Partial Ambiguity

CHEW Soo Hong, MIAO Bin, and ZHONG Songfa*

February 2015

Abstract

We examine experimentally attitude towards partial ambiguity. One form called interval ambiguity involves a symmetric range of possible compositions. Another called disjoint ambiguity, consisting of a union of two disjoint intervals of possible compositions, is complementary to interval ambiguity. The third called two-point ambiguity involves either $50 - n$ or $50 + n$ cards red with the rest of the cards black. Each form of partial ambiguity may be viewed as a two-stage lottery with a symmetrically distributed prior. Experiment 1 studies attitudes towards these three forms of partial ambiguity. Experiment 2 studies attitude towards the corresponding compound risks with uniform stage-1 probabilities. Experiment 3 combines experiments 1 and 2 in a within-subject design and studies potential connections between attitude towards partial ambiguity and attitude towards uniform compound risks. This paper contributes to broadening the range of observed choice behavior and testing of decision making models beyond pure risk and full ambiguity.

Keywords: Risk, Ambiguity, Ellsberg paradox, Experiment, Choquet expected utility, Maxmin expected utility, Recursive non-expected utility, Source preference.
JEL Classification: C91, D81

*Chew: Department of Economics, National University of Singapore, chewsoohong@gmail.com. Miao: School of Economics, Shanghai University of Finance and Economics, binmiao11@gmail.com, Zhong: Department of Economics, National University of Singapore, zhongsongfa@gmail.com. The paper combines two early working papers, namely "Partial Ambiguity" by Chew, Miao and Zhong, and "An Experimental Study of Attitude towards Compound Lottery" by Miao and Zhong. Acknowledgment: To be added.

The essence of the situation is action according to opinion, of greater or less foundation and value, neither entire ignorance nor complete and perfect information, but partial knowledge.

– Frank H. Knight (1921)

1 Introduction

In his 1921 book, "Risk, Uncertainty and Profit", Knight distinguishes between risk as measurable uncertainty which can be represented by precise probabilities and unmeasurable uncertainty which cannot. In the same year, Keynes (1921, p75) proposes a thought experiment which may be viewed as a limiting case of unmeasurable uncertainty. Between betting on an urn with a known composition of 50 red and 50 black balls over betting on another urn with an unknown composition of red and black balls which add to 100, Keynes suggests that people may favor betting on the former rather than the latter. Such preference, dubbed ambiguity aversion in Ellsberg (1961), casts doubt on the notion of subjective probability theory as a foundation for decision making under uncertainty.

The phenomenon of ambiguity aversion has given rise to a voluminous experimental and theoretical literature from which we can discern three perspectives. One perspective, traceable to Ellsberg (1961), is that the decision maker sees a range of possible priors and harbors a sense of suspicion or pessimism with the thinking that the composition in the unknown urn will somehow be against her regardless of her choice of color. This complements Keynes' idea of *source preference* viewing the complementary events in the unknown urn as having 50-50 probabilities while allowing for a preference for an even-chance bet on the known urn over an even-chance bet on the unknown urn with the same outcomes. In a third perspective, the bet on the unknown urn may be viewed as a compound lottery with a symmetrically distributed prior over the 101 possible compositions (e.g., Brownson and Becker, 1964) to deliver indifference between betting on red and on black. Ambiguity aversion then corresponds to a violation of reduction of compound lottery axiom (RCLA) with the unambiguous 50-50 lottery being preferred to the compound risk derived from the possible color compositions of the ambiguous lottery.[1]

As observed by Knight in the epigraph, the essence of uncertainty is partial knowledge. In this paper, we adopt this view in going beyond the original 2-urn paradox with full ambiguity, i.e., no knowledge regarding the true composition of red and black balls, and examine ambiguity attitude systemically in a richer domain of ambiguity with partial knowledge provided. One kind of partial ambiguity, called interval ambiguity and denoted by $[50-n, 50+n]$, is based on Becker and Brownson (1964) as well as Curley and Yates (1985) and involves a symmetric interval of possible compositions where the number of red or black balls lies between $50-n$ and $50+n$. Another kind of partial ambiguity, called disjoint ambiguity and denoted by $[0, n] \cup [100-n, 100]$, consists of a union of two disjoint intervals of possible compositions. Note that the *size of ambiguity* in terms of the number of possible compositions increases in n for both interval ambiguity and disjoint ambiguity. The third kind of partial ambiguity, called two-point ambiguity and denoted by $\{50-n, 50+n\}$, involves precisely two possible compositions – either $50-n$ red balls or $50+n$ red balls with the rest of the balls black. Here, while its size of ambiguity remains constant, its *spread* given by $2n$ increases in n.

We study the three kinds of partial ambiguity, illustrated in Figure 1 below, in three experiments using a price-list elicitation mechanism. Experiment 1 studies attitude towards the three kinds of partial ambiguity directly. Partially motivated by the two-stage perspective of ambiguity, Experiment 2 studies attitude towards the three corresponding kinds of compound risks under uniform stage-1 priors giving rise to what we term as interval compound risk, disjoint compound risk, and two-point compound risk. In combining experiments 1 and 2 in a within-subject design, Experiment 3 enables us to investigate the degree of similarity in aggregate choice behavior across ambiguity and compound risk as well as potential

[1]Intuitively, RCLA requires a compound lottery to be indifferent to its reduction to a simple lottery whose outcomes are taken from the component lotteries with the corresponding probabilities derived from the given compound lottery. Under a symmetric prior, the compound lottery derived from the bet on the unknown urn reduces to a simple 50-50 lottery.

connections between attitude towards ambiguity and attitude towards compound risks at the individual level.

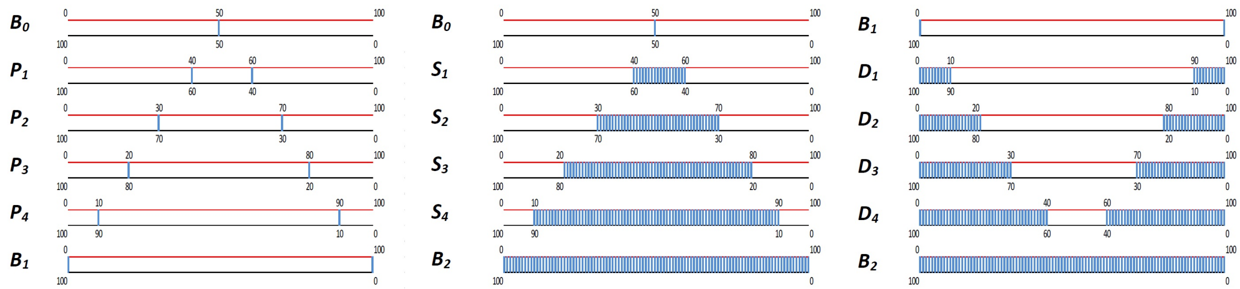


Figure 1: Illustration of Three Variants. *The upper line represents the number for red balls and the lower line for black balls, while each vertical line represents one possible composition of the urn.*

We summarize our main results at the aggregate level as follows.

Aversion to the number of possible compositions in ambiguity and compound risk. In both experiments 1 and 2, we observe an overall aversion to the number of possible compositions for both interval and disjoint lotteries. Interestingly, the aversion to the number of possible compositions in disjoint compound risk corresponds to an affinity towards mean-preserving spread in stage-1 risk (see subsection 2.2 for definition). We continue to observe this aversion to the number of possible compositions in Experiment 3 for both ambiguity and compound risk.

Aversion to spread in two-point lotteries. In Experiment 1, subjects exhibit an initial aversion towards the spread in two-point ambiguity but not for the comparison between $\{10, 90\}$ and the end-point $\{0, 100\}$. In contrast, we observe in Experiment 2 an overall aversion to spread in two-point compound risk. The initial aversion to spread in two-point ambiguity as well as compound risk is replicated in Experiment 3, while there is significant heterogeneity in comparisons involving the end-point case of $\{0, 100\}$.

To varying extent, the aggregate choice patterns relating to partial ambiguity can be accounted for by one-stage models as in Wald (1950) and Gilboa and Schmeidler (1989) as well as their derivatives including Ghirardato, Maccheroni and Marinacci (2004), Maccheroni, Marinacci and Rustichini (2006), Gajdos et al. (2008), Siniscalchi (2009), Gilboa (1987), and Schmeidler (1989). For example, the maxmin utility in Gilboa and Schmeidler (1989) can account for the observed aversion to increasing number of possible compositions in both interval and disjoint groups by making the set of priors depending on the size of ambiguity. Nevertheless, most of these one-stage models, except Gilboa (1987) which adopts a Savagian framework, adopt the Anscombe and Aumann (1963) framework in which RCLA is assumed for objective risks. They are thus not compatible with the strong incidence of non-RCLA behavior relating to compound risk. The similarity in choice patterns across partial ambiguity and compound risk suggests the need to explore modeling ambiguity from a two-stage perspective, including recursive expected utility (Halevy and Feltkamp, 2005; Klibanoff, Marinacci and Mukerji, 2005; Nau, 2006; Seo, 2009) and recursive non-expected utility (Segal, 1987; Ergin and Gul, 2009).

Our results shed light on some key assumptions in two-stage models. Under the time neutrality axiom in Segal (1987), $\{50\}$ and $\{0, 100\}$ would have the same CE since they differ only in the timing of uncertainty resolution. This implication is not compatible with the significant heterogeneity in relative valuation between $\{50\}$ and $\{0, 100\}$ across the three experiments. Under an assumption of uniform stage-1 priors, full ambiguity $[0, 100]$ can be represented as a convex combination of interval ambiguity $[n, 100-n]$ and disjoint ambiguity $[0, n] \cup [100-n, 100]$. For two-stage models whose first-stage preference satisfies betweenness (e.g., Klibanoff, Marinacci and Mukerji, 2005), full ambiguity would then be ranked in between interval ambiguity and its complementary disjoint ambiguity. This implication does not accord well with the consistent observation of full ambiguity being the least preferred lottery in all three experiments. More details on the statements of axioms and how we arrive at the theoretical implications discussed here are provided in Appendix A which reviews the compound risk axioms in the literature.

At the individual level, the within-subject design of Experiment 3 enables us to examine potential links between attitudes towards partial ambiguity and compound risk. We observe a tight association between ambiguity attitude and RCLA: 96.7% of the subjects with reduction are ambiguity neutral and 93.6% of the subjects without reduction are not ambiguity neutral. This extends the observations in Halevy (2007), which identifies the association between attitude towards full ambiguity and RCLA, and provides further support to two-stage approach in modeling attitudes towards ambiguity when partial knowledge is provided. For subjects exhibiting non-RCLA behavior, we examine their relative valuations between partial ambiguity lotteries and the corresponding uniform compound risks to study the extent to which stage-1 priors in partial ambiguity may be compatible with the commonly applied assumption of uniformity, which has not been the focus of earlier experimental studies. 31.5% of our subjects assign higher certainty equivalents (CEs) to partial ambiguity lotteries than the corresponding compound lotteries, 22.0% exhibit the reverse preference, 19.7% assign similar CEs, and the remaining 26.7% do not exhibit any systematic patterns. Given that the compound lotteries are implemented with objective uniform stage-1 priors, the observed difference between partial ambiguity lotteries and the corresponding compound lotteries suggests that subjects may have non-uniform priors for partial ambiguity lotteries or possess source preference distinguishing between objective and subjective stage-1 priors. Since symmetric stage-1 priors for two-point ambiguity lotteries, $\{0, 100\}$ and $\{25, 75\}$, are necessarily uniform, the observed non-indifference between them and their corresponding compound risk counterparts favors the source preference hypothesis.[2]

Finally, we classify subjects in Experiment 3 in terms of whether they satisfy RCLA and the extent to which they are more proximate to being of a specific utility type (Halevy 2007). We observe a moderate proportion (32.4%) satisfying RCLA, of which 65.6% are of the expected utility type and 34.4% are of the multiple-priors type. Of the remaining

[2]The notion of source preference is advanced by Tversky and his co-authors in the early 1990s (Fox and Tversky 1995; see also Tversky and Kahneman 1992; Health and Tversky, 1991). Chew and Sagi (2008) axiomatize source preference which can accommodate decision makers having distinct attitudes towards identically distributed risks arising from different sources of uncertainty. It is further studied experimentally in Abdellaoui et al. (2011). In our setting, source preference enables one to hold uniform stage-1 prior in partial ambiguity lotteries, and evaluate them distinctly from their corresponding compound lotteries with objective uniform stage-1 prior, through distinguishing between attitudes towards subject and objective stage-1 priors. For two-point ambiguity lotteries, indifference between betting on red or black implies that stage-1 priors must be symmetric, suggesting the incidence of source preference in differentiating exogenously generated stage-1 risks from those that arise subjectively.

subjects (67.6%) who do not conform to RCLA, we examine whether their behaviors are more consistent with recursive expected utility or recursive rank-dependent utility for ambiguity and compound risk separately. Under partial ambiguity, 45.7% of our subjects are of the recursive rank-dependent utility type and 37.8% are of the recursive expected utility type. Under compound risk, 42.5% are of the recursive rank-dependent utility type and 41.7% are of the recursive expected utility type. Moreover, we observe that the type classifications are highly correlated across the two domains. Specifically, for subjects classified as recursive rank-dependent utility type under partial ambiguity, 55.2% of them remain classified as recursive rank-dependent utility type and 29.3% of them classified as recursive expected utility type under compound risk. For subjects classified as recursive expected utility type under partial ambiguity, 56.3% of them remain classified as recursive expected utility type while 25.0% of them classified as recursive rank-dependent utility type under compound risk. This again renders support for the two-stage perspective on ambiguous lotteries.

In sum, our results suggest that the subjective expected utility account only for the behavior of a small proportion of the subjects. Among the non-expected utility models, the two-stage models of recursive expected utility and recursive rank-dependent utility explain the behavior of the subjects, especially the strong correlation between RCLA and ambiguity attitude, better than one-stage models, with slightly more subjects being categorized as recursive rank-dependent utility type.

The rest of this paper is organized as follows. Section 2 presents the overall experimental framework, reviews the utility model literature, and derives their implications for attitudes towards partial ambiguity and compound risk. Section 3 presents the design of Experiment 1 on partial ambiguity, the aggregate observed choice behaviors towards three groups of partial ambiguity, and their implications for the utility models considered. Section 4 presents the design of Experiment 2 on uniform compound risks, the aggregate observed choice behaviors towards three groups of compound risks, and their implications especially for the two-stage utility models considered. Section 5 describes the design and results of

Experiment 3 combining both Experiment 1 and Experiment 2 which enables us to study the robustness of the observed choice patterns in experiments 1 and 2. We further conduct individual level analyses linking ambiguity and compound risks and discuss the implications of our overall evidence on the utility models reviewed, including a classification of subjects into types based on proximity to specific utility models in terms of observed choice behavior. Section 6 concludes.

2 Experimental Framework and Theoretical Implications

In this section, we begin with a description of the experimental framework, which we employ to study partial ambiguity (Experiment 1), followed by a discussion of models on ambiguity attitude in the literature and their implications for choice behavior in the setting of partial ambiguity. Next, we present a parallel design on uniform compound risk (Experiment 2), followed by a discussion linking uniform compound risks and partial ambiguity through the two-stage perspective under uniform priors. We further discuss the implications of different utility models on choice behavior in the combined setting of partial ambiguity and compound risk (Experiment 3). Our overall objective is to study attitude towards partial ambiguity and attitude towards compound risk individually in experiments 1 and 2 followed by a within-subject study of both attitudes in Experiment 3. Doing so enables us to better discriminate among utility models in the literature on decision making under ambiguity.

2.1 Partial Ambiguity

2.1.1 Experimental Framework

In an Ellsberg setting, let $\{50\}$ denote the known deck of 100 cards with 50 red cards and 50 black cards and let $[0, 100]^A$ denote the unknown deck whose composition of the cards is unknown. In Experiment 1, we consider three symmetric variants of full ambiguity $[0, 100]^A$ (see Figure 1). Interval ambiguity, denoted by $\mathbf{S}_n^A = [50 - n, 50 + n]^A$, refers to a deck containing between $50 - n$ and $50 + n$ red (black) cards. Disjoint ambiguity, denoted by $\mathbf{D}_n^A = [0, n] \cup [100 - n, 100]^A$, refers to a deck whose number of red (black) cards is either between 0 and n or between $100 - n$ and 100. Two-point ambiguity, denoted by $\mathbf{P}_n^A = \{50-n, 50+n\}^A$, refers to a deck containing either $50-n$ or $50+n$ red (black) cards. In each lottery subjects choose their own colors to bet on. The three kinds of partial ambiguity is symmetric in the sense that betting on either color results in the same description of the possible compositions.

We define three benchmark lotteries: $\mathbf{B}_0 = \{50\}$, $\mathbf{B}_1^A = \{0, 100\}^A$, and $\mathbf{B}_2^A = [0, 100]^A$, which are the limiting cases for the three variants. Note that $\mathbf{B}_1^A$ appears to admit some flexibility in interpretation. Besides its intended interpretation as being two-point ambiguous, being either all red or all black may give it a semblance of a 50-50 lottery. In the experiment, we vary n in each of the symmetric variants to obtain different partially ambiguous lotteries.

Our design enables us to examine the effect of varying the parameters in our experiments. In particular, changing n would vary the size of ambiguity in terms of the number of possible compositions in the interval and disjoint groups. The two-point group enables us to study the effect of spread while fixing the size of ambiguity.

Elicitation Mechanism

To elicit the CE of a lottery in the three experiments, we use a price list design (e.g., Miller, Meyer, and Lanzetta 1969; Holt and Laury 2002), where subjects are asked to make a number of binary choices between betting on the color of a card drawn by the subject and receiving a specific amount of money for sure. For each lottery, subjects choose the color to bet on in order to minimize the potential confounding factor of suspicion. To incentivize participation, we pay each subject at the end of the experiment based on one of his/her randomly selected decisions in the experiment.

This pay-1-in-n method, also known as the random lottery incentive mechanism (RIM), has been widely used in the literature and has triggered debates from both theoretical and experimental perspectives. Holt (1986) shows that RIM is incentive compatible if both RCLA and the independence axiom hold. Karni and Safra (1987) provide an example in which the incentive compatibility of RIM is problematic if RCLA holds and the independence axiom fails. Subsequently, Segal (1988) provides another example to show that RIM may not elicit the true preference if the independence axiom holds and RCLA fails. To justify the use of RIM, some have invoked the argument of isolation to justify the usage of RIM, which corresponds to the compound independent axiom (see Segal, 1990, for a detailed discussion) that is both necessary and sufficient for the incentive compatibility of RIM. In the domain of subjective uncertainty, Baillon, Halevy, and Li (2014) show recently that RIM may not be incentive compatible if subjects choose the color to bet on prior to making decisions in a list of choices due to ex-ante hedging motives. In our experiment, subjects choose the color to bet subsequent to making the decisions.

Besides theoretical considerations, evidence from a number of experimental studies provides mixed support for validity of RIM. For instance, Starmer and Sugden (1991) experimentally compare between pay-1-in-1 and pay-1-in-2 methods, and find subjects' behavior inconsistent with RCLA but they do not uncover evidence against the compound independence axiom. Freeman, Halevy, and Kneeland (2014) compare multiple price list and simple binary choice, and show that RIM could bias the elicitation of risk preference. Notwithstanding these potential problems, we adopt RIM in our current study as it offers an efficient way to elicit subjects' preference besides being relatively simple. Moreover, in applying the same elicitation mechanism for each lottery, potential bias would be less of concern for our focus to compare choice behavior across different lotteries. Finally, it enables us to analyze choice behavior at the individual level.

2.1.2 Theoretical Implications

This subsubsection analyzes the implications of various models on ambiguity, including subjective expected utility (SEU), Choquet expected utility (CEU), maxmin expected utility (MEU), recursive expected utility (REU) and recursive rank-dependent utility (RRDU). Among these theories, SEU, CEU and MEU adopt one-stage approach in evaluating ambiguous lotteries, while REU and RRDU link ambiguity aversion to compound risk attitude coupled with relaxing RCLA. To facilitate our analysis, we impose the following behavioral assumption throughout this section:

Symmetry: The decision maker is indifferent between betting on red and black for each of the given set of lotteries considered.[3]

Models with Reduction

Subjective expected utility

Under the benchmark subjective expected utility model (SEU) or more generally probabilistic sophistication, the probabilities of the events R_α and B_α always equal 0.5 given symmetry, where R_α and B_α denote the respective events in ambiguous lottery α. In particular,

$$SEU_\alpha = u\left(w\right)/2, \tag{1}$$

where w denotes the payment should subjects guess correctly and we normalize $u\left(0\right) = 0$. Thus, SEU predicts that all ambiguous lotteries and $\mathbf{B}_0$ have the same CEs.

Choquet expected utility

One alternative to SEU, dubbed Choquet expected utility (CEU), is to formulate a non-additive generalization by using a capacity ν in place of a probability measure (Gilboa 1987, Schmeidler 1989). Under CEU, the utility for lottery α is given by:

$$CEU_\alpha = \nu(R_\alpha)u\left(w\right) = \nu(B_\alpha)u\left(w\right), \tag{2}$$

[3]This symmetry assumption, commonly made in the ambiguity literature, is viewed as a weak assumption (see, e.g., Epstein and Halevy, 2014, and Abdellaoui et al., 2011, for a related assumption of uniformity) and we are not aware of studies showing a color preference under conditions of symmetry in the lottery design.

with $\nu(R_\alpha) = \nu(B_\alpha)$ from symmetry.[4] In relaxing additivity, the capacities or decision weights assigned to red (or black) for different ambiguous lotteries need not be the same. Thus, CEU exhibits maximal flexibility in being compatible with a wide range of choice behavior.

Maxmin expected utility

The maxmin expected utility (MEU) in Gilboa and Schmeidler (1989) evaluates an ambiguous lottery α with the expected utility corresponding to the worst prior in a convex set of priors Π_α as follows:[5]

$$MEU_\alpha = \min_{\mu \in \Pi_\alpha} \mu\left(R_\alpha\right) u\left(w\right). \tag{3}$$

Note that indifference between betting on red and black implies that Π_α is symmetric so that MEU would exhibit global ambiguity aversion: $\mathbf{B}_0$ is preferred to any ambiguous lottery α. Without further restriction on the sets of priors, MEU can account for a wide range of ambiguity averse choice behavior with a judicious choice of the worst prior in each Π_α. The qualitative behavior of MEU also applies to some follow up models with built-in ambiguity aversion including variational preference (Maccheroni, Marinacci and Rustichini, 2006) and the contraction model (Gajdos, et al., 2008) and to a lesser extent in α-MEU (Ghirardato, Maccheroni and Marinacci, 2004).[6]

Models without Reduction

The idea of linking ambiguity aversion with aversion towards two-stage risks is evident in the work of Becker and Brownson (1964). This is formalized in Segal (1987) who proposes a two-stage model with a common rank-dependent utility (Quiggin 1982) for both first and second stage risks. Maintaining a two-stage setting without requiring RCLA, several subsequent papers (Klibanoff, Marinacci and Mukerji 2005, Nau 2006, Seo 2009) provide axiomatizations of a decision maker possessing distinct expected utility preferences across

[4] In Fox and Tversky's (1998) CEU model, the capacity takes the form of $f \circ P$, where P is a possibly non-additive judged probability and f is a probability weighting function.

[5] Since the utilities of betting on R_α and on B_α are the same given symmetry, we use only the utility betting on R in our subsequent exposition.

[6] See Chew, Miao and Zhong (2013) for a detailed discussion on the implications of these one-stage models.

the two stages to model ambiguity aversion.

In our setup, the two-stage approach associates each ambiguous lottery with a stage-1 prior π_α, a distribution on stage-2 risk μ . A general two-stage representation is axiomatized in Ergin and Gul (2009):

$$U\left(\pi\left(\mu\right), c_\mu; \pi\left(\mu'\right), c_{\mu'}; ...\right), \text{ where } c_\mu = V^{-1}\left(V\left(w, \mu\left(R\right)\right)\right), \tag{4}$$

where c_μ is the CE of stage-2 risk μ with U and V being general utility functions that can represent stage-1 and stage-2 preferences that may be identical or distinct. If U and V admit identical expected utility preferences, RCLA holds and the model reduces to SEU.

Note that being indifferent to betting on either color regardless of the underlying two-stage preference implies symmetric stage-1 priors around $\{50\}$.[7] In the sequel, we shall first focus the analysis on one specific symmetric prior – uniform prior – and discuss the implications for general symmetric priors subsequently.

Recursive rank-dependent utility (RRDU)

Segal (1987, 1990) considers the same rank-dependent utility specification in both stages, and shows that such a decision maker can exhibit ambiguity aversion under certain restrictions on the probability weighting function. Segal's (1990) representation corresponds to (4) with the same rank dependent functional U for both stages:

$$U\left(\pi\left(\mu\right), c_\mu; \pi\left(\mu'\right), c_{\mu'}; ...\right) = \int v\left(c_\mu\right) df\left(M\right), \text{ where } c_\mu = v^{-1}\left(v\left(w\right) f\left(\mu\left(R\right)\right)\right), \tag{5}$$

where f is a probability weighting function and v is a utility function both applied to both stages, and M is the cumulative distribution function of π, which is piecewise linear given uniform stage-1 prior. Segal (1987) shows that the model can account for ambiguity aversion when f is strictly convex. Naturally, an S-shaped probability weighting function could also

[7] Otherwise, should there be a pair of symmetrically placed second-stage risks, $\{n\}$ and $\{100-n\}$, whose assigned stage-1 probabilities are different, then we can pick a monotone stage-1 utility preference specification which is responsive to the difference between the CEs for $\{n\}$ and $\{100-n\}$ while minimizing the contributions of all other pairs. It follows that the overall indifference can no longer hold when the probabilities assigned to $\{n\}$ and $\{100-n\}$ along with those for the other pairs get reversed when switching from betting on red to betting on black.

deliver the same implication if the effect of its being initially concave n is dominated by a stronger degree of convexity nearer 1. This gives rise to the following implications:[8]

Implication 1. Aversion to increasing size of ambiguity in interval group: $\mathbf{S}_n^A \succ \mathbf{S}_m^A$ if $n < m$.

Implication 2. Aversion to increasing size of ambiguity in disjoint group: $\mathbf{D}_n^A \succ \mathbf{D}_m^A$ if $n < m$.

Implication 3. Initial aversion to spread for two-point ambiguity followed by a reversal: There exist a n^* such that $\mathbf{P}_n^A \succ \mathbf{P}_m^A$ for $n < m \leq n^*$, $\mathbf{P}_m^A \succ \mathbf{P}_n^A$ for $n^* \leq n < m$, and $\mathbf{B}_0 \sim \mathbf{B}_1^A$.

To establish Implication 3, we first normalize $u(w) = 1$ and $u(0) = 0$. Note that

$$(6) \qquad U(\{50-n, 50+n\}^A) = f(0.5)\, f(0.5 - \widehat{n}) + (1 - f(0.5))\, f(0.5 + \widehat{n}),$$

where $\widehat{n} = n/100$ with n varying between 0 and 50. Implication 3 follows from observing that (6) is strictly convex in $\widehat{n}$ given that f is strictly convex and that $U(\{50\}^A) = f(0.5) = U(\{0, 100\}^A)$.

We provide some intuition here for implications 1 and 2 and relegate details of their proofs to Appendix B. As n increases, for interval ambiguity $[50-n, 50+n]^A$, the decision weight on the best stage-2 risk $\{50+n\}$, given by $f(1/(2n+1))$, becomes disproportionately small while the decision weight on the worst stage-2 risk $\{50-n\}$, given by $1 - f(2n/(2n+1))$, becomes disproportionately large. The overall effect of changes in decision weights consistently more than offsets the effect of increasing utility of $\{50+n\}$ relative to $\{50-n\}$, thereby delivering Implication 1. A similar intuition applies in establishing Implication 2 for the disjoint group.

Recursive expected utility (REU)

Several recent papers, including Klibanoff, Marinacci and Mukerji (2005), Nau (2006), and Seo (2009), axiomatize a two-stage model involving distinct SEUs in the two stages (REU):

$$(7) \qquad U(\pi(\mu), c_\mu; \pi(\mu'), c_{\mu'}; ...) = \int v(c_\mu)\, dM, \text{ where } c_\mu = u^{-1}(u(w)\,\mu(R)).$$

[8] We have the reverse implications with a strictly concave probability weighting function. See Appendix B for a detailed proof.

Depending on the relative concavity between the stage-1 and stage-2 vNM utility functions v and u, REU can exhibit different attitudes towards changes in the size of ambiguity. Define a *stage-1 relative curvature function* as $v \circ u^{-1}$, we have the following predictions of REU with $v \circ u^{-1}$ being strictly concave:[9]

Implication 1'. Aversion to increasing size of ambiguity in interval group: $\mathbf{S}_n^A \succ \mathbf{S}_m^A$ if $n < m$.

Implication 2'. Affinity to increasing size of ambiguity in disjoint group: $\mathbf{D}_n^A \succ \mathbf{D}_m^A$ if $n > m$.

Implication 3'. Aversion to point spread: $\mathbf{P}_n^A \succ \mathbf{P}_m^A$ if $n < m$.

Non-uniform Priors

Uniform prior is one possible symmetric belief underpinning a two-stage perspective on ambiguity, we proceed to check whether the above implications still hold under weaker conditions. In this regard, we provide a formal definition of stage-1 mean-preserving spread which applies to the three groups of compound risks considered. For given symmetric distributions M and M' on μ, we say M is a *stage-1 spread* of M' if (1) $M(\mu) \leq M'(\mu)$ for $\mu(R) < 0.5$; (2) $M(\mu) \geq M'(\mu)$ for $\mu(R) > 0.5$; and (3) M and M' reduce to the same simple lottery.[10]

For REU, a concave relative curvature function directly implies aversion to all kind of stage-1 mean-preserving spread. Thus, the implications remain unchanged if the priors in each group satisfy the corresponding spread condition, e.g., the prior in $\mathbf{S}_{30}^A$ is a stage-1 spread of that in $\mathbf{S}_{20}^A$, and the prior in $\mathbf{D}_{20}^A$ is a stage-1 spread of that in $\mathbf{D}_{30}^A$, etc.

For RRDU, the robustness of the implication for disjoint ambiguity lotteries requires additionally that priors in all disjoint ambiguity lotteries are spreads of uniform stage-1 prior. We will then have aversion to increasing size of ambiguity in the disjoint group. Similarly, if uniform stage-1 prior is a spread of the priors in all interval ambiguous lotteries, we will again have aversion to increasing size in the interval group (see Appendix B for a detailed proof).

[9]We have the reverse implications with $v \circ u^{-1}$ being strictly convex.

[10]Besides uniform prior, the stage-1 spread condition is compatible with a binomial belief (treating each card as being equally likely to be red or black), a geometric belief (viewing the unknown deck of 100 cards as a random draw from a deck of 100 red and 100 black cards), and a U-shaped belief which captures a more extreme view in which the worst and best outcomes are disproportionately more likely to occur.

2.2 Compound Risk

We describe here the experimental framework for uniform compound risk followed by a discussion of the theoretical implications of different utility models on choice behavior for compound risk alone as well as encompassing partial ambiguity through the two-stage perspective.

2.2.1 Experimental Framework

In Experiment 2, we study three kinds of compound risk corresponding to the three kinds of partial ambiguity in the preceding subsection: interval compound risk denoted by $\mathbf{S}_n^C = [50-n, 50+n]^C$, disjoint compound risk by $\mathbf{D}_n^C = [0, n] \cup [100-n, 100]^C$ and two-point compound risk by $\mathbf{P}_n^C = \{50-n, 50+n\}^C$, with the limiting cases of $\mathbf{B}_0 = \{50\}$, $\mathbf{B}_1^C = \{0, 100\}^C$, and $\mathbf{B}_2^C = [0, 100]^C$. Here, compound risk is implemented with objective uniform stage-1 priors.

Each kind of uniform compound risk can be linked to the corresponding partial ambiguity through the two-stage perspective and this link is strengthened under an additional assumption of uniform stage-1 priors under partial ambiguity. Moreover, our use of objective uniform stage-1 priors enables us to examine attitude towards the three kinds of stage-1 mean-preserving spread, defined in subsubsection 2.1.2., where interval spread and two-point spread increases as n increases while disjoint spread increases as n decreases.

2.2.2 Theoretical Implications for Compound Risk

In Experiment 2, one-stage models satisfying RCLA (including SEU, CEU and MEU) predict the same CEs for all compound lotteries while two-stage models (including RRDU and REU) can generate distinct non-RCLA choice behavior.[11] In particular, two-stage models deliver the same implications for uniform compound risks as for their corresponding ambiguous

[11] Most of the one-stage models considered here adopt the Anscomb-Aumann framework and assume RCLA. One exception is Gilboa (1987) which adopts the Savagian framework in which RCLA is absent. Regardless of the frameworks adopted, the one-stage models are silent on the link between attitudes towards partial ambiguity and attitudes towards compound risks.

lotteries under uniform stage-1 priors. Thus, RRDU with a convex probability weighting function implies aversion to uniform interval spread, affinity to uniform disjoint spread, and initial aversion to two-point spread followed by a reversal near the end-point $\{0, 100\}^C$. In contrast, REU with concave stage-1 relative curvature function implies aversion to spread in all three groups.[12]

Our design of objective uniform stage-1 risks also enables tests of specific axioms in the literature on compound risks. First, we can check the extent to which RCLA may hold given that all of the compound risks reduce to the same simple lottery $\{50\}$. Second, since $\{50\}$ and $\{0, 100\}^C$ differ only in terms of the timing of uncertainty resolution, the time neutrality axiom implies that $\{50\} \sim \{0, 100\}^C$ as long as stage-1 preference is identical to stage-2 preference. Third, under uniform stage-1 risk, $[0, 100]^C$ can be expressed as a convex combination of $[n, 100 - n]^C$ and $[0, n] \cup [100 - n, 100]^C$ assuming that the overlapping two points are negligible. Thus, $[0, 100]^C$ would be intermediate in preference between $[n, 100 - n]^C$ and $[0, n] \cup [100 - n, 100]^C$ if stage-1 preference, e.g., REU, satisfies the betweenness axiom (Chew, 1983; Dekel, 1986).[13]

2.3 Linking Partial Ambiguity and Compound Risk

Besides investigating attitude towards partial ambiguity and compound risk separately in experiments 1 and 2, we study them jointly in Experiment 3 in a within-subject design. The respective designs of partial ambiguity and compound risk in Experiment 3 inherit the main features of Experiment 1 and Experiment 2, and the within-subject design enables us to examine not only the robustness of our observations in experiments 1 and 2, but also potential links between attitude towards partial ambiguity and attitude towards compound risk. Specifically, ambiguity attitude can be linked to RCLA under two-stage models, while

[12] Applying two-stage distinct utility models to evaluate compound lotteries is subject to the concern that decision makers may not differentiate objective risks in different stages in an atemporal setup. Nevertheless, stage-1 risk and stage-2 risk are in principle different and we apply two-stage distinct utility models for objective probabilities in Experiment 2. See Halevy (2007) for a related discussion.

[13] The assumption of stage-1 independence in Klibanoff, Marinacci and Mukerji (2005) has been recently discussed in Epstein (2010) and subsequently in Klibanoff, Marinacci and Mukerji (2012).

one-stage models are silent on such a link. This enables a test to discriminate between these two approaches as suggested in Halevy (2007). Given that the CEs for ambiguous lotteries under uniform prior would be identical to those of the corresponding uniform compound risks under two-stage models, harboring non-uniform priors could yield different CEs between ambiguous lotteries and uniform compound lotteries. For example, in REU, binomial prior in $[0, 100]^A$ would deliver a higher CE than that for $[0, 100]^C$ with U-shaped prior implying the reverse. The corresponding implication is distinct for RRDU with a convex probability weighting function as a U-shaped prior would still deliver a higher CE since it is a stage-1 spread of uniform prior. Moreover, given symmetry, priors in two-point ambiguity lotteries are necessarily uniform so that $\{50 - n, 50 + n\}^A \sim \{50 - n, 50 + n\}^C$, i.e., subjective and objective stage-1 risks are treated the same. Otherwise, we would need to incorporate source preference in modeling differential attitudes towards subjective and objective stage-1 priors.

3 Experiment on Partial Ambiguity

This section presents the design and results of Experiment 1 on partial ambiguity. We analyze the choice patterns for the three groups of partial ambiguity at both aggregate and individual levels, followed by a discussion of their implications on the utility models reviewed in the preceding section.

3.1 Design

Experiment 1 comprises 3 groups of six lotteries each with a total of 15 lotteries as illustrated in Figure 1.

Interval ambiguity. This group comprises 6 lotteries with interval ambiguity: $\mathbf{B}_0 = \{50\}^A$, $\mathbf{S}_{10}^A = [40, 60]^A$, $\mathbf{S}_{20}^A = [30, 70]^A$, $\mathbf{S}_{30}^A = [20, 80]^A$, $\mathbf{S}_{40}^A = [10, 90]^A$, $\mathbf{B}_2^A = [0, 100]^A$.

Disjoint ambiguity. This group involves 6 lotteries with disjoint ambiguity: $\mathbf{B}_1 = \{0, 100\}^A$, $\mathbf{D}_{10}^A = [0, 10] \cup [90, 100]^A$, $\mathbf{D}_{20}^A = [0, 20] \cup [80, 100]^A$, $\mathbf{D}_{30}^A = [0, 30] \cup [70, 100]^A$, $\mathbf{D}_{40}^A = [0, 40] \cup$

$[60, 100]^A$, $\mathbf{B}_2^A = [0, 100]^A$.

Two-point ambiguity. This group involves 6 lotteries with two-point ambiguity: $\mathbf{B}_0 = \{50\}$, $\mathbf{P}_{10}^A = \{40, 60\}^A$, $\mathbf{P}_{20}^A = \{30, 70\}^A$, $\mathbf{P}_{30}^A = \{20, 80\}^A$, $\mathbf{P}_{40}^A = \{10, 90\}^A$, $\mathbf{B}_1^A = \{0, 100\}^A$.

In the experiment, subjects were shown the 15 desks of the cards. For each lottery, betting on the color of a drawn card correctly would deliver S$40 (about US$30) while betting incorrectly would deliver nothing. To ameliorate potential confound due to suspicion, subjects can choose the color to bet.[14] We use the price list design and RIM in eliciting the CEs of various lotteries (see Appendix E for experiment instructions). The order of appearance of the 15 lotteries is randomized for the subjects who each make 150 choices in total. At the end of the experiment, in addition to a S$5 show-up fee, each subjects is paid based on his/her randomly selected decision in the experiment. One out of 150 choices is randomly chosen using dice.

We recruited 112 undergraduate students from National University of Singapore (NUS) as participants using advertisement posted in its Integrated Virtual Learning Environment. The experiment consisted of 4 sessions with 20 to 30 subjects for each session. It was conducted by one of the authors with two research assistants. After arriving at the experimental venue, subjects were given the consent form approved by NUS' Institutional Review Board. Subsequently, general instructions were read to the subjects followed by our demonstration of several examples of possible compositions of the deck before subjects began making decisions. Most subjects completed the decision making tasks within 40 minutes.[15] The payment stage took up about 40 minutes.

[14] Charness, Karni and Levin (2013) observe a significantly lower degree of ambiguity averse than is typical in the literature. They attribute this difference to the common practice of asking subjects to choose between betting on an unambiguous event and a specific ambiguous event. This may raise suspicion in subjects' minds – if they choose to bet on the ambiguous events, somehow the deck is stacked against them – so that the observed preference for betting on the unambiguous event may reflect the incidence of suspicion besides a possible aversion towards ambiguity. To address this issue, subjects in our experiment choose which color to bet on in all decks.

[15] After finishing this experiment, subjects were given the instructions and decision sheets for a second part on skewed ambiguity, which was reported in our original working paper titled "Partial Ambiguity".

3.2 Observed Choice Behavior

We present the observed choice behavior at both aggregate and individual levels for 106 subjects. The choice data are coded in terms of the switch point given by the number of times a subject chooses a given lottery over different increasingly ordered sure amounts before switching over to choosing the sure amounts. Consequently, a lower switch point corresponds to a smaller CE. Aggregate choice patterns are presented in Figure 2 below.[16]

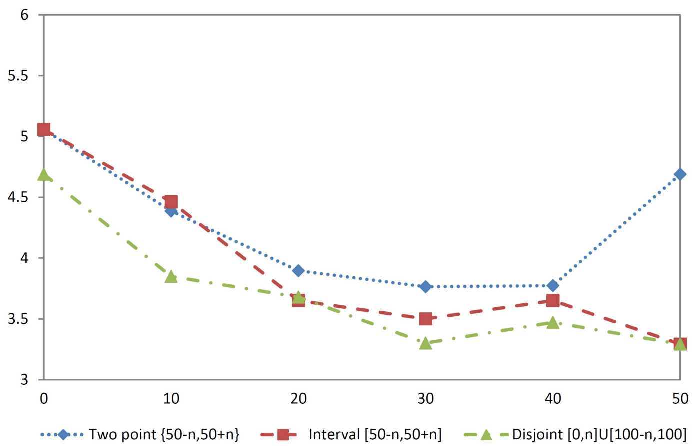


Figure 2: Mean switch points for partial ambiguity.

We first examine the implication of ambiguity neutrality that subjects assign the same CE to the 15 lotteries and reject the null hypothesis that the CEs of the 15 lotteries come from a single distribution using a Friedman test ($p < 0.001$). Besides replicating the standard finding on ambiguity aversion with CE of $\{50\}$ being significantly higher than that of $[0, 100]^A$ (paired Wilcoxon Signed-rank test, $p < 0.001$), our subjects have distinct attitudes towards different kinds of partial ambiguity. Specifically, for the comparison between $\{50\}$ and $[0, 100]^A$, 62 (58.5%) of the subjects exhibit ambiguity aversion, 33 (31.1%) exhibit ambiguity neutrality, and 11 (10.4%) exhibit ambiguity affinity. Comparing $\{50\}$ with the other 14 ambiguous lotteries at the individual level, 16 (15.1%) out of 106 subjects have the same CEs for the 15 lotteries. Among the others, 48 (45.3%) subjects exhibit overall ambiguity aversion in having weakly larger CEs for $\{50\}$ than for the other 14 ambiguous lotteries. 13 (12.3%) have

[16]Six subjects exhibit multiple switching in some of the tasks. Their data are excluded from our analysis. See Table C1 in Appendix C for details.

weakly lower CEs for $\{50\}$ than that for the other 14 ambiguous lotteries revealing some degree of ambiguity affinity. The remaining 29 (24.3%) subjects do not exhibit uniform attitude towards ambiguity.

We next study the correlations among the CEs for the 15 lotteries. We find these CEs to be highly and positively correlated ranging from 51.5% to 89.9% (see Table C2 in Appendix C). The correlations between risk attitude measured by the CE for $\{50\}$, and ambiguity premium given by the difference in CEs between that of $\{50\}$ and those of the 14 ambiguous lotteries are generally high, between 37.7% and 60.7%, except for $\{0, 100\}^A$ with a correlation of 15.7% (see Table C3 in Appendix C), which supports the earlier observation that $\{0, 100\}^A$ may admit an alternative interpretation as being almost a 50-50 lottery. The pairwise correlations for the ambiguity attitude towards the 14 ambiguous lotteries are also highly positive, ranging from 55.0% to 85.6%, except for the correlations with $\{0, 100\}^A$ which range from 21.7% to 49.8% (see Table C4 in Appendix C).

To identify specific choice patterns across the three groups, we apply a non-parametric trend test, an extension of the Wilcoxon rank-sum test, in Cuzick (1985), which requires the data to be ordinal and ordered. This test enables us to examine whether there is an increasing or decreasing trend for each group, against the null hypothesis that there is no trend in the data. Applying this test yields the following three observations for the three kinds of partial ambiguity.

Observation A1 (*Interval ambiguity*): For the interval ambiguity group, $\mathbf{B}_0$, $\mathbf{S}^A_{10}$, $\mathbf{S}^A_{20}$, $\mathbf{S}^A_{30}$, $\mathbf{S}^A_{40}$ and $\mathbf{B}^A_2$, there is a statistically significant *decreasing* trend in the CEs as the size of ambiguity increases ($p < 0.001$).

At the individual level, 20 (18.9%) of the subjects have the same CEs, 25 (23.6%) have weakly decreasing CEs, while none of the subjects has weakly increasing CEs.

Observation A2 (*Disjoint ambiguity*): For the disjoint ambiguity group, $\mathbf{B}^A_1$, $\mathbf{D}^A_{10}$, $\mathbf{D}^A_{20}$, $\mathbf{D}^A_{30}$, $\mathbf{D}^A_{40}$ and $\mathbf{B}^A_2$, there is a statistically significant *decreasing* trend in the CEs as the size of ambiguity increases ($p < 0.001$).

At the individual level, 19 (17.9%) of the subjects have the same CEs, 19 (17.9%) of the subjects have weakly decreasing CEs, and 4 (3.8%) of the subjects have weakly increasing CEs.

Observation A3 (*Two-point ambiguity*): For the two-point ambiguity group, $\mathbf{B}_0$, $\mathbf{P}^A_{10}$, $\mathbf{P}^A_{20}$, $\mathbf{P}^A_{30}$, $\mathbf{P}^A_{40}$ and $\mathbf{B}^A_1$, there is a significant *decreasing* trend in the CEs from $\mathbf{B}_0$ to $\mathbf{P}^A_{40} = \{10, 90\}$ ($p < 0.001$). Interestingly, the CE of $\mathbf{B}^A_1$ reverses this trend and is significantly higher than the CE of $\mathbf{P}^A_{40}$ (paired Wilcoxon Signed-rank test, $p < 0.001$). Moreover, the CE of $\mathbf{B}^A_1$ is not significantly different from that of $\mathbf{B}_0$ (paired Wilcoxon Signed-rank test, $p > 0.225$).

At the individual level, 22 (20.8%) of the subjects have the same CEs, 14 (13.2%) of the subjects have weakly decreasing CEs, 33 (31.1%) have weakly decreasing CEs until $\{10, 90\}$ with an increase at $\mathbf{B}^A_1$, and 7 (6.6%) have weakly increasing CEs. Between $\mathbf{B}_0$ and $\mathbf{B}^A_1$, 49 (46.2%) of the subjects have the same CEs, 33 (31.1%) display a higher CE for $\mathbf{B}_0$ than that for $\mathbf{B}^A_1$, and 24 (22.6%) exhibit the reverse. Between $\mathbf{B}^A_1$ and $\mathbf{P}^A_{40}$ ($\{10, 90\}$), 48 (45.3%) of the subjects have the same CEs, 45 (42.5%) have a higher CE for $\mathbf{B}^A_1$ than that for $\mathbf{P}^A_{40}$, and 13 (12.3%) exhibit the reverse. These findings corroborate the potentially ambiguous interpretation of $\mathbf{B}^A_1$.

3.3 Implications for Utility Models

Overall, one-stage non-expected utility models have some flexibility in accommodating the observed choice patterns in Experiment 1. The CEU model with a non-additive capacity ν possesses the most flexibility in allowing ν to be tailored to observed choice patterns, e.g., being size-dependent to account for aversion to the increasing size of ambiguity in the interval and disjoint groups and the reversal in preference in two-point ambiguity as the spread approaches $\{0, 100\}^A$. By making the set of priors dependent monotonically on the size of ambiguity in interval and disjoint ambiguity and the spread in two-point ambiguity, MEU can account for the observed aversion to an increase in ambiguity in the interval and the disjoint groups but not the reversal as the spread increases in two-point ambiguity.

For two-stage models, RRDU with a convex probability weighting function is compatible with the observed aversion to increasing the size of ambiguity in both the interval and the disjoint groups as long as stage-1 priors in each group satisfy the spread condition in subsubsection 2.1.2. In contrast, REU with a concave stage-1 relative curvature function fails to generate such behavior under the same conditions given that it implies aversion to increasing size of ambiguity in the interval group but affinity to increasing size in the disjoint group. For two-point ambiguity lotteries, the overall aversion towards spread except for a reversal at the end point $\{0, 100\}^A$ is in line with RRDU but not REU.[17]

4 Experiment on Compound Risk

This section presents the design of Experiment 2 on uniform compound risk which can be linked to partial ambiguity with uniform priors under the two-stage perspective. We analyze the choice patterns for the three groups of compound risks at both the aggregate and the individual levels, followed by a discussion of their implications on the utility models reviewed in Section 2.

4.1 Design

Experiment 2 on uniform compound risk links naturally to the two-stage perspective of ambiguity under uniform priors. For each compound lottery, we implement objective uniform stage-1 prior as follows: one ticket is randomly drawn from a bag containing some tickets with different numbers written on them. The number drawn determines the number of red cards in the deck with the rest black. The resulting stage-1 risk is thus uniformly distributed among different numbers while the bet at stage 2 involves betting on the color of a card randomly

[17] The distinct attitudes towards interval and disjoint spreads may arise from subjects being more averse to increasing the number of possible compositions (Neilson, 1992; Humphrey, 1998), which may in turn be modeled by a complexity-dependent REU whose curvature of its stage-1 utility function depends on the number of possible compositions. Kovarik, Levin and Wang (2014) present an alternative model of complexity aversion to account for the non-neutral ambiguity attitudes.

drawn from the deck. There are 3 groups of 9 lotteries included in this experiment.[18]

Interval compound risk. This involves 4 lotteries with symmetric interval stage-1 risk: $\mathbf{B}_0 = \{50\}$, $\mathbf{S}_{10}^C = [40, 60]^C$, $\mathbf{S}_{30}^C = [20, 80]^C$, $\mathbf{B}_2^C = [0, 100]^C$.

Disjoint compound risk. This involves 4 lotteries with symmetric disjoint stage-1 risk: $\mathbf{B}_1^C = \{0, 100\}^C$, $\mathbf{D}_{10}^C = [0, 20] \cup [80, 100]^C$, $\mathbf{D}_{30}^C = [0, 40] \cup [60, 100]^C$, $\mathbf{B}_2 = [0, 100]^C$.

Two-point compound risk. This involves 4 lotteries with symmetric two-point stage-1 risk: $\mathbf{B}_0 = \{50\}$, $\mathbf{P}_{10}^C = \{40, 60\}^C$, $\mathbf{P}_{30}^C = \{20, 80\}^C$, $\mathbf{B}_1^C = \{0, 100\}^C$.

The elicitation mechanism and experimental procedure are similar as Experiment 1 (see Appendix E for detailed instructions). We have 109 subjects for Experiment 2.

4.2 Observed Choice Behavior

We report the observed choice patterns at both aggregate and individual levels. The aggregate choice patterns are presented in Figure 3 below.[19]

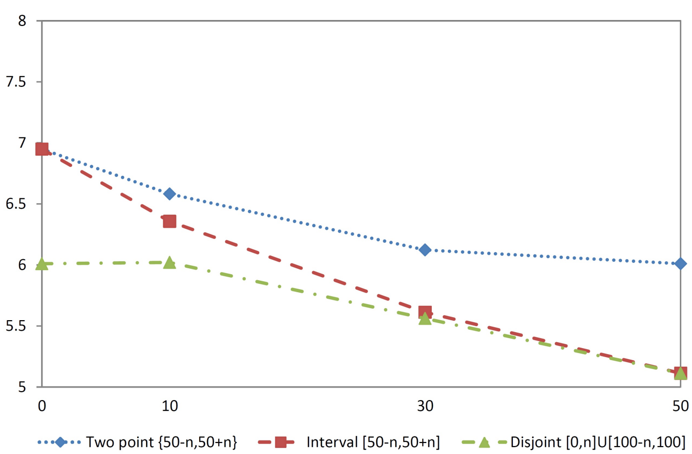


Figure 3: Mean switch points for compound risk.

To test the implication of RCLA that the CEs of the 9 lotteries are the same, we apply the Friedman test and reject the null hypothesis that their CEs come from the same distribution

[18]Experiment 2 is based on "An Experimental Study of Attitude towards Compound Lottery" by Miao and Zhong (2013) while Experiment 1 is based on an earlier version of "Partial Ambiguity" by Chew, Miao and Zhong (2013). The differences in design arise from the two experiments being conducted independently.

[19]Eleven subjects exhibit multiple switching in some of the tasks. Their data are excluded from our analysis. See Table C5 in Appendix C for details.

($p < 0.001$).[20] At the individual level, 12 (12.2%) out of 98 subjects have the same CE for the 9 lotteries. Besides these subjects, 39 (40.0%) have weakly larger CEs for $\{50\}$ than that of the other eight compound lotteries while 17 subjects (17.3%) exhibit the opposite pattern with weakly lower CEs for $\{50\}$ than the other eight lotteries. This suggests that subjects tend to weakly prefer receiving the reduced simple lottery than any of the eight other compound lotteries.

We next examine the correlations among the 9 lotteries. The CEs for the 9 lotteries are found to be positively correlated ranging from 12.7% to 75.5% (see Table C6 in Appendix C for pairwise correlations). The correlations between risk attitude reflected by the CE for $\{50\}$ and compound risk premium, given by the difference between the CE for $\{50\}$ and those of the compound lotteries, are in general high, ranging between 38.1% and 62.3% (see Table C7 in Appendix C). The pairwise correlations for compound risk attitude over the 8 compound lotteries are also highly positive, ranging from 25.3% to 79.7% (see Table C8 in Appendix C).

To study the choice patterns across the 3 groups of compound lotteries, we again apply the non-parametric trend test to examine whether there is a significant trend in each group corresponding to attitudes towards different patterns spread in stage-1 risks. Our overall findings are summarized below.

Observation B1 (*Interval compound risk*): For the interval group, $\mathbf{B}_0$, $\mathbf{S}_{10}^C$, $\mathbf{S}_{30}^C$,and $\mathbf{B}_2^C$, there is a statistically significant *decreasing* trend in the CEs as the stage-1 risks spread away from the mid-point ($p < 0.001$).

At the individual level, 21 subjects (21.4%) have the same CEs, and 30 (30.6%) have weakly increasing CEs, and 12 (12.2%) have weakly decreasing CEs, with the rest of the subjects not exhibiting monotonic preference in relation to uniform interval spread.

Observation B2 (*Disjoint compound risk*): For the disjoint group, $\mathbf{B}_1^C$, $\mathbf{D}_{10}^C$, $\mathbf{D}_{30}^C$, and $\mathbf{B}_2^C$,

[20]Lotteries $\mathbf{B}_0$, $\mathbf{B}_1^C$ and $\mathbf{B}_2^C$ are used in Halevy (2007), where he finds that CE of $\{50\}$ > CE of $\{0, 100\}^C$ > CE of $[0, 100]^C$. As a robustness check, we replicate his finding (Trend test across ordered groups, $p < 0.001$).

there is a statistically significant *increasing* trend in the CEs as the stage-1 risks spread away from the mid-point ($p < 0.001$).

At the individual level, 16 subjects (16.3%) have the same CEs, 26 (26.5%) have weakly increasing CEs, and 22 (22.4%) have weakly decreasing CEs, with the rest of the subjects not exhibiting monotonic preference in relation to uniform disjoint spread.

<u>Observation B3</u> (*Two-point compound risk*): For the two-point group, $\mathbf{B}_0^C$, $\mathbf{P}_{10}^C$, $\mathbf{P}_{30}^C$, and $\mathbf{B}_1^C$, there is a statistically significant *decreasing* trend in the CEs as the stage-1 risks spread away from the mid-point ($p < 0.042$).

At the individual level, 18 (18.4%) have weakly increasing CEs, 14 subjects (14.3%) have the same CEs, 8 (8.2%) have weakly decreasing CEs, and 17 subjects (17.3%) have weakly decreasing CE initially followed by an increase near the end point, with the remaining 41 (42%) subjects not exhibiting of these patterns. Focusing on $\mathbf{B}_0$ and $\mathbf{B}_1^C$, 34 subjects (34.7%) have the same CEs, 43 (43.9%) have a higher CE for $\mathbf{B}_0$ than that of $\mathbf{B}_1^C$, while the rest of 21 subjects (21.4%) have the reverse preference. Paired Wilcoxon Signed-rank test shows that the CE of $\mathbf{B}_0$ is significantly higher than that of $\mathbf{B}_1^C$ ($p < 0.022$).

4.3 Implications for Utility Models

We first observe that RCLA, characteristic of most one-stage models, implies that all the compound lotteries considered in Experiment 2 would be indifferent to $\{50\}$, which does not accord with observed choice behavior. For two-stage models, REU with a concave stage-1 relative curvature function is compatible with the aversion to interval spread and two-point spread but not the affinity to disjoint spread. In exhibiting stage-1 betweenness, REU implies that $[0, 100]^C$ is intermediate in preference between an interval compound lottery and its complementary disjoint compound lottery, which runs counter to $[0, 100]^C$ being the least valued lottery in Experiment 2. In contrast, RRDU with a convex probability weighting function is able to capture both aversion to uniform interval spread and affinity to uniform disjoint spread, but not aversion to two-point spread especially the preference for $\{50\}$ over

$\{0, 100\}^C$ which violates its neutrality axiom.[21]

Finally, notice that we observe similar overall behavioral patterns between Experiment 1 and Experiment 2, and the correlation between risk attitude and ambiguity attitude in Experiment 1 are also similar to the correlation between risk attitude and compound risk attitude in Experiment 2, These suggest a potential link between ambiguity and compound risk, and we proceed to examine this link in details in Experiment 3.

5 Combining Partial Ambiguity and Compound Risk

This section presents the design of Experiment 3 combining both Experiment 1 and Experiment 2 in a within-subject setting (see Appendix E for Experimental Instructions). Experiment 3 enables us to study the robustness of choice patterns observed in Experiment 1 and 2 as well as potential connections between attitude towards partial ambiguity and attitude towards uniform compound risks. We also provide an individual level analysis on how subjects relate ambiguity to compound risk and their classification into types based on the proximity of their choice behavior vis-a-vis their implications on specific utility models.

5.1 Design

The design details of Experiment 3 are similar to those in experiments 1 and 2 with two exceptions. In order to have a more refined assessment of CE and to have a more balanced price list of sure amounts ranging from S\$8 to S\$32, the number of sure amounts has been increased from 10 to 21 with the expected payoff of S\$20 in the middle. To moderate the number of choices each subject makes, we reduce the number of intermediate cases. Besides the simple risk lottery $\mathbf{B}_0 = \{50\}$, we have 5 cases of partial ambiguity:

$\mathbf{P}^A = \{25, 75\}^A, \mathbf{S}^A = [25, 75]^A, \mathbf{D}^A = [0, 25] \cup [75, 100]^A, \mathbf{B}_1^A = \{0, 100\}^A, \mathbf{B}_2^A = [0, 100]^A$,

and 5 cases of compound risk:

[21] The evidence against time neutrality can be captured by allowing for distinct probability weighting functions in RRDU for risks arising at different stages.

$\mathbf{P}^C = \{25, 75\}^C, \mathbf{S}^C = [25, 75]^C, \mathbf{D}^C = [0, 25] \cup [75, 100]^C, \mathbf{B}_1^C = \{0, 100\}^C, \mathbf{B}_2^C = [0, 100]^C$.

Experiment 3 is conducted in two different ordering between ambiguity appearing first and compound risk appearing first. In ambiguity-first treatment, subjects make choices in 6 decision tables comprising $\{50\}$ and 5 ambiguous lotteries followed by choices for the 5 compound lotteries. In compound-first treatment, subjects make choices in 6 decision tables comprising $\{50\}$ and 5 compound lotteries, followed by choices for the 5 ambiguous lotteries. Within each treatment, the order of appearance of the lotteries for each subject is randomized. The experiment consisted of 8 sessions with 20 to 30 subjects for each session. Altogether, 102 subjects are in the ambiguity-first treatment, and 86 subjects are in the compound-first treatment.

5.2 Observed Choice Behavior

In this subsection, we examine whether the observations in each group in Experiment 1 and Experiment 2 are robust. The summary statistics are presented in Figure 4 below. For the interval group, there is a statistically significant decreasing trend in the CEs as the number of possible compositions increases for both ambiguous and compound lotteries ($p < 0.001$). This replicates our findings in experiments 1 and 2. A decreasing trend in the CEs as the number of possible compositions increases is also observed for disjoint ambiguity ($p < 0.039$) but not significantly for disjoint compound lotteries ($p > 0.203$).

For the two-point ambiguity group, the observed aggregate attitude appears similar as Experiment 1 except for CE of $\{50\}$ being significantly greater that of $\{0, 100\}^A$ in Experiment 3, which may be attributed to its significantly larger sample size. For the two-point compound group, we do not observe a decreasing trend in the aggregate of CEs for two-point compound lotteries $\{50 - n, 50 + n\}^C$ as n approaches 50, in contrast with such a trend being observed in Experiment 2. Here, CE of $\{50\}$ is significantly higher than that of $\{25, 75\}^C$ ($p < 0.001$) as well as that of $\{0, 100\}^C$ ($p < 0.001$), but the latter two CEs are not significantly

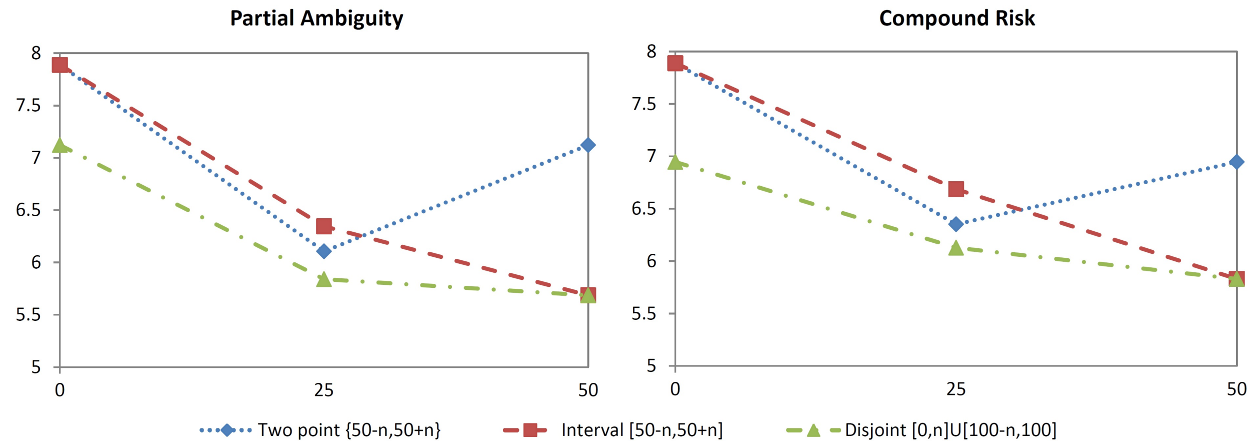


Figure 4: Mean switch points for partial ambiguity (Left) and compound risk (Right).

different from each other (p $>$ 0.645).[22]

We take a closer look at the individual level choice behavior within the two-point group across experiments (see Table C9 in Appendix C for the details). We first compare the proportions of subjects who are two-point ambiguity seeking, averse and neutral between Experiment 1 and Experiment 3. Multinomial logistic regression test shows no significant difference for $\{0,100\}^A$ (p $>$ 0.333).[23] Similarly, no significant difference is identified for $\{0,100\}^C$ (p $>$ 0.602) when comparing the proportions of subjects exhibiting two-point compound risk affinity, aversion and neutrality between Experiment 2 and Experiment 3.[24]

We further compare two-point ambiguity premium with two-point compound risk premium between Experiment 1 and Experiment 2, and within Experiment 3. Between Experi-

[22]In Experiment 1 and 2, we observe different choice patterns in the two-point group, in particular, between $\{0,100\}^A$ and $\{0,100\}^C$. While the either-all-red-or-all-black nature of $\{0,100\}$ may give it a semblance of a 50-50 lottery, the observed reversal near the end point in partial ambiguity but not in compound risk suggests that this semblance could have been diluted by the two-stage procedure in generating the lottery $\{0,100\}^C$.

[23]Notice that experiments 1 and 2 share the same 10-amount price list which differs from the 21-amount price list in Experiment 3. Therefore, we focus solely on ambiguity (compound risk) attitude when comparing between Experiments 1, 2 and Experiment 3. For the multinomial logistic regression, We code the two-point ambiguity attitude for $\{0,100\}^A$ as dependent variable, and the treatment dummy as independent variable.

[24]We conduct similar analysis for end-point behavior across the three experiments. For example, we compare the proportions of subjects based on whether they exhibit a reversal near the end-point in the two-point ambiguity group between Experiment 1 and Experiment 3. That is, we compare the proportions of subjects having higher/equal/lower CEs for $\{0,100\}^A$ than that of $\{20,80\}^A$ in Experiment 1 with the corresponding proportions for $\{0,100\}^A$ and $\{25,75\}^A$ in Experiment 3. In the same manner, we compare the end-point behavior in the two-point compound risk group between Experiment 2 and Experiment 3. No significant differences are identified.

ment 1 and Experiment 2, the ambiguity premium for $\{0, 100\}^A$ is not significantly different from the compound risk premium for $\{0, 100\}^C$ (two sample t-test, $p > 0.219$). Within Experiment 3, the two premia for $\{0, 100\}^A$ and $\{0, 100\}^C$ also do not differ significantly (paired t-test, $p > 0.618$).

Taken together, these analyses suggest that the observed choice behavior in the two-point group do not differ significantly when comparing within ambiguity (Experiment 1 versus Experiment 3) and within compound risk (Experiment 2 versus Experiment 3), as well as across ambiguity and compound risk (Experiment 1 versus Experiment 2, and within Experiment 3).

5.3 Attitude, Prior and Type

In this subsection, we examine the association between ambiguity attitude and compound risk attitude given that one-stage models generally permit RCLA while two-stage models usually link ambiguity aversion with a failure of RCLA. In addition, we probe stage-1 priors in ambiguous lotteries under the two-stage perspective by comparing the CEs for ambiguous lotteries and those of the corresponding compound lotteries (Amarante, Halevy and Ozdenoren, 2011) and discuss their implications for the utility models reviewed. Doing this further enables us to conduct individual type analysis in terms of the proximity of the observed behavior to the predictions of specific utility models.

5.3.1 Ambiguity Attitude and Compound Risk Attitude

Of 188 subjects, 31 are observed to reduce all compound lotteries, i.e., the CEs for all compound lotteries and $\{50\}$ are the same. Of these, 30 are ambiguity neural, i.e., the CEs for all ambiguous lotteries are the same as that of $\{50\}$. This is more than four times the expected frequency under the null hypothesis of independence. Among these 30 subjects, 12 switch to choosing the sure amount whenever it is at least as much as the expected value of 20, suggesting that they are expected value maximizers. Out of 157 subjects who did not conform to RCLA, 10 are ambiguity neutral, which exceeds one third of the expected frequency under the null hypothesis of independence (see Table 1 below).[25]

Table 1: Association between ambiguity attitude and RCLA.

Ambiguity	Compound Risk: Reduction	Non-Reduction	Total
Neutral	30 (6.6)	10 (33.4)	40
Non-Neutral	1 (24.4)	147 (123.6)	148
Total	31	157	188

Note. RCLA holds if the CEs for all compound lotteries and {50} are the same. Ambiguity neutrality holds if the CEs for all ambiguity lotteries and {50} are the same. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. The Pearson's chi-squared test is highly significant at $p < 0.001$.

We further investigate the association between ambiguity attitude and RCLA by assessing the correlation between ambiguity premium and the compound risk premium. Their consistently high correlation, ranging between 0.441 and 0.694, points to a tight association between ambiguity attitude and compound risk attitude for each of the five lotteries.

5.3.2 Priors and Types

We observe the following procedure to arrive at individual types according to the implications of different utility models. We first differentiate subjects according to whether they conform to RCLA. For subjects conforming to RCLA, we proceed to examine whether they behave in accordance with SEU or other one-stage models. For those who do not exhibit RCLA, we analyze their stage-1 priors for ambiguous lotteries and classify them either as REU or RRDU type. These classifications are reported with choice error 1, i.e., the CEs of two lotteries are considered equal if the absolute difference in terms of switch points does not exceed 1.

As pointed out before, we have 31 subjects performing RCLA without choice error with 30 of them being ambiguity neutral and consistent with SEU. The single remaining subject is ambiguity seeking. With choice error 1, the number of subjects in accordance with RCLA increases to 61, of whom 40 are ambiguity neutral, 13 are ambiguity averse, and the rest of

[25] We classify whether the subjects is ambiguity averse or ambiguity seeking by whether the CE difference between {50} and the four ambiguous lotteries is positive or negative.

8 subjects are ambiguity seeking.

For the remaining 127 subjects not exhibiting RCLA and potentially harboring a two-stage perspective for ambiguous lotteries, we examine their actual priors by comparing between the CEs of ambiguous lotteries and those of the corresponding compound lotteries. As discussed earlier, two-stage models predict similar CEs for ambiguous lotteries and the corresponding compound lotteries under uniform priors. Moreover, when considering the two-point lotteries of $\{0, 100\}$ and $\{25, 75\}$, this implication relies solely on the assumption of symmetry.

Table 2 below displays the results of comparisons in CE between two-point ambiguity and two-point compound lotteries in Experiment 3 for the 127 subjects not exhibiting RCLA. Of these, 31 have similar CEs, 44 weakly prefer two-point compound risks, 43 exhibit the reverse, and the remaining 9 subjects do not exhibit a consistent preference. While symmetry appears to be a weak behavioral assumption, the observed behavior suggests that subjects tend to distinguish between two-point lotteries depending on whether they arise from ambiguity or from compound risk. When incorporating the remaining three lotteries $[25, 75]$, $[0, 25] \cup [75, 100]$ and $[0, 100]$ in this comparison, 25 (19.7%) have similar CEs between each of the five ambiguous lotteries and the corresponding compound lottery, 28 (22.0%) weakly prefer ambiguous lotteries to compound lotteries, 40 (31.5%) exhibit the reverse, and the remaining 34 (26.7%) do not reveal any of these patterns.

Table 2: Comparison between ambiguous and compound two-point lotteries.

		$\{0, 100\}$			
		A < C	A = C	A > C	Total
$\{25, 75\}$	A < C	15 (9.1)	15 (14.6)	3 (9.4)	33
	A = C	14 (19.3)	31 (30.9)	25 (19.8)	70
	A > C	6 (6.6)	10 (10.6)	8 (6.8)	24
	Total	35	56	36	127

Note. The table presents the number of subjects in each of the categories – A < C, A = C, and A > C – indicating that the CE of a two-point ambiguity lottery may be smaller, equal, or larger than that of the corresponding two-point compound lottery. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. The Pearson's chi-squared test is significant at p = 0.024.

The preceding analysis reveals considerable individual difference between the CEs across the domains of ambiguity and compound risk, which may be traceable to subjects having non-uniform priors or source preference that differentiates stage-1 risks arising subjectively in partial ambiguity from those arising exogenously in compound risks. Furthermore, such differences in two-point group favor the source preference explanation rather than that based on subjects having non-uniform stage-1 priors.

Given the possible existence of non-uniform priors or source preference in the domain of ambiguity, it is not straightforward to conduct cross-domain analysis in classifying individual choice patterns. Thus, we focus on within-source choice patterns in arriving at individual types: RRDU with convex/concave probability weighting function and REU with a concave/convex stage-1 relative curvature function. For each source, whether ambiguity or compound risk, since we have three lotteries for three groups, this classification scheme yields 3×3 pairs of possible binary comparisons. For these 9 comparisons, as each model predicts specific choice patterns (as shown in subsubsection 2.1.2), we count the number of consistent choice patterns of each subject for each set of theoretical predictions, and associate the subject with the type delivering the highest number of consistent choices.

Under partial ambiguity, 58 subjects are of RRDU type with 52 having convex probability weighting functions and 6 having the reverse, 48 subjects are of REU type with 36 having concave stage-1 relative curvature function and 12 having the reverse, and 21 subjects are unclassified.[26] Under compound risk, 54 subjects are of RRDU type with 45 having convex probability weighting functions and 9 having the reverse, 53 subjects are of REU type with 38 having concave stage-1 relative curvature function and 15 having the reverse, and 20 subjects are unclassified.[27]

Table 3 reports the classification results across the domains of ambiguity and compound risk, and reveals that the types are highly correlated (Pearson's chi-squared test, $p < 0.001$). For the 36 subjects classified as REU with concave relative curvature function in the domain of ambiguity, 20 remain classified as REU with concave relative curvature function

[26]For the unclassified subjects, some subjects could be equally explained by both REU and RRDU, and the rest do not fit well with either model.

[27]Alternatively, we can calculate how much the CEs need to change in order to be exactly in line with the prediction of one type. Comparing the minimal changes in order to fit different predictions allows us to classify the subject into particular types. This method delivers highly similar observations.

Table 3: Individual types with two-stage perspective.

		Compound Risk					
		REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
Ambiguity	REU(concave)	20 (10.8)	2 (4.3)	7 (12.8)	3 (2.6)	4 (5.7)	36
	REU(convex)	0 (3.6)	5 (1.4)	2 (4.3)	1 (0.9)	4 (1.9)	12
	RRDU(convex)	12 (15.6)	4 (6.1)	27 (18.4)	1 (3.7)	8 (8.2)	52
	RRDU(concave)	0 (1.8)	1 (0.7)	1 (2.1)	3 (0.4)	1 (0.9)	6
	Unclassified	6 (6.3)	3 (2.5)	8 (7.4)	1 (1.5)	3 (3.3)	21
	Total	38	15	45	9	20	127

Note. The two-way table displays the counts for 127 subjects violating RCLA. The subjects are classifies as REU or RRDU with concave (convex) stage-1 relative curvature (probability weighting) functions separately for ambiguity and compound risk. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. The Pearson's chi-squared test is highly significant at $p < 0.001$.

in the domain of compound risk. For 52 subjects classified as RRDU with convex probability weighting functions under ambiguity, 27 of them continue to be classified as RRDU with convex probability weighting functions under compound risk. We further conduct a robustness check conditional on whether subjects have similar CEs between each of the five ambiguous lotteries and the corresponding compound lottery. The observed correlation in type classification across ambiguity and compound lottery remains robust (see Table C10 in Appendix C). These results lend further support to the two-stage perspective applied to partial ambiguity.

Finally, the results of order effect tests are reported in Appendix D, in which we find that the observed choice patterns are robust to varying the order of presentation of ambiguity tasks and compound risk tasks.

5.4 Summary

As exposited in the preceding subsection, the aggregate choice behavior in the two-point group does not differ significantly when comparing within or across ambiguity and compound risk. In terms of choice behavior in the interval and the disjoint groups, Experiment 1 reveals an overall aversion to size of ambiguity. In Experiment 2, we do not find an overall aversion to mean-preserving spread in compound risk. Specifically, we observe an aversion towards mean-preserving spread in interval compound risk but an affinity towards mean-preserving spread in disjoint compound risk. This finding appears to be at variance with the intuition behind risk aversion towards stage-1 risks, while it may be accounted for by bringing in considerations involving the overweighting of stage-1 probabilities closer to the end points of 0 or 1. At the same time, we note that the overall finding in observations 1 and 2 across the two experiments is compatible with the two-stage perspective on partial ambiguity which implies the switch in attitude towards mean-preserving spread from interval to disjoint compound risk observed in Experiment 2, given the aversion to increasing size of ambiguity in both interval and disjoint ambiguity observed in Experiment 1. This implication of the two-stage perspective in the concurrence of aversion towards size of ambiguity and switch in attitude towards mean-preserving spread in compound risk is further supported by our within-subject findings in Experiment 3.

6 Conclusion

This paper contributes to broadening the range of observed ambiguity-related choice behavior beyond pure risk and full ambiguity in a recent and growing literature testing models of decision making under uncertainty in a laboratory setting (Halevy, 2007; Machina, 2009; Baillon, L'Haridon and Placido, 2011; Hayashi and Wada, 2011; Epstein and Halevy, 2014; Yang and Yao, 2014). We study attitude towards three groups of partial ambiguity – interval, disjoint, and two-point – and their corresponding compound risk with uniform stage-1 probabilities. Our design enables a direct observation of attitude towards different degrees of partial ambiguity as well as attitude towards different types of spread in stage-1 risk. This further enables an examination of the two-stage perspective of ambiguity being viewed as compound risk with symmetrically distributed priors.

The observed patterns of choice behavior in partial ambiguity and compound risk have implications on a number of utility models in the literature. The concurrence of aversion to increasing the size of ambiguity and switch in attitude towards mean-preserving spread in stage-1 risk lends support to the two-stage perspective on partial ambiguity. This is further corroborated by the tight association between ambiguity attitude and compound risk attitude, while the significant difference between the valuations of partial ambiguity and those of their compound risk counterparts suggests non-uniform stage-1 prior in ambiguous lotteries or the incidence of source preference distinguishing between subjective and objective stage-1 risk. At the same time, the robust observation of full ambiguity being the least valued lottery is not compatible with two-stage models satisfying betweenness in their stage-1 preference. In an individual type analysis, we find significant heterogeneity in subjects' behavior with a moderate proportion (32.4%) of subjects satisfying RCLA, most of whom are expected utility type with the rest classified as the multiple-priors type. Of the remaining non-RCLA subjects, a slightly more proportion of subjects are of the recursive rank-dependent utility type than of the recursive expected utility type in both domains of ambiguity and compound risk. Moreover, the classifications of recursive rank-dependent utility or recursive subjective expected utility are consistent across ambiguity and compound risk.

Beyond the symmetric variants arising from the 2-urn paradox, the evidence on ambiguity attitude in the 3-color paradox tends to be mixed (e.g., Charness, Karni and Levin 2012, Binmore, Stewart and Voorhoeve 2012). Furthermore, Becker and Brownson (1964. p. 63) describe a suggestion of Ellsberg, "*Consider two urns with 1000 balls each. In Urn 1, each ball is numbered from 1 to 1000, and in Urn 2 there are an unknown number of balls bearing any number. If you draw a specific number say 687, you win a prize. There is an intuition that many subjects would prefer the draw from Urn 2 over Urn 1, that is, ambiguity seeking when probability is small.*" In this regard, affinity for skewed ambiguity has been observed in a number of studies (e.g., Kahn and Sarin 1988; Abdellaoui et al. 2011; Abdellaoui, Klibanoff and Placido, 2011; Chew, Miao and Zhong, 2013).

Findings from lab-based experimental studies point to the need to investigate different types of ambiguity or uncertainty in natural settings. Building on Knight's (1921) suggestion of treating entrepreneurial risks as being distinct from risk, our paper suggests a richer range of attitude towards entrepreneurial uncertainty from settings with moderate ambiguity to those more akin to all-or-nothing ambiguity. In financial markets, how might novice investors respond to convergent versus conflicting stock tips from experts? Facing the prospect of a community-wise calamity, e.g., involving environment or health, Viscusi (1997) finds a tendency for government agencies to make alarmist decisions from vague or contradictory information. In sum, we envisage the importance of incorporating partial knowledge in the economic analysis of uncertainty arising in different applied domains, including entrepreneurship, financial investment, and public policy.

REFERENCES

[1] Abdellaoui, M., A. Baillon, L. Placido, and P. P. Wakker (2011): "The Rich Domain of Uncertainty: Source Functions and Their Experimental Implementation," *American Economic Review* 101: 695-723.

[2] Abdellaoui, M., P. Klibanoff, and L. Placido (2011): "Ambiguity and Compound Risk Attitudes: An Experiment," *working paper*.

[3] Amarante, M., Y. Halevy, and E. Ozdenoren (2011): "Two-Stage Probabilistic Sophistication," *working paper*.

[4] Anscombe, F. J., and R. J. Aumann (1963): "A definition of subjective probability," *Annals of mathematical statistics* 34: 199-205.

[5] Baillon, A., O. L'Haridon, and L. Placido (2011): "Ambiguity Models and the Machina Paradoxes," *American Economic Review* 101: 1547-60.

[6] Baillon, A., Y. Halevy, and C. Li (2014): "Experimental Elicitation of Ambiguity Attitude using the Random Incentive System," *working paper*.

[7] Becker, S. W., and F. O. Brownson (1964): "What Price Ambiguity? Or the Role of Ambiguity in Decision-Making," *Journal of Political Economy* 72: 62-73.

[8] Binmore, K., L. Stewart, and A. Voorhoeve (2012): "How Much Ambiguity Aversion?," *Journal of Risk and Uncertainty* 45: 215-38.

[9] Charness, G., E. Karni, and D. Levin (2012): "Ambiguity Attitudes: An Experimental Investigation," *working paper*.

[10] Chew, S. H. (1983): "A Generalization of the Quasilinear Mean with Applications to the Measurement of Income Inequality and Decision Theory Resolving the Allais Paradox," *Econometrica* 51: 1065-1092.

[11] Chew, S. H., B. Miao., and S. Zhong (2013): "Partial Ambiguity," *working paper*.

[12] Chew, S. H., and J. S. Sagi (2008): "Small Worlds: Modeling Preference over Sources of Uncertainty," *Journal of Economic Theory* 139: 1-24.

[13] Curley, S. P., and J. F. Yates (1985): "The Center and Range of the Probability Interval as Factors Affecting Ambiguity Preferences," *Organizational Behavior and Human Decision Processes* 36: 273-287.

[14] Cuzick, J. (1985): "A Wilcoxon-type test for trend," *Statistics in Medicine* 4(4): 543-547.

[15] Dekel, E. (1986): "An Axiomatic Characterization of Preferences under Uncertainty: Weakening the Independence Axiom," *Journal of Economic Theory* 40: 304-318.

[16] Ellsberg, D. (1961): "Risk, Ambiguity, and the Savage Axioms," *Quarterly Journal of Economics* 75: 643-669.

[17] Epstein, L. G. (2010): "A Paradox for the 'Smooth Ambiguity' model of Preference," *Econometrica* 78: 2085-2099.

[18] Epstein, L. G., and Y. Halevy (2014): "No Two Experiments Are Identical," *working paper*.

[19] Ergin, H., and F. Gul (2009): "A Theory of Subjective Compound Lotteries," *Journal of Economic Theory* 144: 899-929.

[20] Fox, C. R., and A. Tversky (1995): "Ambiguity Aversion and Comparative Ignorance," *The Quarterly Journal of Economics* 110: 585-603.

[21] Fox, C. R., and A. Tversky (1998): "A Belief-Based Account of Decision under Uncertainty," *Management Science* 44: 879-895.

[22] Freeman, D., Y. Halevy, and T. Kneeland (2014): "List Elicitation of Risk Preferences," *working paper*.

[23] Gajdos, T., T. Hayashi., J. M. Tallon., and J. C. Vergnaud (2008): "Attitude toward Imprecise Information," *Journal of Economic Theory* 140: 23–56.

[24] Ghirardato, P., F. Maccheroni, and M. Marinacci (2004): "Differentiating Ambiguity and Ambiguity Attitude," *Journal of Economic Theory* 118: 133–173.

[25] Gilboa, I. (1987): "Expected Utility with Purely Subjective Nonadditive Probabilities," *Journal of Mathematical Economics* 16: 65-88.

[26] Gilboa, I., and D. Schmeidler (1989): "Maxmin expected Utility with Non-unique Prior," *Journal of Mathematical Economics* 18: 141-153.

[27] Gul, F. (1991): "A Theory of Disappointment Aversion," *Econometrica* 59: 667–686.

[28] Halevy, Y. (2007): "Ellsberg Revisited: An Experimental Study," *Econometrica* 75: 503-536.

[29] Hayashi, T., and R. Wada (2011): "Choice with Imprecise Information: an Experimental Approach," *Theory and Decision* 69: 355-373

[30] Heath, C., and A. Tversky (1991): "Preference and Belief: Ambiguity and Competence in Choice under Uncertainty," *Journal of Risk and Uncertainty* 4: 5-28.

[31] Holt, C. A. (1986): "Preference Reversals and the Independence Axiom," *American Economic Review* 76: 508-515.

[32] Holt, C. A., and S. K. Laury (2002): "Risk Aversion and Incentive Effects," *American Economic Review* 92: 1644-1655.

[33] Humphrey, S. J. (1998): "More Mixed Results on Boundary Effects," *Economic Letters* 61: 79-84.

[34] Kahn, B. E., and R. K. Sarin (1988): "Modeling Ambiguity in Decisions Under Uncertainty," *Journal of Consumer Research* 15: 265-272.

[35] Karni, E., and Z. Safra (1987): "'Preference Reversal' and the Observability of Preferences by Experimental Methods," *Econometrica* 55, 675-685.

[36] Keynes, J. M. (1921): *A treatise on probability*. London: MacMillan.

[37] Klibanoff, P., M. Marinacci, and S. Mukerji (2005): "A Smooth Model of Decision Making under Ambiguity," *Econometrica* 73: 1849-1892.

[38] Klibanoff, P., M. Marinacci, and S. Mukerji (2012): "On the Smooth Ambiguity Model: A reply," *Econometrica* 80: 1303-1321.

[39] Knight, F. (1921): textitRisk, Uncertainty and Profit. Houghton Mifflin, Boston, New York.

[40] Kovarik, J., D. Levin, and T. Wang (2013): "Ellsberg Revisited; Can Complexity Aversion Explain the Paradox? An Experimental Investigation," *working paper*.

[41] Maccheroni, F., M. Marinacci, and A. Rustichini (2006): "Ambiguity Aversion, Robustness, and the Variational Representation of Preferences," *Econometrica* 74: 1447-1498.

[42] Machina, M. J. (2009): "Risk, Ambiguity, and the Rank-Dependence Axioms," *American Economic Review* 99: 385-92.

[43] Miller, L., D. E. Meyer, and J. T. Lanzetta (1969): "Choice among Equal Expected Value Alternatives: Sequential Effects of Winning Probability Level on Risk Preferences," *Journal of Experimental Psychology* 79: 419–423.

[44] Miao, B., and S. Zhong (2012): "An Experimental Study of Attitude towards Two-stage Lottery," *working paper*.

[45] Nau, R. F. (2006): "Uncertainty Aversion with Second-Order Utilities and Probabilities," *Management Science* 52: 136-145.

[46] Neilson, S. W. (1998): "Some Mixed Results on Boundary Effects," *Economic Letters* 39: 275-278.

[47] Quiggin, J. (1982): "A Theory of Anticipated Utility," *Journal of Economic Behavior and Organization* 3: 323-343.

[48] Schmeidler, D. (1989): "Subjective Probability and Expected Utility without Additivity," *Econometrica* 57: 571–587.

[49] Segal, U. (1987): "The Ellsberg Paradox and Risk Aversion: An Anticipated Utility Approach," *International Economic Review* 28: 175-202.

[50] —— (1988): "Does the preference reversal phenomenon necessarily contradict the independence axiom?" *The American Economic Review*, 78: 233-236.

[51] —— (1990): "Two-Stage Lotteries without the Reduction Axiom," *Econometrica* 58: 349-377.

[52] Seo, K. (2009): "Ambiguity and Second-Order Belief," *Econometrica* 77: 1575-1605.

[53] Starmer, C., and R. Sugden (1991): "Does the Random-Lottery Incentive System Elicit True Preferences? An Experimental Investigation," *American Economic Review* 81: 971-978.

[54] Siniscalchi, M. (2009): "Vector Expected Utility and Attitudes toward Variation," *Econometrica* 77: 801-855.

[55] Tversky, A., and D. Kahneman (1992): "Advances in Prospect Theory: Cumulative Representation of Uncertainty," *Journal of Risk and Uncertainty* 5: 297-323.

[56] Viscusi, W. K. (1997): "Alarmist Decisions with Divergent Risk Information," *The Economic Journal* 107: 1657-1670.

[57] Wald, A. (1950): *Statistical Decision Functions*. New York 660.

[58] Yang, C. L., and L. Yao (2011): "Testing Ambiguity Theories: Revisiting Ellsberg's Paradox in a New Experimental Design," *working paper*.

Appendix A: Axioms of Compound Risk and their Implications

Let $X_j = (p_j, x_j)_j$ denote a simple lottery paying x_j with probability p_j, and $\mathbf{X} = \left(q^k, X^k\right)_k$ a compound lottery paying simple lottery $X^k = \left(p_j^k, x_j^k\right)_j$ with probability q^k. In addition, denote a degenerate lottery paying x for sure by δ_x. Similarly, a degenerate compound lottery paying simple lottery X_j for sure is denoted by δ_{X_j} and $\left(q^j, \delta_{x_j}\right)_j$ is another kind of degenerate compound lottery which pays degenerate simple lottery δ_{x_j} with probability q^j. We define two operations $+$ and $\oplus$ to combine risks at two different stages. We use $+$ to denote a mixture operation for simple risks and $\oplus$ to denote mixture operation for stage-1 risks.

Given two simple lotteries $X_m = (p_1, x_1; p_2, x_2; ...; p_m, x_m)$ and $Y_n = (q_1, y_1; q_2, y_2; ...; q_n, y_n)$, a mixture with probability r, $rX_m + (1-r)Y_n$, is identified with a simple lottery given by:

$$(rp_1, x_1; ...; rp_m, x_m; (1-r)q_1, y_1; ...; (1-r)q_n, y_n).$$

In other words, $+$ can be used as a mixture operation for stage-2 risks as follow:

$$\delta_{rX_m+(1-r)Y_n} = \delta_{(rp_1,x_1;...;rp_m,x_m;(1-r)q_1,y_1;...;(1-r)q_n,y_n)}.$$

Given two compound lotteries $\mathbf{X} = (p^1, X^1; p^2, X^2; ...; p^m, X^m)$ and $\mathbf{Y} = (q^1, Y^1; q^2, Y^2; ...; q^n, Y^n)$, a stage-1 mixture with probability r, $r\mathbf{X} \oplus (1-r)\mathbf{Y}$, is identified with the compound lottery

$$\left(rp^1, X^1; ...; rp^m, X^m; (1-r)q^1, Y^1; ...; (1-r)q^1, Y^n\right).$$

To illustrate the difference between $+$ and $\oplus$, consider two compound lotteries, $\left(1, \left(\frac{1}{2}, x; \frac{1}{2}, 0\right)\right)$ and $\left(1, \left(\frac{1}{3}, y; \frac{2}{3}, 0\right)\right)$. A mixture operation $+$ with probability $\frac{1}{2}$ delivers the following:

$$\left(1, \frac{1}{2}\left(\frac{1}{2}, x; \frac{1}{2}, 0\right) + \frac{1}{2}\left(\frac{1}{3}, y; \frac{2}{3}, 0\right)\right) = \left(1, \left(\frac{1}{4}, x; \frac{1}{6}, y; \frac{7}{12}, 0\right)\right),$$

while a mixture operation $\oplus$ with probability $\frac{1}{2}$ delivers the following:

$$\frac{1}{2}\left(1, \left(\frac{1}{2}, x; \frac{1}{2}, 0\right)\right) \oplus \frac{1}{2}\left(1, \left(\frac{1}{3}, y; \frac{2}{3}, 0\right)\right) = \left(\frac{1}{2}, \left(\frac{1}{2}, x; \frac{1}{2}, 0\right); \frac{1}{2}, \left(\frac{1}{3}, y; \frac{2}{3}, 0\right)\right).$$

We now introduce several commonly used axioms in the literature on decision making involving compound risk and discuss their implications for choice behavior in our setup. We begin with the following axiom which has largely been implicit in the literature on generalizing expected utility under different weakening of its independence axiom.

Reduction of Compound Lottery Axiom (RCLA): $\left(q^k, X^k\right)_k \sim q^1X^1 + q^2X^2 + ... + q^kX^k$.

RCLA requires a compound lottery $\left(q^k, X^k\right)_k$ to be indifferent to a simple lottery $q^1X^1 + q^2X^2 + ... + q^kX^k$ whose outcomes are taken from the component lotteries X^k with the corresponding probabilities derived from the given compound lottery. This property is inherent to any utility model whose domain of choice comprises a set of probability measures with a convex combination of two lotteries interpreted as a compound lottery. In relaxing RCLA, people may exhibit distinct attitudes towards risks at different stages in a compound lottery. To accommodate this, we may limit the scope of a preference axiom to simple lotteries in a single-stage setting. Clearly, applying + on within-stage risks does not imply that RCLA holds.

Here, we adapt the independence axiom and the betweenness axiom to the domain of simple lotteries for both stage-1 and stage-2 risks.

Stage-1 Independence: $(q^m, X^m)_m \succeq (q^n, X^n)_n$ *implies that* $\alpha (q^m, X^m)_m \oplus (1-\alpha) \left(q^l, X^l\right)_l \succeq \alpha (q^n, X^n)_n \oplus (1-\alpha) \left(q^l, X^l\right)_l$.

Stage-2 Independence: $X_m \succeq X_n$ *implies that* $\alpha X_m + (1-\alpha) X_l \succeq \alpha X_n + (1-\alpha) X_l$.

Independence requires that the preference between two lotteries to be preserved when each is mixed with a common third lottery at the same probability.

Stage-1 Betweenness: $(q^m, X^m)_m \succeq \alpha (q^m, X^m)_m \oplus (1-\alpha) (q^n, X^n)_n \succeq (q^n, X^n)_n$ *if* $(q^m, X^m)_m \succeq (q^n, X^n)_n$.

Stage-2 Betweenness: $X_m \succeq \alpha X_m + (1-\alpha) X_n \succeq X_n$ *if* $X_m \succeq X_n$.

Betweenness requires a mixture between two lotteries to be intermediate in preference between the preference for two respective lotteries.

The following axiom provides a link between stage-1 and stage-2 risk preference.

Time Neutrality: Given $X_j = (p_j, x_j)_j$, $\delta_{X_j} \sim \left(p^j, \delta_{x_j}\right)_j$.

This axiom requires a decision maker to be indifferent between two degenerate compound lotteries if they reduce to the same simple lottery. Put differently, whether the resolution of risks occurs at stage-1 or stage-2 does not influence the preference for degenerate compound lotteries.

It is straightforward to see that RCLA implies time neutrality and that independence implies betweenness (see Segal, 1990, for a detailed discussion). For completeness in exposition, we present the following axiom which together with RCLA implies independence.

Compound Independence Axiom: $X^k \succeq X^{k'}$ *iff* $\left(q^1, X^1; q^2, X^2; ...; q^k, X^{k'}; ...; q^n, X^n\right) \succeq \left(q^1, X^1; q^2, X^2; ...; q^k, X^{k'}; ...; q^n, X^n\right)$.

Compound independence requires a compound lottery $\left(q^k, X^k\right)_k$ to becomes less preferred if any of the component simple lotteries is replaced with a less preferred simple lottery.

We summarize below the implications of RCLA, stage-1 betweenness and time neutrality for choice behavior in experiments 2 and 3.

Implication R: RCLA implies that all compound lotteries are indifferent to $\{50\}$.

This follows from observing that the compound lotteries in our setup reduce to $\{50\}$.

Implication B: Stage-1 Betweenness implies that $[0, 100]^C$ is ranked between $[n, 100-n]^C$ and $[0, n] \cup [100-n, 100]^C$.

This follows from observing that $[0,100]^C \approx \frac{2n}{100}[n,100-n]^C \oplus \frac{100-2n}{100}[0,n] \cup [100-n,100]^C$ in our setup.

Implication T: Time Neutrality implies that $\{50\} \sim \{0,100\}^C$.

This follows from observing that $\{50\}$ and $\{0,100\}^C$ differ only in the stage of resolution of uncertainty.

Appendix B: Proofs of Implications 1 and 2 under RRDU and Stage-1 Spread

Implication 1 on Interval Compound Risk

For the interval group, the utility for a lottery $[50-n, 50+n]$ is given by:

$$U([50-n,50+n]) = \sum_{i=50-n}^{50+n} f\left(1-\frac{i}{100}\right)\left[f\left(\frac{i+1-(50-n)}{2n+1}\right) - f\left(\frac{i-(50-n)}{2n+1}\right)\right].$$

This can be approximated using a uniform random variable over $[0,1]$ with cumulative distribution function F as follows:

$$U([50-n,50+n]) = \int_{0.5-\widehat{n}}^{0.5+\widehat{n}} f(s)\, d\left(-f\left(1-F(s)\right)\right),$$

where $\widehat{n}$ takes the values between 0 and 0.5, and $F = \frac{s+\widehat{n}-0.5}{2\widehat{n}}$ for $s \in [0.5-\widehat{n}, 0.5+\widehat{n}]$. Let $x = \frac{s+\widehat{n}-0.5}{2\widehat{n}}$. We have:

$$U = \int_0^1 -f\left(2\widehat{n}x + 0.5 - \widehat{n}\right) df\left(1-x\right).$$

Differentiating w.r.t $\widehat{n}$ yields:

$$U' = \int_0^1 \left(2x-1\right) f'\left(\left(1-2\widehat{n}\right)x + \widehat{n}\right) f'\left(1-x\right) dx.$$

Evaluating U' at $\widehat{n} = 0$ gives:

$$U'|_{\widehat{n}=0} = \int_0^1 \left(2x-1\right) f'\left(x\right) f'\left(1-x\right) dx.$$

which can be into

$$\text{(B.1)} \qquad -\int_0^{0.5} \left(1-2x\right) f'\left(x\right) f'\left(1-x\right) dx + \int_{0.5}^1 \left(2x-1\right) f'\left(x\right) f'\left(1-x\right) dx,$$

which equals 0 given the symmetry of the two terms after changing the variable in the second term to $1-x$. Observe that $f\left(2\widehat{n}x + 0.5 - \widehat{n}\right) > f\left(x\right)$ when $x < 0.5$ since $2\widehat{n}x + 0.5 - \widehat{n} > x$. Similarly, we have $f\left(2\widehat{n}x + 0.5 - \widehat{n}\right) < f\left(x\right)$ when $x > 0.5$. It follows that when f is convex, $U' < 0$, i.e., aversion to increasing size of ambiguity for the interval group, since changing $f'\left(x\right)$ to $f'\left(2\widehat{n}x + 0.5 - \widehat{n}\right)$ will increase the first term of (B.1) and decrease its second term.■

Implication 2 on Disjoint Compound Risk

The utility $U([0,n] \cup [100-n, 100])$ for disjoint ambiguity $[0,n] \cup [100-n, 100]$ is given by:

$$\sum_{i=0}^{n} f\left(1-\tfrac{i}{100}\right)\left[f\left(\tfrac{i+1}{2(n+1)}\right) - f\left(\tfrac{i}{2(n+1)}\right)\right] + \sum_{i=n+1}^{2n+1} f\left(\tfrac{2n+1-i}{100}\right)\left[f\left(\tfrac{i+1}{2(n+1)}\right) - f\left(\tfrac{i}{2(n+1)}\right)\right].$$

This can be approximated using a uniform random variable over $[0,1]$ with cumulative distribution function F as follows:

$$U=\int_0^{\widehat{n}} f(s)\, d(-f(1-F(s)))+\int_{1-\widehat{n}}^1 f(s)\, d(-f(1-F(s))),$$

where $\widehat{n}$ takes the values from 0.5 to 0 in the disjoint group, and $F(s)=\frac{s}{2\widehat{n}}$ for $s\in[0,\widehat{n}]$ and $F(s)=\frac{s-(1-2\widehat{n})}{2\widehat{n}}$ for $s\in[1-\widehat{n},1]$. Let x equal $\frac{s}{2\widehat{n}}$ in the first integral and equal $\frac{s-(1-2\widehat{n})}{2\widehat{n}}$ in the second integral. We have:

$$U=\int_0^{0.5} -f(2\widehat{n}x)\, df(1-x)-\int_{0.5}^1 f(2\widehat{n}x+(1-2\widehat{n}))\, df(1-x).$$

Differentiating w.r.t $\widehat{n}$ yields:

$$U'=\int_0^{0.5} 2xf'(2\widehat{n}x)\, f'(1-x)\, dx+\int_{0.5}^1 (2x-2)\, f'(2\widehat{n}x+(1-2\widehat{n}))\, f'(1-x)\, dx.$$

Evaluating U' at $\widehat{n}=0.5$ gives:

$$U'|_{\widehat{n}=0}=\int_0^{0.5} 2xf'(x)\, f'(1-x)\, dx+\int_{0.5}^1 (2x-2)\, f'(x)\, f'(1-x)\, dx, \tag{B.2}$$

which again equals 0 given the symmetry of the two terms. Observe that $f(2\widehat{n}x)<f(x)$ when $x<0.5$ and $f(2\widehat{n}x+(1-2\widehat{n}))>f(x)$ when $x>0.5$. It follows that when f is convex, $U'<0$, i.e., aversion to increasing size of ambiguity for the disjoint group, since changing $f'(x)$ to $f'(2\widehat{n}x)$ will decrease the first term of (B.2) while changing $f'(x)$ to $f'(2\widehat{n}x+(1-2\widehat{n}))$ will increase its second term of (B.2).■

Stage-1 Spread

Given two ambiguous lotteries represented by stage-1 priors with cumulative distribution functions F and G such that G is a stage-1 spread of F, consider the difference:

$$\int f(x)\, d(-f(1-F(x)))-\int f(x)\, d(-f(1-G(x))).$$

This becomes $\int f'(x)[f(1-F(x))-f(1-G(x))]\, dx$ after integrating by parts. We have that $f(1-F(x))-f(1-G(x))\geq 0$ for $x<0.5$ and $f(1-F(x))-f(1-G(x))\leq 0$ for $x>0.5$, since $F(x)\leq G(x)$ for $x<0.5$ and $F(x)\geq G(x)$ for $x>0.5$. Changing variable yields:

$$\int_0^{0.5} f'(x)[f(1-F(x))-f(1-G(x))]\, dx-\int_0^{0.5} f'(1-x)[f(1-G(1-x))-f(1-F(1-x))]\, dx.$$

We proceed to compare $\frac{f'(x)}{f'(1-x)}$ and $\frac{f(1-G(1-x))-f(1-F(1-x))}{f(1-F(x))-f(1-G(x))}$. Since f is convex, we have

$$f'(1-F(1-x))\leq\frac{f(1-G(1-x))-f(1-F(1-x))}{F(1-x)-G(1-x)}\leq f'(1-G(1-x)),$$

and

$$f'\left(1-F\left(x\right)\right)\geq\frac{f\left(1-F\left(x\right)\right)-f\left(1-G\left(x\right)\right)}{G\left(x\right)-F\left(x\right)}\geq f'\left(1-G\left(x\right)\right).$$

Given symmetry of F and G, $F\left(1-x\right)-G\left(1-x\right)=G\left(x\right)-F\left(x\right)$. Dividing the above two inequalities yields

$$\frac{f'\left(1-F\left(1-x\right)\right)}{f'\left(1-F\left(x\right)\right)}\leq\frac{f\left(1-G\left(1-x\right)\right)-f\left(1-F\left(1-x\right)\right)}{f\left(1-F\left(x\right)\right)-f\left(1-G\left(x\right)\right)}\leq\frac{f'\left(1-G\left(1-x\right)\right)}{f'\left(1-G\left(x\right)\right)}.$$

Suppose F is a stage-1 spread of uniform prior, then $\frac{f'(1-F(1-x))}{f'(1-F(x))}\geq\frac{f'(x)}{f'(1-x)}$ for $x\leq 0.5$. Thus, the decision maker prefers G to F if both of them are spreads of uniform prior. Conversely, suppose uniform prior is a stage-1 spread of G, then $\frac{f'(1-G(1-x))}{f'(1-G(x))}\leq\frac{f'(x)}{f'(1-x)}$ at $x\leq 0.5$ and we have the decision maker preferring F to G if uniform prior is a stage-1 spread of both F and G.■

Appendix C: Supplementary Tables

TABLE C1. Summary statistics of switch points for Experiment 1.

Two-Point			Interval			Disjoint		
Lottery	Mean	S.E	Lottery	Mean	S.E	Lottery	Mean	S.E
$\mathbf{B}_0$	5.06	0.29	$\mathbf{B}_0$	5.06	0.29	$\mathbf{B}_1^A$	4.69	0.33
$\mathbf{P}_{10}^A$	4.39	0.27	$\mathbf{S}_{10}^A$	4.46	0.28	$\mathbf{D}_{10}^A$	3.85	0.28
$\mathbf{P}_{20}^A$	3.9	0.26	$\mathbf{S}_{20}^A$	3.65	0.24	$\mathbf{D}_{20}^A$	3.68	0.25
$\mathbf{P}_{30}^A$	3.76	0.26	$\mathbf{S}_{30}^A$	3.5	0.24	$\mathbf{D}_{30}^A$	3.3	0.24
$\mathbf{P}_{40}^A$	3.77	0.28	$\mathbf{S}_{40}^A$	3.65	0.27	$\mathbf{D}_{40}^A$	3.47	0.26
$\mathbf{B}_1^A$	4.69	0.33	$\mathbf{B}_2$	3.29	0.27	$\mathbf{B}_2^A$	3.29	0.37

Note. This table presents the mean and standard errors for the two point group (column 1 to 3), interval group (column 4 to 6), and disjoint group (column 7 to 9).

TABLE C2. Spearman correlation of CEs for lotteries in Experiment 1.

	$\mathbf{B}_0$	$\mathbf{P}_{10}^A$	$\mathbf{P}_{20}^A$	$\mathbf{P}_{30}^A$	$\mathbf{P}_{40}^A$	$\mathbf{B}_1^A$	$\mathbf{S}_{10}^A$	$\mathbf{S}_{20}^A$	$\mathbf{S}_{30}^A$	$\mathbf{S}_{40}^A$	$\mathbf{B}_2^A$	$\mathbf{D}_{10}^A$	$\mathbf{D}_{20}^A$	$\mathbf{D}_{30}^A$	$\mathbf{D}_{40}^A$
$\mathbf{B}_0$	1.000														
$\mathbf{P}_{10}^A$	0.748	1.000													
$\mathbf{P}_{20}^A$	0.736	0.892	1.000												
$\mathbf{P}_{30}^A$	0.658	0.776	0.827	1.000											
$\mathbf{P}_{40}^A$	0.621	0.708	0.753	0.841	1.000										
$\mathbf{B}_1^A$	0.692	0.759	0.767	0.668	0.732	1.000									
$\mathbf{S}_{10}^A$	0.763	0.827	0.817	0.776	0.732	0.699	1								
$\mathbf{S}_{20}^A$	0.666	0.829	0.839	0.768	0.687	0.611	0.829	1.000							
$\mathbf{S}_{30}^A$	0.614	0.831	0.835	0.760	0.697	0.567	0.781	0.899	1.000						
$\mathbf{S}_{40}^A$	0.640	0.712	0.705	0.780	0.726	0.520	0.737	0.799	0.788	1.000					
$\mathbf{B}_2^A$	0.557	0.735	0.723	0.671	0.675	0.515	0.651	0.792	0.872	0.777	1.000				
$\mathbf{D}_{10}^A$	0.608	0.752	0.773	0.776	0.685	0.584	0.748	0.842	0.804	0.741	0.782	1.000			
$\mathbf{D}_{20}^A$	0.670	0.797	0.837	0.802	0.719	0.655	0.783	0.836	0.815	0.754	0.727	0.856	1.000		
$\mathbf{D}_{30}^A$	0.632	0.785	0.811	0.812	0.753	0.698	0.774	0.851	0.804	0.783	0.754	0.863	0.886	1.000	
$\mathbf{D}_{40}^A$	0.685	0.714	0.785	0.844	0.826	0.619	0.800	0.771	0.719	0.768	0.659	0.769	0.768	0.803	1.000

TABLE C3. Spearman correlation of risk attitude and ambiguity attitude in Experiment 1.

Ambiguity	$\mathbf{P}_{10}^A$	$\mathbf{P}_{20}^A$	$\mathbf{P}_{30}^A$	$\mathbf{P}_{40}^A$	$\mathbf{B}_1^A$	$\mathbf{S}_{10}^A$	$\mathbf{S}_{20}^A$	$\mathbf{S}_{30}^A$	$\mathbf{S}_{40}^A$	$\mathbf{B}_2^A$	$\mathbf{D}_{10}^A$	$\mathbf{D}_{20}^A$	$\mathbf{D}_{30}^A$	$\mathbf{D}_{40}^A$
Risk	0.44	0.467	0.467	0.45	0.157	0.377	0.607	0.592	0.489	0.505	0.53	0.584	0.553	0.394

TABLE C4. Spearman correlation of ambiguity attitudes in Experiment 1.

	$\mathbf{P}_{10}^A$	$\mathbf{P}_{20}^A$	$\mathbf{P}_{30}^A$	$\mathbf{P}_{40}^A$	$\mathbf{B}_1^A$	$\mathbf{S}_{10}^A$	$\mathbf{S}_{20}^A$	$\mathbf{S}_{30}^A$	$\mathbf{S}_{40}^A$	$\mathbf{B}_2^A$	$\mathbf{D}_{10}^A$	$\mathbf{D}_{20}^A$	$\mathbf{D}_{30}^A$	$\mathbf{D}_{40}^A$
$\mathbf{P}_{10}^A$	1.000													
$\mathbf{P}_{20}^A$	0.759	1.000												
$\mathbf{P}_{30}^A$	0.716	0.835	1.000											
$\mathbf{P}_{40}^A$	0.675	0.706	0.772	1.000										
$\mathbf{B}_1^A$	0.406	0.365	0.444	0.498	1.000									
$\mathbf{S}_{10}^A$	0.680	0.700	0.635	0.600	0.398	1.000								
$\mathbf{S}_{20}^A$	0.621	0.680	0.656	0.670	0.269	0.675	1.000							
$\mathbf{S}_{30}^A$	0.694	0.722	0.674	0.719	0.229	0.643	0.852	1.000						
$\mathbf{S}_{40}^A$	0.600	0.661	0.638	0.623	0.249	0.572	0.788	0.811	1.000					
$\mathbf{B}_2^A$	0.586	0.639	0.641	0.666	0.217	0.528	0.737	0.806	0.752	1.000				
$\mathbf{D}_{10}^A$	0.550	0.659	0.698	0.620	0.268	0.659	0.755	0.779	0.696	0.766	1.000			
$\mathbf{D}_{20}^A$	0.650	0.771	0.751	0.701	0.339	0.678	0.807	0.826	0.746	0.711	0.801	1.000		
$\mathbf{D}_{30}^A$	0.674	0.739	0.761	0.681	0.389	0.703	0.813	0.819	0.778	0.747	0.816	0.856	1.000	
$\mathbf{D}_{40}^A$	0.625	0.791	0.757	0.733	0.322	0.598	0.651	0.689	0.634	0.639	0.683	0.646	0.698	1.000

TABLE C5. Summary statistics of switch points for Experiment 2.

Two-point			Interval			Disjoint		
Lottery	Mean	S.E	Lottery	Mean	S.E	Lottery	Mean	S.E
$\mathbf{B}_0$	6.95	0.7	$\mathbf{B}_0$	6.95	0.7	$\mathbf{B}_1^C$	6.01	0.61
$\mathbf{P}_{10}^C$	6.58	0.66	$\mathbf{S}_{10}^C$	6.36	0.64	$\mathbf{D}_{10}^C$	6.02	0.61
$\mathbf{P}_{30}^C$	6.12	0.62	$\mathbf{S}_{30}^C$	5.61	0.57	$\mathbf{D}_{30}^C$	5.56	0.56
$\mathbf{B}_1^C$	6.01	0.61	$\mathbf{B}_2^C$	5.11	0.52	$\mathbf{B}_2^C$	5.11	0.52

Note. This table presents the mean and standard errors for the two point group (column 1 to 3), interval group (column 4 to 6), and disjoint group (column 7 to 9).

TABLE C6. Spearman correlation of CEs for lotteries in Experiment 2.

	$\mathbf{B}_0$	$\mathbf{P}_{10}^C$	$\mathbf{P}_{30}^C$	$\mathbf{B}_1^C$	$\mathbf{S}_{10}^C$	$\mathbf{S}_{30}^C$	$\mathbf{B}_2^C$	$\mathbf{D}_{10}^C$	$\mathbf{D}_{30}^C$
$\mathbf{B}_0$	1.000								
$\mathbf{P}_{10}^C$	0.541	1.000							
$\mathbf{P}_{30}^C$	0.438	0.450	1.000						
$\mathbf{B}_1^C$	0.333	0.372	0.613	1.000					
$\mathbf{S}_{10}^C$	0.535	0.686	0.432	0.134	1.000				
$\mathbf{S}_{30}^C$	0.191	0.564	0.597	0.356	0.534	1.000			
$\mathbf{B}_2^C$	0.173	0.440	0.338	0.127	0.482	0.752	1.000		
$\mathbf{D}_{10}^C$	0.287	0.591	0.614	0.417	0.564	0.817	0.755	1.000	
$\mathbf{D}_{30}^C$	0.211	0.432	0.646	0.555	0.359	0.533	0.333	0.653	1.000

TABLE C7. Spearman correlation of risk attitude and compound attitude in Experiment 2.

Compound	$\mathbf{P}_{10}^C$	$\mathbf{P}_{30}^C$	$\mathbf{B}_1^C$	$\mathbf{S}_{10}^C$	$\mathbf{S}_{30}^C$	$\mathbf{B}_2^C$	$\mathbf{D}_{10}^C$	$\mathbf{D}_{30}^C$
Risk	0.394	0.472	0.381	0.496	0.623	0.521	0.521	0.533

TABLE C8. Spearman correlation of compound risk attitudes in Experiment 2.

	$\mathbf{P}_{10}^{C}$	$\mathbf{P}_{30}^{C}$	$\mathbf{B}_{1}^{C}$	$\mathbf{S}_{10}^{C}$	$\mathbf{S}_{30}^{C}$	$\mathbf{B}_{2}^{C}$	$\mathbf{D}_{10}^{C}$	$\mathbf{D}_{30}^{C}$
$\mathbf{P}_{10}^{C}$	1.000							
$\mathbf{P}_{30}^{C}$	0.382	1.000						
$\mathbf{B}_{1}^{C}$	0.348	0.620	1.000					
$\mathbf{S}_{10}^{C}$	0.624	0.402	0.155	1.000				
$\mathbf{S}_{30}^{C}$	0.560	0.696	0.447	0.622	1.000			
$\mathbf{B}_{2}^{C}$	0.525	0.507	0.253	0.659	0.828	1.000		
$\mathbf{D}_{10}^{C}$	0.565	0.702	0.511	0.563	0.805	0.797	1.000	
$\mathbf{D}_{30}^{C}$	0.564	0.729	0.655	0.542	0.683	0.550	0.797	1.000

TABLE C9. Individual comparison in two-point groups across experiments.

Experiment	>	=	<	>	=	<
	{50} vs {0, 100}			{20, 80} vs {0, 100}		
1 Ambiguity	33 (31.1%)	49 (46.2%)	24 (22.6%)	18 (17.0%)	40 (37.7%)	48 (45.3%)
2 Compound Risk	43 (43.9%)	34 (34.7%)	21 (21.4%)	29 (29.6%)	39 (39.8%)	30 (30.6%)
	{50} vs {0, 100}			{25, 75} vs {0, 100}		
3 Ambiguity	74 (39.4%)	80 (42.6%)	34 (18.1%)	42 (22.3%)	84 (44.7%)	62 (33.0%)
3 Compound Risk	79 (42.0%)	72 (38.3%)	37 (19.7%)	64 (34.0%)	64 (34.0%)	60 (31.9%)

Note. The table displays the counts and proportions (in the parentheses) of subjects when comparing the CEs in terms of more than, equal, and less than of different pairs of lotteries: $\{50\}$ and $\{0, 100\}$ in the three experiments, $\{20, 80\}$ and $\{0, 100\}$ in experiments 1 and 2, and $\{25, 75\}$ and $\{0, 100\}$ in Experiment 3.

TABLE C10. Individual types with two-stage perspective.

Panel A: A < C

Ambiguity \ Compound Risk	REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
REU(concave)	6 (2.8)	2 (3.1)	3 (5.3)	1 (0.7)	2 (2.1)	14
REU(convex)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
RRDU(convex)	0 (3.2)	3 (3.6)	10 (6.0)	0 (0.8)	3 (2.4)	16
RRDU(concave)	0 (0.4)	1 (0.5)	0 (0.8)	1 (0.1)	0 (0.3)	2
Unclassified	2 (1.6)	3 (1.8)	2 (3.0)	0 (0.4)	1 (1.2)	8
Total	8	9	15	2	6	40

Panel B: A = C

Ambiguity \ Compound Risk	REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
REU(concave)	9 (5.2)	0 (0.8)	0 (2.0)	0 (0.8)	1 (1.2)	10
REU(convex)	0 (1.0)	2 (0.2)	0 (0.4)	0 (0.2)	0 (0.2)	2
RRDU(convex)	3 (4.2)	0 (0.6)	5 (1.6)	0 (0.6)	0 (1.0)	8
RRDU(concave)	0 (1.0)	0 (0.2)	0 (0.4)	2 (0.2)	0 (0.2)	2
Unclassified	1 (1.6)	0 (0.2)	0 (0.6)	0 (0.2)	2 (0.4)	3
Total	13	2	5	2	3	25

Panel C: A > C

Ambiguity \ Compound Risk	REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
REU(concave)	4 (1.6)	0 (0.4)	0 (1.8)	0 (0)	1 (1.3)	5
REU(convex)	0 (1.9)	2 (0.4)	1 (2.1)	0 (0)	3 (1.5)	6
RRDU(convex)	3 (2.9)	0 (0.6)	3 (3.2)	0 (0)	3 (2.3)	9
RRDU(concave)	0 (0.3)	0 (0.1)	1 (0.4)	0 (0)	0 (0.3)	1
Unclassified	2 (2.3)	0 (0.5)	5 (2.5)	0 (0)	0 (1.8)	7
Total	9	2	10	0	7	28

Panel D: Unclassified

Ambiguity \ Compound Risk	REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
REU(concave)	1 (1.6)	0 (0.4)	4 (3.1)	2 (1.0)	0 (0.8)	7
REU(convex)	0 (0.9)	1 (0.2)	1 (1.8)	1 (0.6)	1 (0.5)	4
RRDU(convex)	6 (4.5)	1 (1.1)	9 (8.4)	1 (2.8)	2 (2.2)	19
RRDU(concave)	0 (0.2)	0 (0.1)	0 (0.4)	0 (0.1)	1 (0.1)	1
Unclassified	1 (0.7)	0 (0.2)	1 (1.3)	1 (0.4)	0 (0.4)	3
Total	8	2	15	5	4	34

Note. The two-way table displays the counts for 127 subjects violating RCLA. The subjects are classifies as REU or RRDU with concave (convex) stage-1 relative curvature (probability weighting) functions separately for ambiguity and compound risk. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. Panel A for subjects weakly preferring compound risk, Panel B for subjects indifferent between compound risk and ambiguity, Panel C for subjects weakly preferring ambiguity, and Panel D for subjects exhibiting inconsistent preference when comparing between compound risk and ambiguity. The Pearson's chi-squared test is significant at $p = 0.020$ for Panel A, $p < 0.001$ for Panel B, $p = 0.027$ for Panel C, and not significant at $p = 0.323$ for Panel D.

Appendix D: Testing Order Effects in Experiment 3

In this appendix, we assess the extent to which our results may be robust to possible order effects arising from our two treatments - ambiguity-first treatment and compound-first treatment. The plots of the aggregate data for these two treatments displayed in Figure D1 reveals that the observed choice patterns for the three groups - interval, disjoint, and two-point, - are similar across the two order treatments.

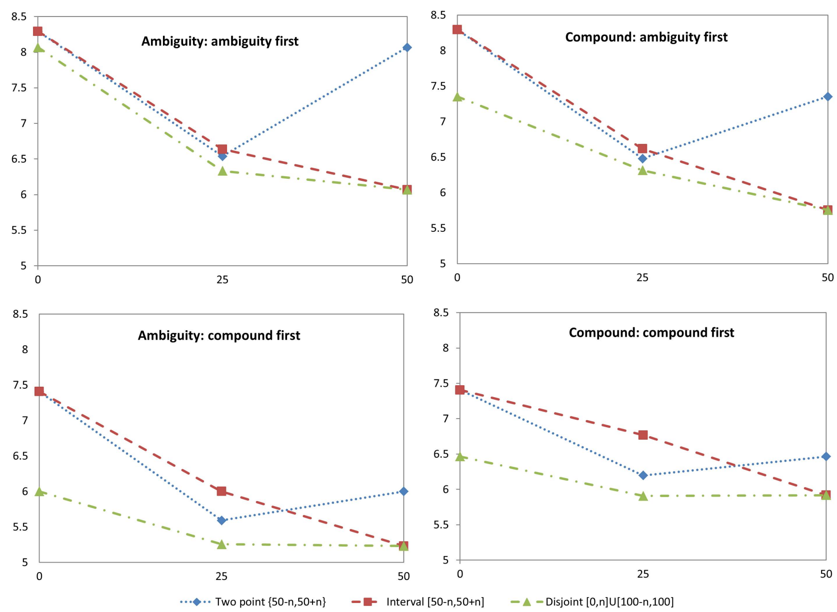


Figure D1. Aggregate choice patterns for the two treatments.

We reject the null hypothesis of independence in both order treatments ($p < 0.001$ for each treatment) and report separate association results in TABLE D1 where we find that the correlation between ambiguity premium and compound premium is 0.81 under ambiguity-first and 0.80 under compound-first. With choice error 1, the number of non-RCLA subjects is 72 (70.5%) for ambiguity first treatment and 55 (64.0%) for compound first treatment, which are not significantly different (proportion test, $p > 0.333$).

Comparing between the ambiguous and compound for the two-point lotteries $\{0, 100\}$ and $\{25, 75\}$ in TABLE D2 under ambiguity-first (compound-first), we find that 19 (12) subjects have similar CEs, 27 (16) subjects weakly prefer ambiguous two-point lotteries to compound two-point lotteries, and 19 (25) subjects exhibit the reverse behavior, with the rest of 7 (2) subjects not revealing a consistent preference. The overall observation that substantial proportions of subjects value these two types of lotteries differently remains robust while there appears to be a marginally significant tendency for subjects to prefer ambiguous two-point lotteries to compound two-point lotteries under ambiguity-first than under compound-first (multinomial logistic regression, $p < 0.069$). In an individual type analysis for REU and RRDU under the two order treatments (see TABLE D3), we find some order effect (proportion test, $p < 0.039$): 17 (25) are classified as REU type and 40 (25) are classified as RRDU type under ambiguity-first (compound-first). The overall behavior of the observed choice patterns across the two order treatments appears robust since it does not significantly affect their choice behavior in terms of RCLA as well as the association between ambiguity attitude and compound attitude, while it has some effect on the classification of type of subjects.

TABLE D1. Association between ambiguity attitude and RCLA.

Panel A: Ambiguity-first

		Compound Risk		
		Reduction	Non-Reduction	Total
Ambiguity	Neutral	18 (3.7)	2 (16.3)	20
	Non-Neutral	1 (15.3)	81 (66.7)	82
	Total	19	157	102

Panel B: Compound-first

		Compound Risk		
		Reduction	Non-Reduction	Total
Ambiguity	Neutral	12 (2.8)	8 (17.2)	20
	Non-Neutral	0 (9.2)	66 (56.8)	66
	Total	12	74	86

Note. RCLA holds if the CEs for all compound lotteries and {50} are the same. Ambiguity neutrality holds if the CEs for all ambiguity lotteries and {50} are the same. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. The Pearson's chi-squared test is highly significant at $p < 0.001$. Panel A for Ambiguity-first treatment, and Panel B for Compound-first treatment.

TABLE D2. Comparison between ambiguous and compound two-point lotteries.

Panel A: Ambiguity-first

		$\{0, 100\}$			
		A < C	A = C	A > C	Total
{25,75}	A < C	7 (3.8)	5 (5.8)	3 (5.4)	15
	A = C	7 (11)	19 (17.1)	18 (15.9)	44
	A > C	4 (3.3)	4 (5.1)	5 (4.7)	13
	Total	18	28	26	72

Panel B: Compound-first

		$\{0, 100\}$			
		A < C	A = C	A > C	Total
{25,75}	A < C	8 (5.6)	10 (9.2)	0 (3.2)	18
	A = C	7 (8)	12 (13.2)	7 (4.7)	26
	A > C	2 (3.4)	6 (5.6)	3 (2)	11
	Total	17	28	10	55

Note. The table presents the number of subjects in each of the categories – A < C, A = C, and A > C – indicating that the CE of a two-point ambiguity lottery may be smaller, equal, or larger than that of the corresponding two-point compound lottery. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. Panel A for Ambiguity-first treatment, and Panel B for Compound-first treatment.

TABLE D3. Individual types with two-stage perspective.

Panel A: Ambiguity-first

Ambiguity \ Compound Risk	REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
REU(concave)	7 (4.0)	1 (1.8)	5 (6.0)	1 (1.1)	2 (3.1)	16
REU(convex)	0 (1.8)	3 (0.8)	1 (2.6)	1 (0.5)	2 (1.4)	7
RRDU(convex)	8 (8.8)	3 (3.9)	17 (13.1)	1 (2.4)	6 (6.8)	35
RRDU(concave)	0 (1.0)	0 (0.4)	1 (1.5)	2 (0.3)	1 (0.8)	4
Unclassified	3 (2.5)	1 (1.1)	3 (3.8)	0 (0.7)	3 (1.9)	10
Total	18	8	27	5	14	72

Panel B: Compound-first

Ambiguity \ Compound Risk	REU(concave)	REU(convex)	RRDU(convex)	RRDU(concave)	Unclassified	Total
REU(concave)	13 (7.3)	1 (2.5)	2 (6.5)	2 (1.5)	2 (2.2)	20
REU(convex)	0 (1.8)	2 (0.6)	1 (1.6)	0 (0.4)	2 (0.5)	5
RRDU(convex)	4 (6.2)	1 (2.2)	10 (5.6)	0 (1.2)	2 (1.9)	17
RRDU(concave)	0 (0.7)	1 (0.3)	0 (0.7)	1 (0.1)	0 (0.2)	2
Unclassified	3 (4.0)	2 (1.4)	5 (3.6)	1 (0.8)	0 (1.2)	11
Total	20	7	18	4	6	55

Note. The two-way table displays the counts for 127 subjects violating RCLA. The subjects are classifies as REU or RRDU with concave (convex) stage-1 relative curvature (probability weighting) functions separately for ambiguity and compound risk. Each cell indicates the number of subjects with expected number of subjects displayed in parenthesis. Panel A for Ambiguity-first treatment, and Panel B for Compound-first treatment. The Pearson's chi-squared test is highly significant at p = 0.022 for Panel A, and p = 0.004 for Panel B.

Appendix E. Experimental Instructions

<u>GENERAL INSTRUCTIONS (Experiment 1)</u>

Welcome to our study on decision making. The descriptions of the study contained in this instrument will be implemented **fully and faithfully**.

Each participant will receive on average $20 for the study. The overall compensation includes a $5 show up fee in addition to earnings based on how you make decisions.

All information provided will be kept CONFIDENTIAL. Information in the study will be used for research purposes only. Please refrain from discussing any aspect of the specific tasks of the study with any one.

1. The set of decision making tasks and the instructions for each task are **the same** for all participants
2. **It is important to read the instructions CAREFULLY** so that you understand the tasks in making your decisions.
3. If you have questions, please raise your hand to **ask our experimenters at ANY TIME.**
4. **PLEASE DO NOT communicate** with others during the experiment.
5. Do take the time to go through the instructions carefully in making your decisions.
6. Cell phones and other electronic communication devices are **not allowed.**

DECISION MAKING STUDY PART 1

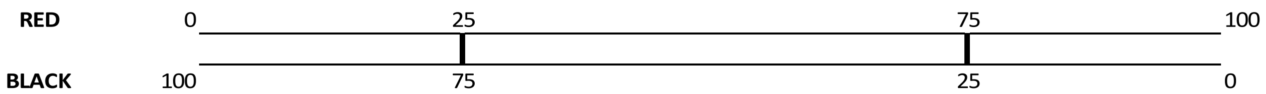
This is the first part for today's study comprising **15 decision sheets** each of which is of the form illustrated in the table below.

	Option A	Option B	Decision
1	A	B1	A □ B □
2	A	B2	A □ B □
3	A	B3	A □ B □
4	A	B4	A □ B □
5	A	B5	A □ B □
6	A	B6	A □ B □
7	A	B7	A □ B □
8	A	B8	A □ B □
9	A	B9	A □ B □
10	A	B10	A □ B □

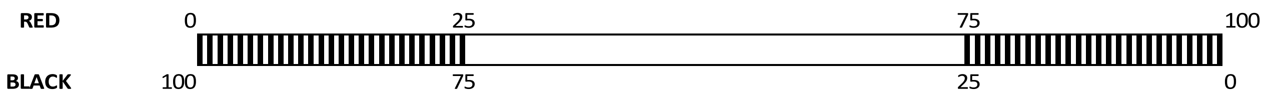
Each such table lists **10 choices** to be made between a fixed **Option A** and 10 different **Option B'**s.

Option A involves a **lottery**, guessing the color of a card randomly drawn from a deck of 100 cards with different compositions of red and black. If you guess correctly, you receive $40; otherwise you receive nothing. **Different tasks will have different compositions of red and black cards as described for each task.**

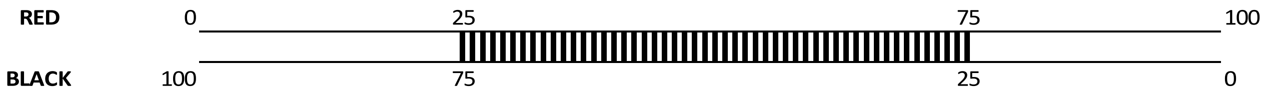
Example 1: This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The deck, illustrated below, has ***either*** *25* ***or*** *75 red cards with the rest of the cards black.*



Example 2: This situation involves your drawing a card randomly from a deck of 100 cards being made up of red and black cards. The number of red cards, illustrated below, may be anywhere between 0 and 25 or between 75 and 100 with the rest black.



Example 3: This situation involves your drawing a card randomly from a deck of 100 cards made up of red and black cards. The number of red cards, illustrated below, may be anywhere between 25 and 75 with the rest of the cards black.



The Option B's refer to receiving the specific amounts of money for sure, and are arranged in an **<u>ascending manner in the amount of money</u>.**

For each row, you are asked to **<u>indicate your choice</u>** in the final "Decision" column – A or B – with a tick **(√).**

<u>Selection of decision sheet to be implemented</u>: **One out of the 15** Decision Sheets (*selected randomly by you*) will be implemented. Should the sheet be chosen, **one of your 10 choices** will be further selected randomly and implemented.

GENERAL INSTRUCTIONS (Experiment 2)

Welcome to our study on decision making. The descriptions of the study contained in this experimental instrument will be implemented **fully and faithfully**.

Each participant will receive on average $20 for the study. The overall compensation includes a $5 show up fee in addition to earnings based on how you make decisions.

All information provided will be kept CONFIDENTIAL. Information in the study will be used for research purposes only. You are not to discuss with anyone any aspect of the specific tasks during or after the study.

1. The set of decision making tasks and the instructions for each task are **the same** for all participants.
2. **It is important to read the instructions CAREFULLY** so that you understand the tasks and make better decisions.
3. If you have any questions, please raise your hand to **ask our experimenters at ANY TIME.**
4. **PLEASE DO NOT communicate** with others during the experiment.
5. Please take the time to go through the instructions carefully and make your decisions.
6. Cell phones and other electronic devices are **not allowed**.

The experiment comprises **9 decision sheets**, which are of the form illustrated in the table below.

	Option A	Option B	Decision
1	A	B1	A ☐ B ☐
2	A	B2	A ☐ B ☐
3	A	B3	A ☐ B ☐
4	A	B4	A ☐ B ☐
5	A	B5	A ☐ B ☐
6	A	B6	A ☐ B ☐
7	A	B7	A ☐ B ☐
8	A	B8	A ☐ B ☐
9	A	B9	A ☐ B ☐
10	A	B10	A ☐ B ☐

Each such table lists **<u>10 choices</u>** to be made between a fixed **Option A** and 10 different **Option B'**s.

Option A involves **lotteries**, guessing the color of card randomly drawn from a deck of 100 cards with different proportions of red and black. If you guess correctly, you receive $40; otherwise you recevie nothing.

In <u>stage 1</u>, You guess the color. The proportion of red and black is determined in the stage 2 as follows.

In <u>stage 2</u>, You draw one ticket from an envelope containing some tickets with different numbers. The number you draw determines how many red cards there are in those 100 cards. *If the ticket drawn is 0, then the deck will have 0 red card and 100 black cards. If the ticket drawn is 100, then the deck will have 100 red cards and 0 black cards. If the ticket drawn is 50, then the deck will have 50 red cards and 50 black cards.* **Different task will have different composition of numbers in the evelop.**

In <u>stage 3</u>, you will draw randomly one card from the 100 cards as constructed in stage 2 and if your initial guess is correct, you will receive $40.

For example, you may guess a color (either red or balck) and <u>then</u> draw a number randomly from 30-70. If the number drawn is 45, this means that the deck will consist of 45 red cards and 55 black cards. Finally, you draw a card randomly from the deck, and you receive $40 if your guess is correct, otherwise you receive nothing.

Option B's a certain amount of money you can choose to receive, and it is arranged in an **<u>ascending manner in the amount of money</u>.**

For each row, you are asked to **<u>indicate your choice</u>** in the final "Decision" column – A or B – with a tick (√).

<u>Selection of decision sheet to be implemented</u>: **One out of the 9** Decision Sheets (*selected randomly by you*) will be implemented. Should the sheet be chosen, **one of your 10 choices** will be further selected randomly and implemented.

You may now begin.

GENERAL INSTRUCTIONS (Experiment 3)

Welcome to our study on decision making. The descriptions of the study contained in this instrument will be implemented **fully.**

Each participant will receive on average $20 for the study. The overall compensation includes a $5 show up fee in addition to earnings based on how you make decisions.

All information provided will be kept CONFIDENTIAL. Information in the study will be used for research purposes only. Please refrain from discussing any aspect of the specific tasks of the study with any one.

7. **It is important to read the instructions CAREFULLY** so that you understand the tasks in making your decisions.
8. **PLEASE DO NOT communicate** with others during the experiment.
9. Cell phones and other electronic communication devices are **not allowed.**
10. **At ANY TIME,** if you have questions, please raise your hand**.**

The study consists of 11 decision sheets of the form illustrated below.

	Option A	Option B	Decision
1	Betting on the cards	Receiving $8 for sure	A ☐ B ☐
2	Betting on the cards	Receiving $10 for sure	A ☐ B ☐
3	Betting on the cards	Receiving $12 for sure	A ☐ B ☐
4	Betting on the cards	Receiving $13 for sure	A ☐ B ☐
5	Betting on the cards	Receiving $14 for sure	A ☐ B ☐
6	Betting on the cards	Receiving $15 for sure	A ☐ B ☐
7	Betting on the cards	Receiving $16 for sure	A ☐ B ☐
8	Betting on the cards	Receiving $17 for sure	A ☐ B ☐
9	Betting on the cards	Receiving $18 for sure	A ☐ B ☐
10	Betting on the cards	Receiving $19 for sure	A ☐ B ☐
11	Betting on the cards	Receiving $20 for sure	A ☐ B ☐
12	Betting on the cards	Receiving $21 for sure	A ☐ B ☐
13	Betting on the cards	Receiving $22 for sure	A ☐ B ☐
14	Betting on the cards	Receiving $23 for sure	A ☐ B ☐
15	Betting on the cards	Receiving $24 for sure	A ☐ B ☐
16	Betting on the cards	Receiving $25 for sure	A ☐ B ☐
17	Betting on the cards	Receiving $26 for sure	A ☐ B ☐
18	Betting on the cards	Receiving $27 for sure	A ☐ B ☐
19	Betting on the cards	Receiving $28 for sure	A ☐ B ☐
20	Betting on the cards	Receiving $30 for sure	A ☐ B ☐
21	Betting on the cards	Receiving $32 for sure	A ☐ B ☐

Each such table lists <u>21 choices</u> to be made between a fixed Option A and 21 different Option B's.

Option A involves a **lottery**, guessing the color of a card randomly drawn from a deck of 100 cards with different compositions of red and black. If you guess correctly, you receive $40; otherwise you receive nothing. **Different tasks will have different compositions of red and black cards as described in each task.**

The Option B's refer to receiving the specific amounts of money for sure, and are arranged in an <u>ascending manner in the amount of money from $8 to $32</u>.

For each row, you are asked to indicate your choice in the final "Decision" column – A or B – either with a tick (√) or by drawing vertical lines as indicated above.

<u>Selection of decision sheet to be implemented</u>: **One out of the 11** Decision Sheets (*selected randomly by you*) will be implemented. Should the sheet be chosen, **one of your 21 choices** will be further selected randomly and implemented.

Part I

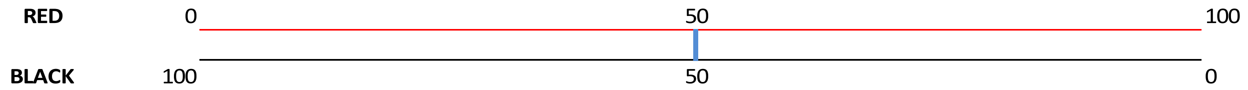
This is Part I, which has 6 decision sheets with different composition of cards. The description of each of the 6 bets begins with:

Option A: You guess the color first. You then draw a card from the deck of cards constructed in the manner described below**. If you guess the color correctly, you receive $40**. **Otherwise, you receive $0.**

This is followed by specific wordings for the 6 bets which are provided below. We begin with a bet which is based on a 100-card deck whose composition is known: 50 red cards and 50 black cards.

Bet I {50}

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The number of red cards is 50 and the number of black cards is also 50, as illustrated below.



For the remaining 5 bets, the composition of the cards and procedure of the bets are described as follows.

Stage 1. You guess the color of a card to be drawn from a deck to be constructed in Stage 2.

Stage 2. You draw one ticket from an **envelope** containing tickets of different numbers. The number drawn will determine the number of red cards in a deck of 100 cards. If the ticket drawn is 30, then the deck will have 30 red card and 70 black cards. If the ticket drawn is 68, then the deck will have 68 red cards and 32 black cards. **Note that different bets will involve different compositions of numbers in the envelope.**

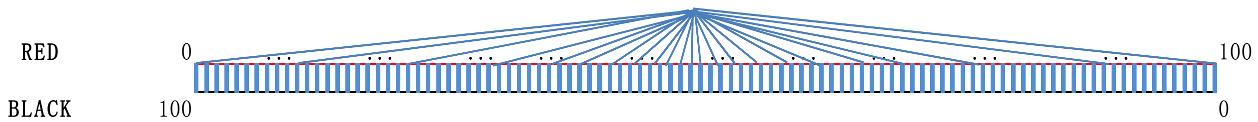
Stage 3. You will draw randomly one card from the 100 cards as constructed in stage 2 and receive $40 if your guess in Stage 1 is correct.

Summary: Guess the color in Stage 1. Draw a numbered ticket randomly to construct the deck in Stage 2. Then draw a card in Stage 3 to see if you have guessed correctly.

The 5 bets are explained below.

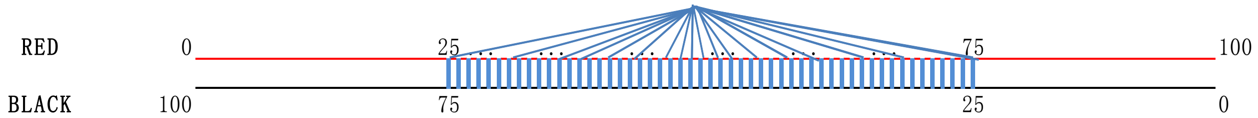
Bet I [0-100]

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The composition of this card deck is determined as follows. You draw one ticket from an envelope containing 101 tickets numbered from 0 and 100. The number you draw determines how many red cards there are in this deck of 100 cards.



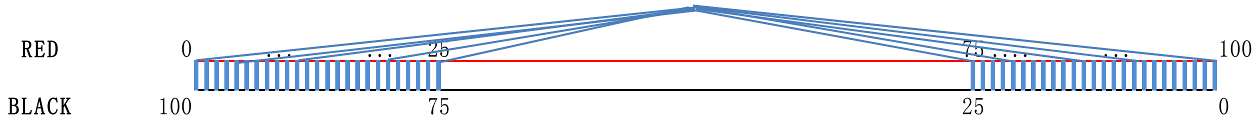
Bet I [25-75]

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The composition of this card deck is determined as follows. You draw one ticket from an envelope containing 51 tickets numbered from 25 and 75. The number you draw determines how many red cards there are in this deck of 100 cards.



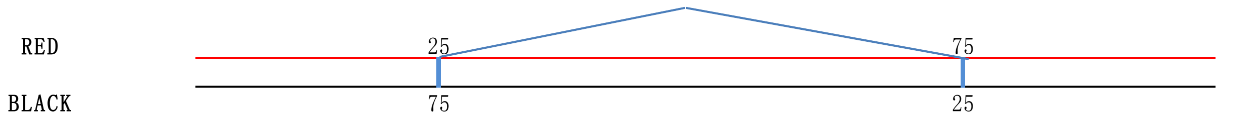
Bet I [0-25]U[75-100]

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The composition of this card deck is determined as follows. You draw one ticket from an envelope containing 52 tickets numbered from 0 and 25 and 75 to 100. The number you draw determines how many red cards there are in this deck of 100 cards.



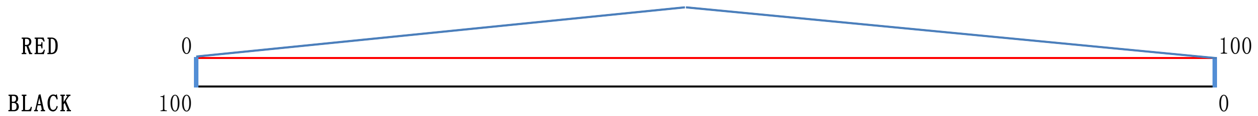
Bet I {25, 75}

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The composition of this card deck is determined as follows. You draw one ticket from an envelope containing only two tickets numbered 25 and 75. The number you draw determines how many red cards there are in this deck of 100 cards.



Bet I {0, 100}

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The composition of this card deck is determined as follows. You draw one ticket from an envelope containing only two tickets numbered 0 and 100. The number you draw determines how many red cards there are in this deck of 100 cards.

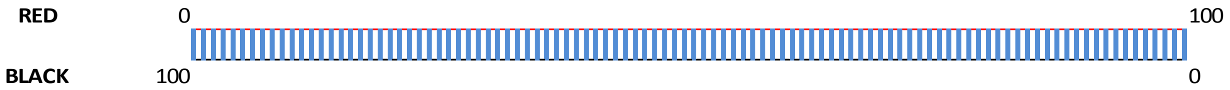


Part II

This is Part II, which consists of 5 decision sheets similiar as that in Part I. The composition of the cards are unknown as described below.

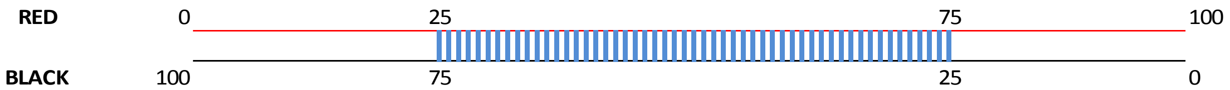
Bet II [0-100]

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The number of red cards may be anywhere from 0 to 100 with the rest of the cards black, as illustrated below.



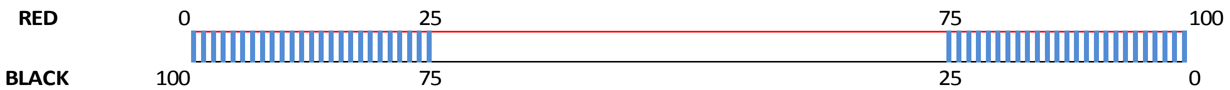
Bet II [25-75]

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The number of red cards may be anywhere from 25 to 75 with the rest of the cards black, as illustrated below.



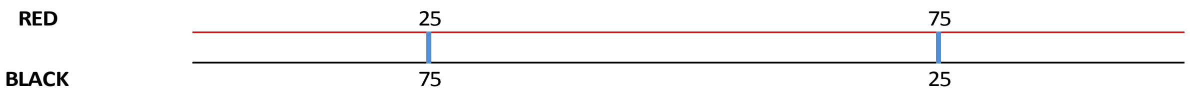
Bet II [0-25]U[75-100]

This situation involves your drawing a card randomly from a deck of 100 cards containing red and black cards. The number of red cards may be anywhere from 0 to 25 or from 75 to 100 with the rest of the cards black, as illustrated below.



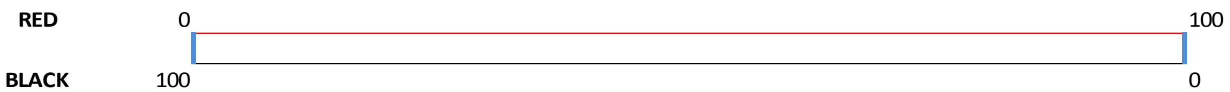
Bet II {25, 75}

This situation involves your drawing a card randomly from a deck of 100 cards containing either 25 or 75 red cards with the rest of the cards black, as illustrated below.



Bet II {0, 100}

This situation involves your drawing a card randomly from a deck of 100 cards containing either 100 red cards or 100 black cards, as illustrated below.



[This is the instructions for compound first treatment. The instructions for ambiguity first treatment are presented in a similar manner.]