	$0, $0

When prompted with the 7th task, the screen will display a button containing choices A, B, or C. On this page, you must choose one of the choices and then click the OK button to move to the next task.

If this task is selected for payment, you will be paid for the combination of actual choices made by you and the person with whom you are randomly matched.

Section 2 (Coordination Game)

This section contains 7 tasks. In the first 6 tasks, you will be asked to choose between **Option 1**, a choice related to the behavior of the person you are randomly matched with, and **Option 2**, a list of ascending probabilities. If 1 of these first 6 tasks is selected for payment, the computer will retrieve the option you selected. If you chose **Option 1**, the computer would retrieve the other person's choice in task 7 and payout $20 if the other person made the choice indicated in **Option 1**, and $0 otherwise. If you chose **Option 2**, the computer would pick 1 ball out of a box containing 100 numbered balls from 1 to 100; if the selected ball's number is strictly less than your

probability, p%, when you switched from **Option 1** to **Option 2**, then you will win the prize of $20, and $0 otherwise.

For the 7th task of this section, you will be asked to choose 1 out of the 3 choices, A, B or C, according to the payoff table seen below. The person you are randomly matched with will be choosing 1 out of the 3 choices, X, Y, or Z, according to the same payoff table. The two of you will be making these choices independently and simultaneously.

	X	Y	Z
A	$10, $10	$10, $5	$10, $0
B	$5, $10	$15, $15	$15, $10
C	$0, $10	$10, $15	$20, $20

When prompted with the 7th task, the screen will display a button containing choices A, B, or C. On this page, you must choose one of the choices and then click the OK button to move to the next task.

If this task is selected for payment, you will be paid for the combination of actual choices made by you and the person with whom you are randomly matched.

Section 3 (Rock-Paper-Scissors Game)

This section contains 7 tasks. In the first 6 tasks, you will be asked to choose between **Option 1**, a choice related to the behavior of the person you are randomly matched with, and **Option 2**, a list of ascending probabilities. If 1 of these first 6 tasks is selected for payment, the computer will retrieve the option you selected. If you chose **Option 1**, the computer would retrieve the other person's choice in task 7 and payout $20 if the other person made the choice indicated in **Option 1**, and $0 otherwise. If you chose **Option 2**, the computer would pick 1 ball out of a box containing 100 numbered balls from 1 to 100; if the selected ball's number is strictly less than your

probability, p%, when you switched from **Option 1** to **Option 2**, then you will win the prize of $20, and $0 otherwise.

For the 7th task of this section, you will be asked to choose 1 out of the 3 choices, A, B or C, according to the payoff table seen below. The person you are randomly matched with will be choosing 1 out of the 3 choices, X, Y, or Z, according to the same payoff table. The two of you will be making these choices independently and simultaneously.

	X	Y	Z
A	$10, $10	$0, $20	$20, $0
B	$20, $0	$10, $10	$0, $20
C	$0, $20	$20, $0	$10, $10

When prompted with the 7th task, the screen will display a button containing choices A, B, or C. On this page, you must choose one of the choices and then click the OK button to move to the next task.

If this task is selected for payment, you will be paid for the combination of actual choices made by you and the person with whom you are randomly matched.

Section 4 (Urn Task)

This section contains 6 tasks. In contrast to the previous three sections, you will not be interacting with anyone in this section and your potential payment for this section depends only on your choices. Each of the 6 tasks in this section will look similar to the first 6 tasks in each of the first three sections. The main difference is that **Option 1** will be based on a draw from an urn, described below, in contrast to the behavior of some other person.

Consider an urn that contains a total of 100 balls. The urn contains balls of three colors: Red, Green, and Blue. The exact number of balls of each color is unknown. All that is known is the sum of the balls of three colors must add to 100.

In each of the 6 tasks of this section, you will be presented with two options of the following type:

Option 1: You win $20 if a ball randomly drawn from the urn is ____ and $0 otherwise.

Option 2: You win $20 with p% probability and $0 otherwise.

As described above, you have a chance to win $20 in all of the 6 tasks. You will be asked to state which one of the two options you prefer for some set of probabilities p% between 0% to 100%. Remember, the selection from the urn is independent of any decisions you or anyone else makes.

If 1 of these 6 tasks is selected for payment, the computer will retrieve the option you selected. If you chose **Option 1**, a person from the group today will pick a colored ball from a physical urn described above and payout $20 if the color of the drawn ball is the one indicated in **Option 1**, and $0 otherwise. If you chose **Option 2**, a person from the group today will pick 1 ball out of a box containing 100 numbered balls from 1 to 100; if the selected ball's number is strictly less than your probability, p%, when you switched from **Option 1** to **Option 2**, then you will win the prize of $20, and $0 otherwise.

Appendix B (Choice Lists)

Example of choice list for singular events

Option 1	1	2	Option 2
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 0% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 3% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 8% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 12% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 18% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 22% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 31% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 36% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 39% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 41% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 43% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 46% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 54% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 61% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 68% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 71% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 79% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 83% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 96% Probability, and $0 otherwise
You win $20 if the other person chooses Z, and $0 otherwise	Option 1	Option 2	You win $20 with 100% Probability, and $0 otherwise

Example of choice list for composite events

Option 1	1	2	Option 2
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 0% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 4% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 17% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 21% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 29% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 32% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 39% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 46% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 54% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 57% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 59% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 61% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 64% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 69% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 78% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 82% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 88% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 92% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 97% Probability,and $0 otherwise
You win $20 if the other person chooses Y or Z, and $0 otherwise	Option 1	Option 2	You win $20 with 100% Probability,and $0 otherwise

Appendix C (Conditions For Each Model)

Table 10: Predictions of Various Models

BC	LA	UA	TA and ITA
	Expected Utility and Probability Sophistication		
$\text{BC}(\text{E}_i) = 0$	$\text{LA}(\text{E}_i, E_j) = 0$	$\text{UA}(\text{E}_i) = 0$	$\text{TA} = \text{ITA} = 0$
	Maxmin EU		
$\text{BC}(\text{E}_i) \geq 0$	$\text{LA}(\text{E}_i, E_j) \leq 0$	$\text{UA}(\text{E}_i) \geq 0$	$\text{TA} \leq 0 \leq ITA$
	Maxmax EU		
$\text{BC}(\text{E}_i) \leq 0$	$\text{LA}(\text{E}_i, E_j) \geq 0$	$\text{UA}(\text{E}_i) \leq 0$	$\text{ITA} \leq 0 \leq TA$
	Variational Model		
$\text{BC}(\text{E}_i) \geq 0$			$\text{TA} \leq 0 \leq ITA$
	α-Maxmin EU for $\alpha \leq \frac{1}{2}$		
$\text{BC}(\text{E}_i) \leq 0$			$\text{ITA} \leq TA$
	α-Maxmin EU for $\alpha = \frac{1}{2}$		
$\text{BC}(\text{E}_i) = 0$			$\text{ITA} = \text{TA}$
	α-Maxmin EU for $\alpha \geq \frac{1}{2}$		
$\text{BC}(\text{E}_i) \geq 0$			$\text{ITA} \geq TA$
	Prospect Theory		
	$\text{LA}(\text{E}_i, E_j) \geq 0$	$\text{UA}(\text{E}_i) \geq 0$	$0 \leq ITA + TA \leq 1$
	Smooth Model (Concave)		
$\text{BC}(\text{E}_i) \geq 0$			$\text{TA} \leq 0 \leq ITA$
	Smooth Model (Concave)		
$\text{BC}(\text{E}_i) \leq 0$			$\text{ITA} \leq 0 \leq TA$

Appendix D (Predictions of Ambiguity Models)

Following Baillon and Bleichrodt (2015), we use five distinct additivity indices to test the descriptive validity of a number of popular models of decision-making under ambiguity (see also Walley (1991), Tversky and Wakker (1995)). When a decision-maker does not perceive any ambiguity about the choice environment, her matching probabilities form a probability distribution over the set of events 2^S, where $S \equiv \{X, Y, Z\}$. This entails additivity requirements for all partitions of the state space S and its subsets. The five indices measure deviations from these additivity requirements:

1) Binary Complementary Index$(E_i) = BC_i = 1 - m_i - m_i^c$

2) Lower Additivity Index$(E_i, E_j) = m_i + m_j - m_{ij}$

3) Upper Additivity Index$(E_i) = 1 - m_{ik} - m_{ij} + m_i$

4) Ternary Additivity Index $= m_i + m_j + m_k - 1$

5) Indirect Ternary Additivity Index $= 2 - m_{ij} - m_{ik} - m_{jk}$

For $j \neq k \neq i$

The *binary complementarity* index (BC) reflects the degree to which the sum of the matching probabilities of a singleton event and its complement diverges from the probability of the universal event, which is equal to 1. Under *Binary complementary*, $BC = 0$. A decision-maker with a strictly positive (negative) value of BC_i perceives ambiguity about event E_i and its complement and is ambiguity averse (seeking) for that partition of the state space.

The *lower additivity* index (LA) measures the difference between the sum of the matching probabilities of two singleton events and their union while the *ternary additivity* index (TA) measures the difference between the matching probabilities of the three singleton events and their union, which is the universal event. The two indices, LA and TA, are similar to BC as they also measure the extra/reduced weight a decision-maker may place on an event compared to the events that form its partition. BC measures ambiguity attitude for a partition of the whole state space into a singleton event and its complement, LA measures it for a partition of a composite event into two singleton events, and TA measures it for a partition of the whole state space into the three singleton events.

The *upper additivity* index (UA) measures how much a singleton event contributes to the perception of ambiguity within a partition of a composite event into two singleton events compared to the partition consisting of a singleton event and the complementary composite event. Finally, the *indirect ternary additivity* index (ITA) measures by how much the average of the matching probabilities of the composite events differs from $\frac{2}{3}$, which is is the average probabilistic weight placed on composite events under additive matching probabilities.

Table 11 reports the mean values of the five indices for each of the four tasks. With one exception, the mean values of all *binary complementary* indices for all four tasks, are slightly below 0. Thus, the subjects exhibit a small amount of ambiguity seeking for events that have relatively small likelihood, namely, the singleton events. This finding is in line with our estimates of indices α and b that also pointed toward a moderate degree of ambiguity seeking.

Table 11: Simple Means for Additivity Indices

	BC_X	BC_Y	BC_Z	LA_{XY}	LA_{XZ}	LA_{YZ}	UA_X	UA_Y	UA_Z	TA	ITA
R-P-S	-0.05	-0.02	-0.02	0.22	0.22	0.19	0.19	0.17	0.17	0.24	0.15
Tullock	0.02	-0.05	-0.04	0.17	0.17	0.23	0.12	0.18	0.18	0.21	0.14
Coordination	-0.04	-0.03	-0.07	0.24	0.27	0.27	0.21	0.20	0.24	0.30	0.17
Ellsberg	-0.05	-0.02	-0.04	0.20	0.21	0.19	0.17	0.15	0.17	0.24	0.12

The mean values of all indices LA are significantly larger than 0. Thus, the sum of the weights placed on any two singleton events exceeds the weight on the composite event that these two events make up. This is again consistent with the tendency of the subjects to overweight singleton events and underweight composite events. In other words, the subjects are willing to give up non-trivial amounts of success probability to avoid (face) ambiguity in the case of composite (singleton) events.

The positive mean values of index UA suggest that the contribution of singleton events to the perception of ambiguity is greater when moving from composite events to the universal event than when moving from singleton to composite events. This pattern is consistent with an inverse S-shaped probability weighting function for which its convex part is longer than the concave part.

The positive mean values of TAs from Table 11 coupled with the positive mean values of m_i, m_j, and m_k from Table 5 suggest that the subjects tend to overweight singleton events. Finally, the means of *indirect ternary additivity* indices for all four tasks are positive, indicating that the subjects are on average averse to ambiguity surrounding composite events.

These five additivity indices give us the ability to test the conformity of our data to various models (see Appendix C for an exact breakdown of the complete set of conditions). Table 12 reports the proportions of subjects that satisfy each model for each task. Overall, the α-Maxmin and Choquet models do the best in terms of conforming with these behavioral patterns.

Table 12: Proportion of Subjects satisfying Each Ambiguity Model

Model	Conditions	R-P-S	Tullock	Coord.	Ellsberg
Probabilistic Sophistication	10	15	11	6	18
Maxmin	10	21	20	9	18
Maxmax	10	30	23	19	32
Variational	4	35	32	27	36
α-Maxmin ($\alpha \leq \frac{1}{2}$)	4	55	52	51	66
α-Maxmin ($\alpha = \frac{1}{2}$)	4	18	15	7	24
α-Maxmin ($\alpha \geq \frac{1}{2}$)	4	43	40	35	44
Choquet	1	94	93	87	91
Prospect Theory	7	68	44	50	50
Smooth (Concave)	4	35	32	27	36
Smooth (Convex)	4	49	46	41	50

Appendix E (CRT Questions)

The seven CRT questions used within the post-experiment survey:

1) A bat and a ball cost $1.10 in total. The bat costs a dollar more than the ball. How much does the ball cost? $_____.

2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? _____ minutes.

3) In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? _____ days.

4) If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together? _____ days.

5) Jerry received both the 15th highest and the 15th lowest mark in the class. How many students are in the class? _____ students.

6) A man buys a pig for $60, sells it for $70, buys it back for $80, and sells it finally for $90. How much has he made? $_____.

7) Simon decided to invest $8,000 in the stock market one day early in 2008. Six months after he invested, on July 17th, the stocks he had purchased were down 50%. Fortunately for Simon, from July 17th to October 17th, the stocks he had purchased went up by 75%. At this point Simon has:

A) Broken even in the stock market.

B) Is ahead of where he began.

C) Has lost money.