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ABSTRACT

Ambiguous prospects are ubiquitous in social and economic life, but the psychological foundations of behavior under ambiguity are still not well understood. One of the most robust empirical regularities is the strong correlation between attitudes towards ambiguity and compound risk which suggests that compound risk aversion may provide a psychological foundation for ambiguity aversion. However, compound risk aversion and ambiguity aversion may also be independent psychological phenomena, but what would then explain their strong correlation? We tackle these questions by training a treatment group's ability to reduce compound to simple risks, and analyzing how this affects their compound risk and ambiguity attitudes in comparison to a control group who is taught something unrelated to reducing compound risk. We find that aversion to compound risk disappears almost entirely in the treatment group, while the aversion towards both artificial and natural sources of ambiguity remain high and are basically unaffected by the teaching of how to reduce compound lotteries. Moreover, similar to previous studies, we observe a strong correlation between compound risk aversion and ambiguity aversion, but this correlation only exists in the control group while in the treatment group it is rather low and insignificant. These findings suggest that ambiguity attitudes are not a psychological relative, and derived from, attitudes towards compound risk, i.e., compound risk aversion and ambiguity aversion do not share the same psychological foundations. While compound risk aversion is primarily driven by a form of bounded rationality – the inability to reduce compound lotteries – ambiguity aversion is unrelated to this inability, suggesting that ambiguity aversion may be a genuine preference in its own right.

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1 Introduction

Many decisions have to be made under conditions of ambiguity where the probability that a particular outcome will realize is unknown (Keynes, 1921; Knight, 1921). In such situations, normative decision theory (Savage, 1954) prescribes people to act as if they had a subjective probability distribution over the outcomes. However, as Ellsberg (1961) showed, people tend not to behave that way, but they rather exhibit ambiguity aversion – a preference for known simple risk[1] over ambiguity. Ambiguity aversion and its consequences are observed in many economic contexts, for instance consumer choice (Kahn and Sarin, 1988), participation and portfolio choice in financial markets (Easley and O'Hara, 2009; Guidolin and Rinaldi, 2013; Dimmock et al., 2016), medical decisions (Berger, Bleichrodt, and Eeckhoudt, 2013), insurance pricing (Hogarth and Kunreuther, 1989), career choice (Xu and Adams, 2020), or adoption of new technologies (Engle-Warnick, Escobal and Laszlo, 2007). Therefore, it is important to understand the mechanisms that govern people's decisions under ambiguity.

One aim in this paper is to advance our understanding of the psychological foundations of ambiguity aversion. A natural starting point for our inquiry is the existence of a strong empirical regularity that appears to connect attitudes towards compound risk and ambiguity. Starting with Halevy (2007), a growing experimental literature documents a large correlation between ambiguity aversion and compound risk aversion[2] (Abdellaoui, Klibanoff, and Placido, 2015; Armantier and Treich, 2016; Prokosheva, 2016; Chew, Miao, and Zhong, 2017; Aydogan, Berger, and Bosetti, 2019; Dean and Ortoleva, 2019; Gillen, Snowberg, and Yariv, 2019; Schneider and Schonger, 2019; and Berger and Bosetti, 2020). For example, controlling for measurement error and the associated attenuation bias, Gillen, Snowberg, and Yariv (2019) find that the correlation between compound risk aversion and ambiguity aversion is 0.86.

These high correlations give rise to many intriguing questions regarding the psychological underpinnings of ambiguity and compound risk aversion. What is the key driver behind the high correlation between compound risk aversion and ambiguity aversion? Is ambiguity aversion merely a consequence of people's compound risk aversion? Do people perceive ambiguous prospects as compound risk such that aversion to compound risk automatically spills over to aversion against ambiguous prospects? Or is it the other way round? To what extend is compound risk aversion a genuine preference that prevails even if people fully understand the nature of compound risk including the mathematical fact that each compound lottery can be reduced to an equivalent simple lottery in terms of

[1] A simple risk is an objective risk that resolves in one shot.
[2] Compound risk aversion refers to the tendency to prefer a simple lottery over a compound lottery that objectively reduces to the same probabilities of outcomes as the simple lottery. Such aversion to compound risk violates the Reduction of Compound Lottery Axiom.

probabilities of outcomes? Or are compound risk aversion and ambiguity aversion simply the consequence of the inability to reduce compound to simple lotteries? How does this inability affect attitudes towards compound risks and ambiguous prospects? In this paper, we provide answers to these questions with the help of an experiment.

A close relationship between ambiguity and compound risk aversion appears quite natural in view of the fact that ambiguous prospects and two-stage compound lotteries may be perceived as similar. This similarity becomes most visible in experiments resembling those of Ellsberg's where subjects faced urns with 100 red or black balls and could bet on a specific color. In the case of an ambiguous prospect, the subjects did not know how many among the 100 balls in an urn were red and black. This situation can be modelled by assuming that the decision-maker has a subjective probability distribution over the possible color compositions of the urn (stage 1), but for every given color composition they face a simple lottery with an objectively known probability of winning from betting on a specific color (stage 2). Ambiguous prospects seen in this way thus indeed share a similar structure as a compound risk, and many prominent models of ambiguity attitudes leveraged the two-stage framework in explaining and characterizing people's ambiguity attitudes (Anscombe and Aumann, 1963; Segal, 1987; Segal, 1990; Klibanoff, Marinacci, and Mukerji, 2005; Seo, 2009)[3].

However, although the high correlation between compound risk attitudes and ambiguity attitudes is intriguing, we have only a limited understanding how we should interpret this correlation because it could be generated by several distinct psychological mechanisms. In the following, we formulate three hypotheses of such mechanisms, each of which is associated with a different psychological foundation of ambiguity attitudes and compound risk attitudes. Then we describe our experiment that enables us to test the behavioral implications of the different hypotheses.

Under the ***first hypothesis***, people view ambiguous prospects as a form of compound risk and, in addition, they have a genuine aversion against compound risk. Being genuinely averse to compound risks means that individuals dislike compound risks even though they understand compound risks well, including the mathematical fact that a compound lottery can be reduced to an equivalent simple lottery in terms of probabilities of outcomes. If people are genuinely averse to compound risks and if they view ambiguous prospects as compound risks, then they will also be ambiguity averse, which explains the high correlation between ambiguity and compound risk attitudes.

Under the ***second hypothesis***, people also view ambiguous prospects as a form of compound risk, but they do not understand that each compound lottery can be reduced to an equivalent simple lottery in terms of probabilities of outcomes. This incomplete understanding of compound risk may then induce

[3] Other models that extend two-stage models by incorporating other components include Chew (1983), Dekel (1986), Chew, Epstein, and Segal (1991), Ahn (2008), Nau (2006), Chew and Sagi (2008), Ergin and Gul (2009).

people to shy away from choosing compound risks, i.e., they display compound risk aversion. This is based on the plausible view that people shy away from risks they don't fully understand. Moreover, because people view ambiguous prospects as a form of compound risk, compound risk aversion due to their limited understanding of compound risk also generates ambiguity aversion.

The ***third hypothesis*** assumes that people have non-neutral attitudes towards ambiguity *per se,* i.e., their ambiguity aversion is not derived from compound risk aversion. In addition, rather than viewing ambiguous prospects as a form of compound risk, people view compound prospects as ambiguous for the very reason that they do not fully understand compound prospects. That is, people's limited understanding of compound risk makes them perceive the probabilities of outcomes in a "blurred" way, i.e., they lack a precise understanding of the probabilities of outcomes. Therefore, if people display an aversion against ambiguity *per se*, and compound prospects are perceived as ambiguous, their ambiguity aversion spills over to compound prospects and renders people also averse to compound risks. The third hypothesis thus also explains the positive correlation between compound risk aversion and ambiguity aversion.

Distinguishing among these three potential mechanisms does not only allow us to provide a deeper understanding of the high correlation between ambiguity attitudes and compound risk attitudes, but it will also allow us to answer several fundamental questions about the "nature" of the two attitudes. First, the fact that ambiguity attitudes are strongly associated with compound risk attitudes gives ambiguity attitudes a flavor of bounded rationality that can potentially be corrected if people were able to reduce compound lotteries. But it is an empirical question whether this is true. Second, it is also unclear whether the perception of ambiguous prospects as a form of compound risk is at the heart of the positive correlation between the two attitudes, or whether it is the other way round. Finally, it is currently also unknown whether compound risk aversion is a "mistake" due to individuals' limited ability to reduce compound lotteries, or whether it is a genuine preference that prevails even when people are perfectly capable of reducing compound to simple lotteries. If we can distinguish among the three hypotheses mentioned above, then we may also be able to make progress in answering these questions.

We designed an experiment that can identify which of the three psychological mechanisms, if any, can explain the tight relationship between observed attitudes towards compound and ambiguous prospects. In view of the decisive, yet differential, role of the ability to reduce compound lotteries in the above hypotheses, we carefully teach participants in a treatment group how to reduce compound lotteries ("ROCL ability") while in the control group they are taught something that is unrelated to the reduction of compound risk (basics of a foreign language). We then elicit attitudes towards compound risk and ambiguity for both groups. If our teaching is effective such that the treatment participants have an increased ability to reduce compound lotteries, the three hypotheses have the following, differential behavioral predictions:

Under the first hypothesis, there is a genuine preference against compound risk (i.e., subjects fully understand compound risk *and* are compound risk averse) and ambiguous prospects are viewed as compound risk. Therefore, the teaching of the reduction of compound lotteries should affect neither subjects' compound risk attitude nor their ambiguity attitude. Moreover, as ambiguity is viewed as a compound risk, the correlation between the two attitudes should also remain unaffected.

Under the second hypothesis, subjects also view ambiguous prospects as compound risk, but they are compound risk averse due to their limited ability to reduce compound risks to simple risks. Therefore, if the treatment renders them capable of reducing compound lotteries, we should observe a strong reduction in both compound risk aversion and ambiguity aversion. Moreover, to the extent to which the limited ability to reduce compound to simple risks is the only or the primary reason for compound risk aversion, on average there should remain little compound risk and ambiguity aversion in the treatment group. In addition, since under this hypothesis ambiguous prospects are viewed as compound risk and the teaching of ROCL affects both the aversion against compound risk and against ambiguity alike, the correlation between them should remain intact. In other words, to the extent to which there is individual variation in compound risk aversion in the treatment group, we should observe covariation with individuals' ambiguity aversion.

Under the third hypothesis, individuals have non-neutral attitudes towards ambiguity *per se*, and, in addition, they view compound prospects as ambiguous because their inability to reduce compound lotteries renders their assessments of the probabilities in the compound lottery blurry. Thus, if the treatment group becomes capable of reducing compound lotteries to simple lotteries, the treated subjects should no longer view compound lotteries as ambiguous and their ambiguity aversion should no longer spills over to choices over compound risk. As a consequence, this should reduce their aversion against compound risks, while leaving ambiguity aversion unaffected because an ambiguous prospect is still viewed as ambiguous. In addition, because the teaching of ROCL means that individuals view compound prospects no longer as ambiguous prospects, there should remain no or little correlation between compound risk aversion and ambiguity aversion in the treatment group while in the control group this correlation should remain high.

To enhance the robustness of our findings, we elicit attitudes to both symmetric compound lotteries and asymmetric compound lotteries. Moreover, we elicit attitudes towards both artificial sources (Ellsberg urns) and natural sources (prices of foreign securities) of ambiguity, and all attitudes were elicited twice. We believe that measuring attitudes towards artificial and natural sources of ambiguity is particularly important because to date, studies on correlations between ambiguity aversion and compound risk aversion have primarily used Ellsberg urns as a source of ambiguity. However, ambiguous Ellsberg urns may be more easily perceived as compound lotteries compared to natural sources of ambiguity because if participants have a well-defined subjective probability distribution over urn compositions, an Ellsberg urn would almost directly turn from an ambiguous prospect into compound risk if thinking about the ambiguous prospect and the compound lottery both involve thinking about possible color compositions of balls in an urn. As Wakker (2022, p. 571) points out, the correlation between compound risk and ambiguity aversion could therefore partly be an artefact of the similar representation, and the extent to which the correlation still exists for naturally ambiguous prospects is unclear. Thus, it is important to examine whether any correlational and causal relationships between compound risk aversion and ambiguity aversion also prevail for ambiguous prospects arising from natural sources. And as a byproduct, we can also examine the extent to which attitudes towards artificial ambiguity relate to attitudes towards natural ambiguity.

We find high correlations between compound risk and ambiguity attitudes in our control group, where ROCL abilities are low. We show, for example, that the correlation between the aversion to symmetric (asymmetric) compound risk and artificial ambiguity is 0.64 (0.71). To evaluate the strength of these correlations, it is useful to compare them to the correlations that we observe when we elicit compound risk aversion or ambiguity aversion twice. We find that the correlation between two elicitations of symmetric (asymmetric) compound risk is 0.675 (0.719). Likewise, the correlation between two elicitations of artificial (natural) ambiguity is 0.771 (0.679). Thus, the correlation between compound risk attitudes and ambiguity attitudes is very similar to the correlations that prevail when we measure the *same* attitudes twice, which strengthens the case for believing that compound risk attitudes and ambiguity attitudes are, psychologically speaking, the same thing or have the same psychological roots.

However, the behavior of subjects in the treatment group thoroughly refutes this view. Compared to the control group, our teaching treatment successfully induces a higher ability to reduce compound lotteries in the treatment group which, in turn, leads to substantial differences in attitudes towards compound risk across groups: while the control group is on average strongly averse towards both symmetric and asymmetric compound risks, compound risk aversion almost vanishes in the treatment group, and a large share of individuals becomes compound risk neutral. This result shows that compound risk aversion basically vanishes when people are able to reduce compound lotteries; that is, compound risk aversion is primarily a form of bounded rationality that can be corrected. In contrast, the increased ability to reduce compound lotteries does not significantly reduce ambiguity aversion, i.e., the treatment and the control group display similar and substantial ambiguity aversion. Therefore, the inability to reduce compound lotteries does not seem to drive ambiguity aversion, although it drives almost all of the compound risk aversion. These results suggest that attitudes towards compound risk and ambiguity do not share the same psychological foundations.

Compared to the control group, the teaching treatment also greatly diminishes the correlations between compound risk aversion and ambiguity aversion which, as a result, are no longer significant. This suggests that the inability to reduce compound lotteries in the control group is a main driver behind the correlations.

Overall, the above results are inconsistent with the first two hypotheses but in line with all predictions of the third hypothesis: The exogenous increase in the ability to reduce compound to simple risk in the treatment group (i) removes almost all compound risk aversion, (ii) has no significant effect on ambiguity aversion such that the treatment group still displays a substantial level of ambiguity aversion that is statistically indistinguishable from the level of ambiguity aversion in the control group and (iii) reduces the correlation between compound risk aversion and ambiguity aversion to low and insignificant levels.

Our study offers several contributions: First, we advance the understanding of the psychological foundations of attitudes towards both ambiguity and compound risk. Despite the existence of a substantial correlation between compound risk attitudes and ambiguity attitudes, our results indicate that these two attitudes are driven by very different psychological forces. The fact that compound risk aversion sharply declines if subjects are capable of ROCL suggests that compound risk aversion is not a genuine preference that prevails even if subjects fully understand the nature of compound risk. Rather, compound risk aversion is largely due to bounded rationality – the inability to reduce compound to simple lotteries. In contrast, our results provide no support for the view that ambiguity aversion is driven by subjects' inability to reduce compound to simple risks because changes in ROCL ability have little effect on ambiguity aversion. Instead, ambiguity aversion exists independently of compound risk aversion and is thus an independent phenomenon of its own kind.

Second, our study provides a deeper understanding of the relationship between compound risk aversion and ambiguity aversion by informing the interpretation of the widely documented correlation between attitudes towards compound risk and ambiguity. Our data rule out the first and the second hypothesis that stipulate that ambiguity aversion is a "psychological relative", and derives from, compound risk aversion. Instead, our results are consistent with the view that the high correlation between compound risk and ambiguity aversion is a consequence of subjects' bounded rationality which renders compound risks ambiguous. Thus, rather than compound risk aversion being the basis for ambiguity aversion, it is more likely the other way round: ambiguity aversion may be the reason why subjects who cannot reduce compound lotteries display compound risk aversion.

Third, we also find that subjects display very similar attitudes towards artificial and natural ambiguity Their aversion against artificial ambiguity is statistically indistinguishable from the aversion against natural ambiguity both in the control *and* the treatment group. Thus, changes in subjects' ROCL ability do not affect the relationship between natural and artificial ambiguity aversion – a finding that is further corroborated by the fact that the correlation between the two ambiguity attitudes is rather high and statistically indistinguishable between the control group and the treatment group. Thus, while the teaching of ROCL breaks up the tight relationship between compound risk aversion and ambiguity aversion, it leaves the relationship between artificial and natural ambiguity attitudes intact, which can be taken as further evidence for the conclusion that compound risk aversion and ambiguity aversion have very different psychological underpinnings.

In our view, the fact that attitudes towards artificial and natural ambiguity are very similar has some relevance for research practices. While it seems true that natural ambiguity is generally empirically more relevant than artificial ambiguity, as pointed out by several researchers (e.g., Heath and Tversky, 1991; Camerer and Weber, 1992; Ellsberg, 2011). our facts suggest that insights about ambiguity attitudes measured through Ellsberg urns in the previous literature may well extend to attitudes towards ambiguity from natural sources.

The remainder of the paper is organized as follows. Section 2 describes the design of the experiment and provides the rationales behind important design features. Section 2 also formulates the different psychological hypotheses in more detail. Section 3 presents the results and Section 4 finishes with conclusions and discussions of potentially broader implications of our findings.

2 Experimental Design

2.1 Design

The experiment has three main parts: (1) the teaching phase, (2) the part where we measured subjects' attitudes towards ambiguity and compound risk, and (3) the manipulation check where we measured subjects' ROCL abilities.

2.1.1 The Teaching Phase

In the first part of the experiment, subjects are randomly assigned into the treatment group or the control group. In the treatment group, subjects are taught how to reduce compound lotteries to simple lotteries over outcomes. In other words, they learned to compute the simple probabilities of outcomes implied by the compound lottery. In the case of a compound lottery with two outcomes (A or B) this means, for example, that the subjects were taught how to compute the probability with which A and B realize. The purpose of this treatment was thus to enable subjects to grasp an objective mathematical fact – the probabilities of outcomes.

Our teaching treatment is based on the idea that subjects may be compound lottery averse because they cannot compute the simple probabilities of outcomes. However, subjects may also be genuinely averse to compound lotteries. Our approach is based on the idea that a behavior represents a genuine preference if subjects exhibit this behavior even when they fully understand the objects that they act upon. Thus, a genuine aversion to compound lotteries implies that people shy away from compound lotteries even though they understand the objective properties of compound lotteries such as the probabilities of outcomes. Our teaching treatment thus enables us to distinguish between a genuine preference against compound risk and compound lottery aversion that is driven by the inability to reduce compound lotteries.

To make sure that the effects of the teaching treatment are not due to the mere fact of investing some effort to learn something new, subjects in the control group are taught three basic grammar rules of a foreign language (Dutch) which is unlikely to affect their ROCL ability in any way. For simplicity, we reserve, however, in the following the term "teaching treatment" for the group that is taught ROCL. To facilitate teaching, subjects in both groups first receive a booklet (the booklet and all other printed materials used in the experiment are reproduced in Appendix A2), a calculator, paper and pencil.

The subjects in the treatment group received three examples of compound lotteries, each of which had two stages and two outcomes. For each example, it was explained how the probabilities of compound lotteries can be reduced to a "simple" probability over the outcomes. The first two examples are asymmetric compound lotteries. The final example is a symmetric compound lottery. Subsequently, to promote learning, subjects were asked to answer several additional questions involving the reduction of compound lotteries, which provided further learning opportunities.

In the control group, the subjects were taught three basic grammar rules of a foreign language (Dutch). Like in the treatment group, subjects received several examples of these grammar rules and subsequently they were asked to answer several additional questions that offered further learning opportunities. Other than the content being taught, all the formats of teaching (booklet, examples, practice questions, duration) are the same as in the treatment group.

Before the experiment proceeds to the attitude elicitation part, we also measured subjects' perceived difficulty of the learning task and their mood. These measures help us examine whether differential effects of the two learning treatments on risk and uncertainty attitudes could be contaminated by differences in perceived difficulty or mood across treatments. Our data show, however, that this is not the case because the teaching in the control and the treatment group does not cause differences in mood or perceived difficulty.

2.1.2 Elicitation of Compound Risk and Ambiguity Attitudes

In the second part of the experiment, we elicit subjects' attitudes towards compound risk and ambiguity through four types of prospects involving (i) symmetric compound risk, (ii) asymmetric compound risk,

(iii) artificial ambiguity, and (iv) natural ambiguity. Our symmetric compound risk and artificial ambiguity tasks are similar to the types of prospects that have previously often been used when eliciting compound risk and ambiguity attitudes. This has the advantage that we can examine whether our subject pool is unusual or whether we find similar correlations between compound risk and ambiguity attitudes in the control group as the previous literature has found. This correlation can then be compared with the one that emerges when subjects have learned how to reduce compound lotteries. In addition, to explore the robustness of the previous design specifications, we also include asymmetric compound risks which are likely to require higher ROCL abilities. Finally, in addition to eliciting attitudes towards artificial ambiguity with urn-type tasks, we were interested in measuring individuals' attitude towards natural ambiguity, i.e., the type of ambiguity that is much more common in everyday life than artificial ambiguity. Our natural ambiguity task is embedded in a setting that requires the evaluation of stocks.

Specifically, we consider prospects P that pay out a prize $x = 20$ if a specific event E occurs, and 0 otherwise. To measure ambiguity and compound risk attitudes, we use the standard method of matching probabilities. For an event E, the method elicits the simple, objective probability that makes participants indifferent between betting on the event E in question and betting on a simple lottery that gives the prize with that probability. This elicitation avoids confounding the measure of attitudes with standard risk attitudes (Raiffa, 1968; Karni, 2009; Dimmock et al., 2016). Note in addition, that a subject's matching probability for an event is a combination of her belief over the "probability" that the event happens and her attitude towards prospects of this type. For instance, given a bet on an ambiguous event, a matching probability of 30% could indicate an ambiguity neutral decision maker with a subjective probability that the likelihood of the ambiguous event occurring is 30%, or an ambiguity averse decision-maker with a higher belief about the likelihood that the event occurs. Hence, to control for beliefs, we follow Baillon and Bleichrodt (2015) and Baillon et al. (2018), and elicit the matching probability not only for event E but also for its complement event E^C. Let $\mu_i(E)$ denote participant i's matching probability for event E. The index of aversion $A_i(P)$ of a prospect P is then given by

$$A_i(P) = 1 - \left(\mu_i(E) + \mu_i(E^C)\right).$$

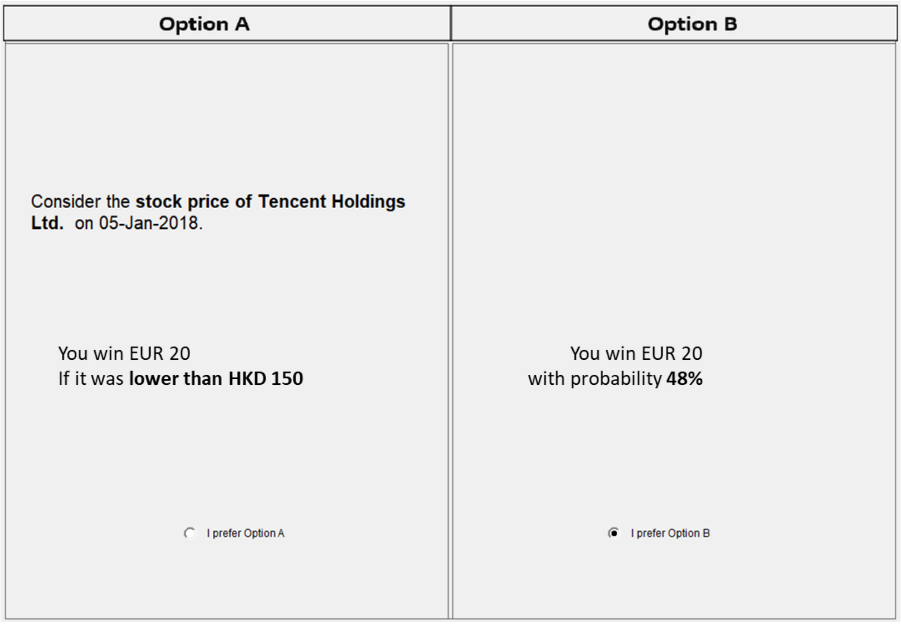
Note, that for an ambiguity neutral decision maker the index takes the value 0. In general, if the matching probabilities of an event and its complement sum to 1, then the participant is neutral to the kind of uncertainty the prospect offers. Instead, if $A_i(P)$ is positive (negative), the participant is averse (favorable) towards this type of prospect.

To operationalize compound risk and artificial ambiguity, we used opaque (black) envelopes filled with ten mosaic stones. Each stone has one of two colors, and a random draw of a stone with one of the colors corresponds to the event E while drawing a stone with the other color corresponds to event E^C. Every participant receives their own set of three opaque envelopes and an information sheet describing the procedure that was used to fill the envelopes (cf. appendix 2). For compound risk envelopes, subjects are informed about the exact compound process according to which the envelopes were filled; for ambiguity envelopes, subjects were simply informed that the exact color composition of the envelopes is unknown. The envelopes remain on each subject's desk throughout the study and subjects are informed that they can inspect their content at the end of the session. This procedure is adopted to also address the potential concern that subjects may suspect that experimenters would manipulate the ambiguous prospects so that it is hard for subjects to win (Hey et al., 2010).

Finally, for natural ambiguity we ask subjects to bet on whether the stock price of a company listed on the Hong Kong Stock Exchange was above a certain threshold or not on a particular trading day. Subjects receive a brief information sheet about the company. We used a company listed on the Hong Kong stock exchange because subjects in Europe are unlikely to be familiar with it, so that the above-mentioned natural event will be ambiguous for them.

To identify the matching probability of each event, the subjects face several binary choice problems. For each choice problem that involves the event E, a subject chooses between betting on the event E and an objective simple lottery L with a known probability of winning. The choice problems are presented to subjects on "choice screens" like the one shown in Figure 1 below, where the prospect P that bets on event E was shown as option A on the left and the objective simple lottery L as option B on the right. Subjects face a number of binary choice problems for the event E such that we can narrow down the range of the matching probability of E to at most 5%. We use the mid-point of this range as our measure of the subject's matching probability. The order in which the choice screens for the 8 events (2 events for each of the 4 prospects) appeared was completely mixed and randomized for each subject. Table 1 below shows how we implemented the 8 prospects.

FIGURE 1: Example choice screen



To ensure incentive-compatibility, we use the BDM (Becker et al. 1964) method. Subjects are informed that one of the 8 prospects that they face during the experiment will be randomly chosen to be payoff-relevant at the end of the experiment. Note that at the end of the experiment we know individual subjects' matching probabilities for each of the 8 prospects. In addition, a simple lottery L with a random winning probability[4] will be determined at that time. If the matching probability of the prospect is above the randomly chosen winning probability of the simple lottery, we know that subjects would have preferred the prospect. In this case the prospect is played out.[5] If the matching probability of the prospect is below the randomly chosen winning probability of the simple lottery, we know that subjects would have preferred the simple lottery. In this case the simple lottery is played out.[6] When explaining the BDM to the subjects, we also made clear to them that the optimal strategy was to choose on each choice screen the option they truly prefer.

Note that the random order in which subjects faced the 8 prospects, and the fact that only one of the 8 prospects will be randomly chosen to be payoff-relevant, increases the likelihood that narrow-bracketing occurs such that across-task contamination effects (e.g., hedging) are unlikely to happen. In addition, there is strong experimental evidence that the random payment mechanism we employed in our

[4] The winning probability of the randomly chosen L is independent of whether it has been encountered by the subject during his/her choices and this is made clear to the participants.

[5] For example, if the prospect involves winning € 20 if the stock price of Tencent Holdings Ltd. is lower than 150 HKD (see Figure 1), then the subject received €20 if the stock price was indeed lower than 150 on the relevant day.

[6] In case that the simple lottery L was played out, a transparent envelope containing one hundred chips numbered from 1 to 100 was used. This transparent envelope was also placed on each participant's desk and subjects knew that one chip would be randomly drawn from this envelope in case that a simple lottery would be played out. If the winning probability of that lottery was, say, 40%, the subject won the €20 in case that a number between 1 and 40 was drawn; otherwise, the subject received 0.

experiment does not lead to behavioral across-task contamination effects (Cubitt, Starmer and Sugden 1998; Healy and Stelnicki 2024).

To enhance the robustness of our attitude measures, we measure participants' attitudes towards the different types of prospects not only in the block of elicitations described above but also again in a second block. For the second block, we slightly modify the task details. Specifically, block 1 and 2 differed in: a) the amounts, colors, and materials of the objects in the envelopes of compound risk and artificial ambiguity prospects, b) the company whose stock price was used for the natural ambiguity prospect, c) the prize at stake in the case of winning (x = 30)[7] and d) most of the winning probabilities of the objective simple lotteries L that are used as Option B during the elicitations. Table 2 summarizes how we implemented the 4 prospects in block 2. By averaging over the elicitations across the two blocks, we can obtain more robust measures of compound risk and ambiguity attitudes for each participant.

TABLE 1: Elicitations of attitudes in block 1 of the experiment

Prospect	Source	States	Winning Events E and E^C
Symmetric, compound lottery	Envelope with 10 stones in 2 colors	11 states with equal probability of 1/11	E: color 1 is drawn E^C: color 2 is drawn
Asymmetric, compound lottery	Envelope with 10 stones in 2 colors	11 states with probabilities 5/17, 1/17, 1/17, 1/17, 1/17, 1/17, 1/17, 1/17, 3/17, 1/17, 1/17	E: color 1 is drawn E^C: color 2 is drawn
Artificial ambiguity	Envelope with 10 stones in 2 colors	11 states with unknown probabilities	E: color 1 is drawn E^C: color 2 is drawn
Natural ambiguity	Stock price of Tencent at Hongkong Stock Exchange	Stock price <150HKD, Stock price ≥ 150HkD	E: Stock price < 150 HKD E^C: Stock price ≥ 150 HKD

Notes: In all prospects of block 1 subjects could win x = €20 if the winning event occurs. For compound lotteries and for artificial ambiguity, each possible color composition of an envelope represents one possible state. For the symmetric compound lottery, each state has the same known probability (1/11) of realization. For the asymmetric compound lottery, the different color compositions (states) occur with different (known) probabilities. For example, the state with ten stones of color 1 and zero stones of color 2 occurs with probability 5/17. If the winning event is E, subjects can win a prize $x = 20$ if color 1 is drawn. If the complementary event E^C is the winning event, subject win the same prize if color 2 is drawn. In case of natural ambiguity, subjects win the same prize x if the stock price is smaller than 150HKD if E is the winning event; if E^C is the winning event, subjects win that prize if the stock price is (weakly) larger than 150HKD. For each of the 4 types of prospects, subjects always face choices with E as the winning event ***and*** choices with E^C as the winning event. The order of the different types of prospects the subjects face is random.

[7] This has the advantage that the increased incentive may help subjects remain focused after they have made choices in the first block, and it is not interfering with the first block because subjects did not know there was a second block.

TABLE 2: Elicitations of attitudes in block 2 of the experiment

Prospect	Sources	States	Winning event
Symmetric compound lottery	Envelope with 8 chips in 2 colors	9 states with equal probabilities 1/9	Drawn chip is in color 1 Drawn chip is in color 2
Asymmetric compound lottery	Envelope with 8 chips in 2 colors	9 states with probabilities 6/17, 1/17, 1/17, 1/17, 1/17, 1/17, 1/17, 4/17, 1/17	Drawn chip is in color 1 Drawn chip is in color 2
Artificial ambiguity	Envelope with 8 chips in 2 colors	9 states with unknown probabilities	Drawn chip is in color 1 Drawn chip is in color 2
Natural ambiguity	Stock price of AIA at Hongkong Stock Exchange	Stock price <150HKD, Stock price ≥ 150HkD	Stock price < 150 HKD Stock price ≥ 150 HKD

Notes: In all prospects of block 2 subjects could win x = €30 if the winning even occurs. For compound lotteries and for artificial ambiguity, each possible color composition of an envelope represents one possible state. For the symmetric compound lottery, each state has the same known probability (1/9) of realization. For the asymmetric compound lottery, the different color compositions (states) occur with different (known) probabilities. For example, the state with eight chips of color 1 and zero chips of color 2 occurs with probability 6/17. If the winning event is E, subjects can win x = €30 if color 1 is drawn. If the complementary event E^C is the winning event, the subjects win the same prize if color 2 is drawn. In case of natural ambiguity, subjects can win the same prize x if the stock price is smaller than 150HKD if E is the winning event; if E^C is the winning event, subjects win that prize if the stock price is (weakly) larger than 150HKD. For each of the 4 types of prospects, subjects always face choices with E as the winning event ***and*** choices with E^C as the winning event. The order of the different types of prospects the subjects face is random.

2.1.3 Measurement of ROCL ability

In the third part of the experiment, we ask both the treatment group and the control group two incentivized ROCL questions to examine the impact of ROCL teaching on ROCL ability. This manipulation check is important because it allows us to check whether the teaching of ROCL indeed increased the ability to perform ROCL in the treatment group relative to the control group. The two ROCL questions are placed after the attitude elicitations so that our main attitude measures are not influenced by answering them. The first ROCL question asks subjects to calculate the reduced probability of winning in an asymmetric compound lottery and in the second ROCL question subjects faced a symmetric compound lottery. Feedback on the correctness of these answers was given only at the very end of the experiment. The results of our manipulation check will be reported at the beginning of the results section.

2.2 Hypotheses

By comparing participants' attitudes towards compound risk and ambiguity between the treatment and the control group, we can pin down the interpretation of the high correlation found in the literature and inform the psychological underpinnings of both attitudes. Specifically, we stipulated three major potential mechanisms that can all lead to the high correlation, but they will lead to different results in our experiment and thus imply different foundations for the two attitudes. To concisely state our hypotheses, we abbreviate the average compound lottery aversion in the treatment and control group with $A^T(CL)$ and $A^C(CL)$ and the average ambiguity aversion in the treatment and control group with $A^T(A)$ and $A^C(A)$. We also abbreviate the correlation between individual's compound risk and ambiguity aversion with $Corr(A^T(CL), A^T(A))$ for the treatment and $Corr(A^C(CL), A^C(A))$ for the control group.

First, if people view ambiguous prospects as a form of compound risk and, in addition, are genuinely averse to compound risks even though they understand how to reduce compound to simple risks, then the teaching of ROCL ability should not affect either attitude. As a consequence, the correlation between compound risk and ambiguity aversion should also remain unaffected:

$$A^T(CL) = A^C(CL) \text{ and } A^T(A) = A^C(A)$$

$$Corr(A^T(CL), A^T(A)) = Corr(A^C(CL), A^C(A))$$

Second, if (like under the first hypothesis) people view ambiguous prospects as a form of compound risk, but they exhibit aversion to compound risks due to their inability to reduce compound to simple risks, the teaching of ROCL ability should reduce both compound lottery aversion and ambiguity aversion. Moreover, to the extent to which there is still individual variation in compound risk aversion, the correlation between compound risk and ambiguity aversion should persist because ambiguous prospects are still viewed as a compound risk under this hypothesis. Thus, we should observe:

$$A^T(CL) < A^C(CL) \text{ and } A^T(A) < A^C(A)$$

$$Corr(A^T(CL), A^T(A)) = Corr(A^C(CL), A^C(A))$$

Third, if subjects are genuinely averse to ambiguous prospects *per se*, i.e., their ambiguity aversion is not derived from compound risk aversion, the teaching of ROCL should leave their ambiguity attitudes unaffected. Moreover, if they perceive compound lotteries as ambiguous because their inability to reduce compound to simple risks renders the probabilities of the outcomes of the compound lottery blurry, the teaching of ROCL should remove or mitigate this blurriness. Thus, the teaching of ROCL should reduce the ambiguity subjects perceive in compound lotteries and reduce their level of compound lottery aversion. And finally, this reduction in compound lottery aversion should weaken the correlational link between compound risk aversion and ambiguity aversion:

$$A^T(CL) < A^C(CL) \text{ and } A^T(A) = A^C(A)$$

$$Corr(A^T(CL), A^T(A)) < Corr(A^C(CL), A^C(A))$$

2.3 Procedure, subjects, and payments

The study was conducted at the economics laboratory of the University of Hamburg in 2019. The subjects were university students. Studying the causal effects of ROCL ability on compound risk and ambiguity attitudes requires a sufficient exogenous change in ROCL ability. Since it is almost impossible to decrease ROCL ability if subjects already know how to reduce compound lotteries, we aimed at increasing the ROCL ability of subjects who are not yet capable of doing so. Therefore, we excluded students with math intensive majors from the experiment. 130 subjects, 65 of whom were in the treatment group, took part in the study. Sessions took on average around 100 minutes and subjects were paid roughly 23 Euros on average. Throughout the study, subjects could make decisions at their own pace. The computerized part of the study was conducted with zTree (Fischbacher, 2007).

3 Results

This section presents the results of the experiment. In section 3.1, we report the results of our manipulation check that examines whether the teaching of ROCL indeed increases subjects ROCL ability in the treatment group relative to the control group. Then in section 3.2, we report the effect of teaching ROCL on compound risk aversion and ambiguity aversion and we discuss the implications of these results. In section 3.3, we first examine the correlations between ambiguity aversion and compound risk aversion in our control group, and then we analyze the extent to which the teaching of ROCL changes the correlation in the treatment group.

3.1 Manipulation Check

To check whether the teaching of ROCL increases participants' ability to reduce compound lotteries, Table 3 reports the fraction of subjects who are able to correctly answer the symmetric and asymmetric compound lottery questions in part 3 of the study. For the symmetric compound lottery question, the proportion of correct answers significantly increases from 55% in the control group to 83% in the treatment group ($p < 0.001$, t-test). For the asymmetric compound lottery question, the change in the proportion of correct answers is even bigger and increases from 28% in the control group to 74% in the treatment group ($p < 0.001$, t-test). Therefore, the teaching of ROCL indeed increases subjects' average ability to reduce compound lotteries.

TABLE 3: Manipulation check: fraction of correct answers

	Control	Treatment
Symmetric ROCL ability	55%	83%
	(6%)	(5%)
Asymmetric ROCL ability	28%	74%
	(6%)	(5%)

Notes: The table shows the fraction of subjects who gave correct answers to the questions that asked them to reduce the probability of either a symmetric or an asymmetric compound lottery. Standard errors are given in the parentheses.

3.2 Effects of ROCL Ability on Aversion to Compound Risk and Ambiguity

To what extent does the increased ROCL ability affect compound risk aversion? The answer to this question can inform us about how much compound risk aversion can be attributed to bounded rationality in the form of ROCL ability. Our first result answers this question.

Result 1 (Effects of ROCL ability on compound lottery aversion):

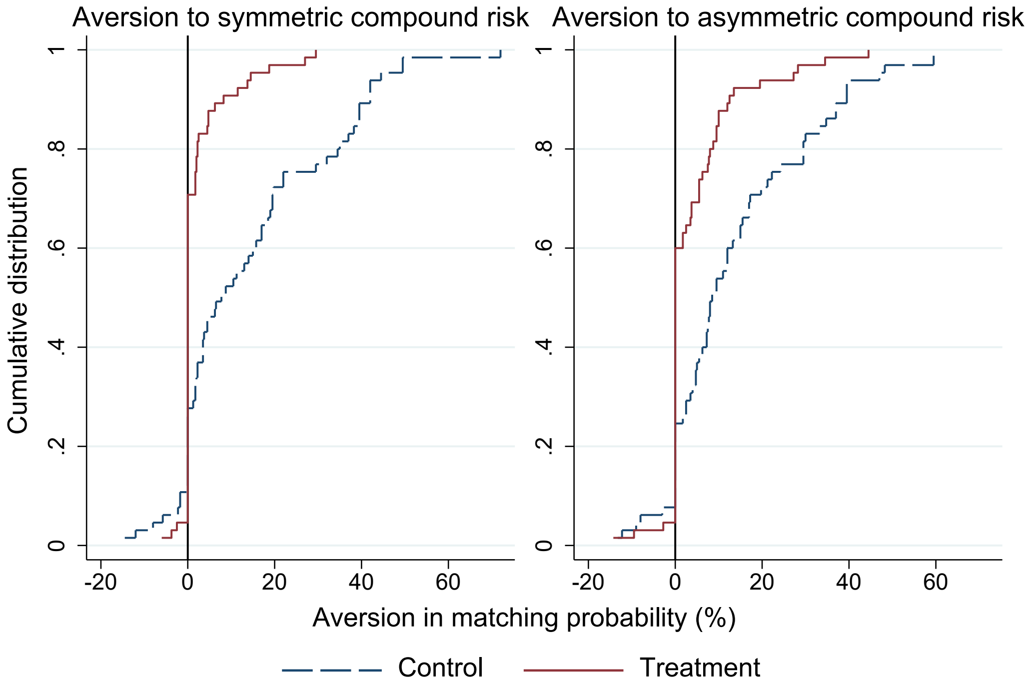
(a) Improving subjects' ability to reduce compound risks significantly reduces aversion to both symmetric and asymmetric compound risk.

(b) On average, subjects in the treatment group exhibit very low levels of compound risk aversion.

(c) Moreover, at full ROCL ability (i.e., if subjects can answer both compound risk questions in the manipulation check correctly), subjects are predicted to no longer show any significant compound risk aversion.

In the following, each individual's aversion to a prospect is calculated by averaging the point estimates from the two experimental blocks. Figure 2 illustrates the cumulative distribution functions of individuals' compound risk aversion across control and treatment groups for both symmetric and asymmetric compound risks. The figure shows that the teaching treatment causes a considerable reduction in compound risk aversion for both symmetric and asymmetric compound risks.

FIGURE 2: The cumulative distribution functions of compound risk aversion in control and treatment group



Notes: The figure shows the cumulative distribution functions of subjects' compound risk aversion for both symmetric compound risk (left) and asymmetric compound risk (right). Individuals' compound risk aversion $A_i(P)$ is measured as 100% minus the matching probabilities $\mu_i(E)$ and $\mu_i(E^C)$ of the pair of (complementary) events of the corresponding prospect: $A_i(P) = 1 - (\mu_i(E) + \mu_i(E^C))$. The dashed line indicates the control group, and the solid line indicates the treatment group.

Table 4 shows the average symmetric and asymmetric compound risk aversion, denoted by $A(P)$, across both treatments. Subjects in the control group exhibit substantial aversion to compound risk, with $A(P) = 14.43\%$ for symmetric compound risk and $A(P) = 13.94\%$ for asymmetric compound risk. However, in sharp contrast to the control group, compound risk aversion in the treatment group drops substantially to $A(P) = 2.27\%$ for symmetric compound risk and $A(P) = 4.25\%$ for asymmetric compound risk. These treatment effects are significant at $p < 0.001$ (based on t-tests) for both types of compound risk, which provides support for Result 1a, while the low levels of compound risk observed in the treatment group support Results 1b.

Therefore, 84% of symmetric compound risk aversion and 70% of asymmetric compound risk aversion observed in the control group disappears in the treatment group. Also, notice that these reductions in compound risk aversion result despite incomplete "compliance" to treatment. That is, these numbers reflect the outcomes when the ROCL ability (measured in terms of the proportion of correct answers to our compound risk questions in part 3) is increased from 55% (28%) to 83% (75%) for symmetric (asymmetric) compound risk. Suppose, however, that subjects were initially, i.e., before the teaching of ROCL ability, not able to answer the two ROCL ability questions of the manipulation check but that the teaching of ROCL renders them capable of answering both questions. By how much would this increase in ROCL ability reduce compound risk aversion?

TABLE 4: Average compound risk aversion in control and treatment group[8]

	Control	Treatment
Average aversion $A(P)$ to symmetric compound risk	14.43% (2.24%)	2.27% (0.76%)
Average aversion $A(P)$ to asymmetric compound risk	13.94% (2.06%)	4.25% (1.15%)

Notes: The table reports subjects' *average* compound risk aversion for both symmetric and asymmetric compound risks. Individuals' compound risk aversion $A_i(P)$ is measured as 100% minus the matching probabilities $\mu_i(E)$ and $\mu_i(E^C)$ of the pair of (complementary) events of the corresponding prospect: $A_i(P) = 1 - (\mu_i(E) + \mu_i(E^C))$. Standard errors are given in the parentheses.

We can compute the answer to this question by estimating the treatment effect on the treated. We can do this by using the treatment as an instrument for ROCL ability and applying two-stage least squares for estimating the treatment effect. The 2SLS results of the treatment effect on the treated are reported in the first column in Table 5. They show the *predicted* reduction in compound risk aversion when moving from 0% ability (i.e., answering both ROCL questions in part 3 of the study incorrectly) to 100% ability (i.e., answering both ROCL questions in part 3 correctly). These results indicate the powerful predicted impact of ROCL ability on compound risk aversion.

The 2SLS regressions can also be used to compute the *predicted level* of compound risk aversion at full ROCL ability (i.e., when subjects are able to answer both compound risk questions correctly).[9] The results of this prediction exercise are reported in the second column of Table 5. They show that the predicted symmetric and asymmetric compound risk aversion at full ROCL ability is no longer significantly different from 0, which supports Result 1c.

[8] Table A1 in the Appendix displays the corresponding table across the two blocks.

[9] To obtain the predicted level of compound risk aversion at full ROCL ability, we code ROCL inability in the first stage regression such that complete inability takes the value of 1 and full ability takes on the value of zero. Then we use the predicted level of ROCL inability as the independent variable in the second stage regression, which implies that the constant of the second stage regression give us the predicted level of compound risk aversion at full ROCL ability.

Table 5: Treatment effect on the treated (ToT) for compound risk aversion

	Treatment effect of improving ROCL ability on the treated	Predicted aversion at full ROCL ability
Aversion to symmetric compound risk	32.93%** (6.41%)	-4.82% (2.83%)
Aversion to asymmetric compound risk	26.24%** (6.40%)	-1.40% (2.82%)

Notes: The table reports the treatment effect on the treated for compound risk aversion. Individuals' compound risk aversion $A_i(P)$ is measured as 100% minus the matching probabilities $\mu_i(E)$ and $\mu_i(E^C)$ of the pair of (complementary) events of the corresponding prospect: $A_i(P) = 1 - (\mu_i(E) + \mu_i(E^C))$. Standard errors are given in the parentheses. The "treatment effect of improving ROCL ability" represents the predicted reduction of compound risk aversion if ROCL ability were increased from 0% (i.e., answering both ROCL questions in part 3 of the study incorrectly) to 100% (i.e., answering both ROCL questions in part 3 correctly). The ToT is calculated with 2SLS using the treatment as an instrumental variable for ROCL ability measured by the number of correct answers given to the two ROCL ability questions. ** and * indicate that the results are significantly different from zero at the 0.01 level and the 0.05 level, respectively.

Taken together, the above results show that ROCL ability plays a large and significant role for compound risk aversion. By teaching ROCL ability to subjects who are initially unable to reduce compound risks, compound risk aversion becomes much lower. In addition, our 2SLS results suggest that little compound risk aversion remains if subjects are fully capable of performing ROCL. This means that there is little support for hypothesis 1 which stipulates that compound risk aversion represents a genuine preference that also prevails if subjects are capable of performing ROCL.

The above results raise the question whether ambiguity aversion is also significantly reduced by the teaching treatment? If that were the case, the data would support our second hypothesis which stipulates that compound risk aversion is due to a lack of ROCL ability and that subjects view ambiguous prospects as compound risk. Our next result refutes, however, this hypothesis.

Result 2 (Effects of ROCL ability on ambiguity aversion):

(a) Improving subjects' ability to reduce compound risks has only a small and insignificant effect on the aversion to artificial and to natural ambiguity.

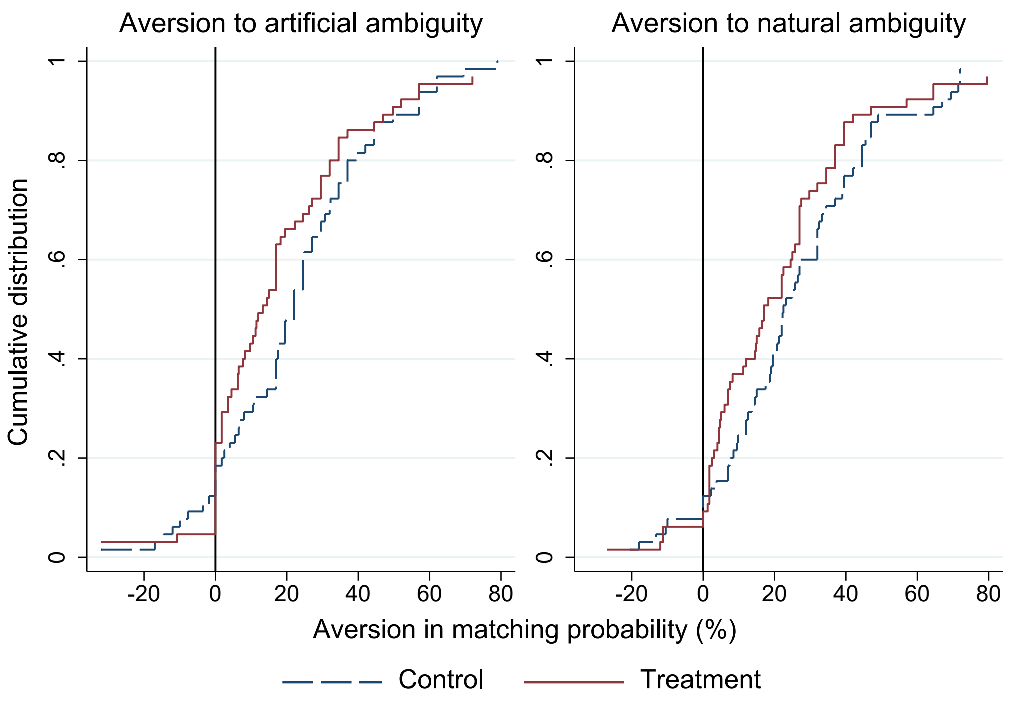
(b) On average, subjects in the treatment group still exhibit substantial aversion to artificial and natural ambiguity.

(c) Moreover, at full ROCL ability (i.e., when subjects answer both compound risk questions in the manipulation check correctly), subjects are predicted to display a significant and sizable level of ambiguity aversion.

Result 2a and 2b are illustrated by Figure 3 which depicts the cumulative distribution functions for both types of ambiguity aversion across the treatment groups. The figure shows that the distribution of ambiguity aversion for the control and the treatment group is very similar to each other for both artificial and natural ambiguity. Correspondingly, Table 6 shows the average aversion to artificial and natural ambiguity across control and treatment groups. Subjects in the control group exhibit substantial aversion to both types of ambiguity, with $A(P)$ = 22.17% for artificial ambiguity and $A(P)$ = 26.15% for natural ambiguity. This level of ambiguity aversion is similar to the levels found in the literature (e.g., Baillon and Bleichrodt, 2015; Dimmock et al., 2016). However, in contrast to the very low levels of compound risk aversion in the treatment group, we still observe an average aversion of $A(P)$ = 17.75% to artificial ambiguity and $A(P)$ = 21.43% to natural ambiguity in this group. The treatment effects on ambiguity aversion are, therefore, rather small and insignificant (p = 0.278 for aversion to artificial ambiguity and p = 0.250 for aversion to natural ambiguity, t-tests).

Like in the case of compound risk aversion, the above numbers reflect treatment effects when ROCL ability is increased from 55% (28%) to 83% (75%) for symmetric (asymmetric) compound risks. This raises again the question of what would happen if ROCL ability is increased from zero to 100% as measured by our manipulation check. Therefore, we compute the treatment effect on the treated for ambiguity aversions in Table 7 by using the treatment as an instrumental variable for ROCL ability. Table 7 indicates two results. First, the *predicted* reduction in ambiguity aversion when moving from 0% ability (i.e., answering both ROCL questions in part 3 of the study incorrectly) to 100% ability (i.e., answering both ROCL questions in part 3 correctly) is not significantly different from zero. Second, the predicted levels of ambiguity aversion at full ROCL ability are still sizable (15.18% for artificial ambiguity and 18.68% for natural ambiguity). Both of these levels of ambiguity aversion are significantly above 0 (p = 0.002 for artificial ambiguity and p < 0.001 for natural ambiguity, t-tests) and in fact even higher than compound risk aversion in the control group, thus supporting Result 2c.

FIGURE 3:
The cumulative distribution functions of the aversion against artificial and natural ambiguity in control and treatment group



Notes: The figure shows the cumulative distribution functions of subjects' aversion to both artificial ambiguity (left) and natural ambiguity (right). Individuals' ambiguity aversion $A_i(P)$ is measured as 100% minus the matching probabilities $\mu_i(E)$ and $\mu_i(E^C)$ of the pair of (complementary) events of the corresponding prospect: $A_i(P) = 1 - \left(\mu_i(E) + \mu_i(E^C)\right)$. The dashed line indicates the control group, and the solid line indicates the treatment group.

TABLE 6: Average ambiguity aversion in control and treatment group[10]

	Control	Treatment
Average aversion $A(P)$ to artificial ambiguity	22.17% (2.74%)	17.75% (2.98%)
Average aversion $A(P)$ to natural ambiguity	26.15% (2.89%)	21.43% (2.89%)

Notes: The table reports subjects' average aversion to both artificial and natural ambiguity. Individuals' ambiguity aversion $A_i(P)$ is measured as 100% minus the matching probabilities $\mu_i(E)$ and $\mu_i(E^C)$ of the pair of complementary events of the corresponding prospect: $A_i(P) = 1 - \left(\mu_i(E) + \mu_i(E^C)\right)$. Standard errors are given in the parentheses.

Taken together, Results 1 and 2 show that while compound risk aversion is largely driven by individuals' limited ROCL ability, ambiguity aversion is not significantly affected by this ability. These results are not consistent with the first two hypothesis, which stipulate that ambiguity is perceived as a compound

[10] Table A2 displays the corresponding table across the two blocks.

risk. If that were the case, the strong reduction in compound risk aversion in the teaching treatment should be associated with a similar reduction in ambiguity aversion, which is not what we observe. Therefore, our results suggest that ambiguity aversion does not share the same psychological foundation as compound risk aversion.

Table 7: Treatment effect on the treated (ToT) for ambiguity aversion

	Treatment effect of improving ROCL ability on the treated	Predicted aversion at full ROCL ability
Aversion to artificial ambiguity	11.96% (10.98%)	15.18%** (4.84%)
Aversion to natural ambiguity	12.79% (11.06%)	18.68%** (4.87%)

Notes: Notes: The table reports the treatment effect on the treated for ambiguity aversion. Individuals' ambiguity risk aversion $A_i(P)$ is measured as 100% minus the matching probabilities $\mu_i(E)$ and $\mu_i(E^C)$ of the pair of (complementary) events of the corresponding prospect: $A_i(P) = 1 - (\mu_i(E) + \mu_i(E^C))$. Standard errors are given in the parentheses. The "treatment effect of improving ROCL ability" represents the predicted reduction of ambiguity risk aversion if ROCL ability were increased from 0% (i.e., answering both ROCL questions in part 3 of the study incorrectly) to 100% (i.e., answering both ROCL questions in part 3 correctly). The ToT is calculated with 2SLS using the treatment as an instrumental variable for ROCL ability measured by the number of correct answers given to the two ROCL ability questions. ** and * indicate that the results are significantly different from zero at the 0.01 level and the 0.05 level, respectively.

Result 1 and Result 2 are, however, consistent with the third hypothesis which assumes that subjects have non-neutral attitudes towards ambiguity *per se*, i.e., ambiguity aversion is not derived from compound risk aversion. In addition, this hypothesis stipulates that rather than viewing ambiguous prospects as a form of compound risk, people view compound prospects as ambiguous for the very reason that their limited understanding of ROCL makes them perceive the probabilities of outcomes in a "blurred" way. Note that the observation that compound risk aversion largely vanishes, while ambiguity aversion remains high, if subjects acquire the ability to reduce compound lotteries is fully consistent with this hypothesis. But in addition, this teaching-induced disruption of the link between compound risk aversion and ambiguity aversion should also directly weaken the high correlation between the two attitudes. Section 3.3 below examines whether this is indeed true.

3.3 Correlations between Aversion to Compound Risk and Ambiguity

As the previous literature has repeatedly found a high correlation between compound risk aversion and ambiguity aversion, we first examine whether we can replicate this finding in the control group. In addition, we will examine the correlation in the treatment group. Moreover, due to the concern (Wakker, 2020) that the similarity in the presentation formats of artificial ambiguity and compound lotteries may contribute to the high correlation between these two attitudes, we also examine the correlation between compound risk aversion and aversion to natural ambiguity. Finally, we will investigate the extent to which aversion to artificial ambiguity and natural ambiguity is correlated.

Result 3 (Effects of ROCL ability on correlation between compound lottery and ambiguity aversion):

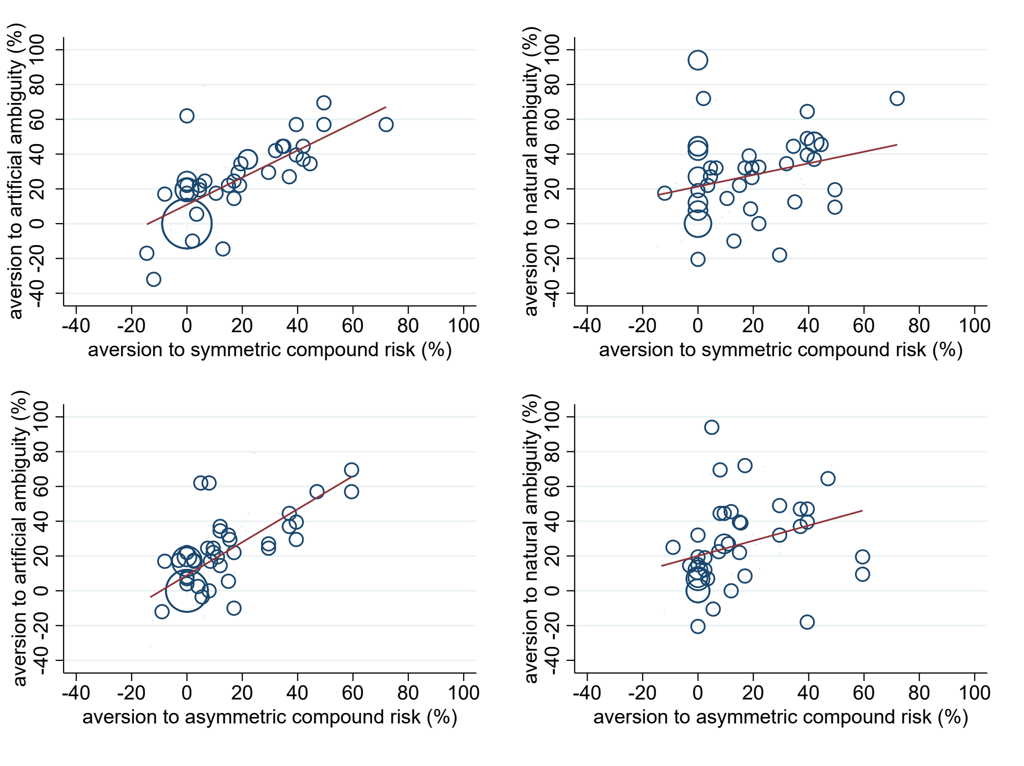
(a) There exists a high and significant positive correlation between compound risk aversion and the aversion to *artificial* ambiguity in the control group, but the correlation basically vanishes in the treatment group.

(b) There exists a moderately high and significant positive correlation between compound risk aversion and the aversion to *natural* ambiguity in the control group, but the correlation becomes small and insignificant in the treatment group.

Figures 4 and 5 illustrate how compound risk aversion and ambiguity aversion are related. Figure 4 shows the scatter plots and the associated regression lines for this relationship in the control group. Figure 5 is the corresponding figure for the treatment group. The left column of Figure 4 shows that the aversion to artificial ambiguity is strongly correlated with compound risk aversion in the control group. Moreover, this correlation is not due to a few outliers but is broadly supported by the overall data pattern. A similar picture emerges in the right column of Figure 4, which show the relationships between compound risk aversion and the aversion to natural ambiguity although these correlations appear to be somewhat less pronounced.

The correlation patterns in the treatment group (see Figure 5) differ sharply from those in the control group. In the treatment group, we observe still a considerable variation in ambiguity aversion but because the distribution of both asymmetric and symmetric compound risk aversion is compressed around zero, the correlations between compound risk aversion and ambiguity aversion basically collapse to very low levels. This is particularly pronounced in the left column of Figure 5 which illustrates the relationship with the aversion to artificial ambiguity. Here, the correlations appear to be close to zero. But it is also true for the relationship between compound risk aversion and the aversion to natural ambiguity in the right column of Figure 5, because the correlations that remain in the treatment group appear to be driven by just a few outliers.

FIGURE 4: The relationship between ambiguity aversion and compound risk aversion in the control group

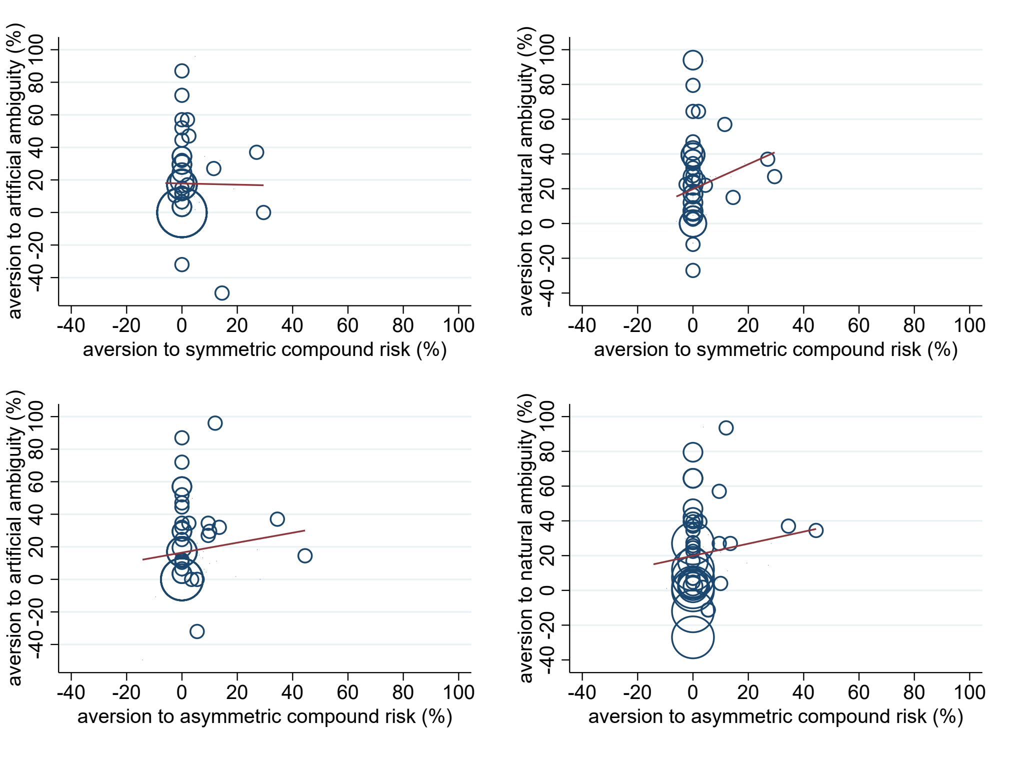


Notes: The figure shows the relationship between subjects' aversion to artificial ambiguity and their aversion to both symmetric and asymmetric compound risk. Each circle presents at least one observation in the data, and the size of the circle represents the number of observations that have the corresponding combination of ambiguity aversion and compound risk aversion.

To provide a quantitative assessment of our correlation results, Table 8 shows the Pearson correlation coefficients between ambiguity aversion and compound risk aversion. This table confirms the impressions conveyed by Figures 4 and 5. First, we find a large and significant correlation of 0.64 (0.71) between the aversion to artificial ambiguity and symmetric compound risk aversion (asymmetric compound risk aversion). This replicates the large correlations that have been previously reported in other studies. In fact, these correlations are in the same ballpark as the correlations between two elicitations of the same attitude in Block 1 and Block 2. For example, the correlation between the two elicitations of symmetric (asymmetric) compound risk is 0.675 (0.719). Likewise, the correlation between two elicitations of artificial (natural) ambiguity is 0.771 (0.679).

Second, the correlations are basically eradicated in the treatment group where the correlation between aversion to artificial ambiguity and aversion to symmetric compound risk aversion (asymmetric compound risk aversion) is -0.01 (0.12), and in both cases not significantly different from zero (p = 0.940 for symmetric, and p = 0.350 for asymmetric compound risk).

FIGURE 5: The relationship between ambiguity aversion and compound risk aversion in the treatment group



Notes: The figure shows the relationships between subjects' aversion to natural ambiguity and compound risk aversion for both symmetric and asymmetric compound risk. Each circle presents at least one observation in the data, and the size of the circle represents the number of observations that have the corresponding combination of ambiguity aversion and compound risk aversion.

Third, there is a significantly positive correlation of 0.26 (0.31) between the aversion to natural ambiguity and symmetric compound risk aversion (asymmetric compound risk aversion) in the control group ($p = 0.037$ for symmetric, and $p = 0.011$ for asymmetric compound risk). The fact that these correlations are considerably lower than for the case of artificial ambiguity is consistent with the view that the presentation formats used to elicit artificial ambiguity may contribute to the correlations between compound risk aversion and aversion to artificial ambiguity. Fourth, Table 8 shows that the correlations between the aversion to natural ambiguity and compound risk aversion are considerably lower and not significantly different from zero in the treatment group ($p = 0.134$ for symmetric, and $p = 0.274$ for asymmetric compound risk).

Taken together, these findings refute hypothesis 1 and 2 and confirm the predictions implied by hypothesis 3.

TABLE 8: Correlations between compound risk aversion and ambiguity aversion

	Control		Treatment	
	Sym CL	Asym CL	Sym CL	Asym CL
Correlation with aversion to artificial ambiguity	0.64***	0.71***	-0.01	0.12
	(0.10)	(0.09)	(0.13)	(0.13)
Correlation with aversion to natural ambiguity	0.26**	0.31**	0.19	0.14
	(0.12)	(0.12)	(0.12)	(0.12)

Notes: The table reports the Pearson correlation coefficients between ambiguity aversion and compound risk aversion. Standard errors are given in the parentheses. ***, ** and * indicates significance at the 0.01 level, the 0.05 level and the 0.1 level, respectively.

Finally, we examine the relationship between the aversion to artificial and natural ambiguity. If the aversion to these two forms of ambiguity reflects common psychological underpinnings one would expect a strong correlation between them. Moreover, if ambiguity aversion is psychologically independent from compound risk aversion, we should observe that the teaching of ROCL has little influence on the correlation between the two forms of ambiguity aversion, and that the levels of ambiguity aversion are similar when subjects face artificial and natural ambiguity. The following findings indeed support these conjectures:

Result 4 (ROCL ability and the relationship between attitudes towards natural and artificial ambiguity):

(a) On average, subjects in the control group show similar levels of aversion against natural and artificial ambiguity and there is a substantial correlation between the two forms of ambiguity aversion at the individual level.

(b) On average, subjects in the treatment group show also similar levels of aversion against natural and artificial ambiguity and they also exhibit a substantial correlation between the two forms of ambiguity aversion at the individual level.

Support for Result 4 is provided by Table 6 above and Table 9 below. Table 6 shows that subjects display relatively similar levels of aversion to artificial ambiguity and to natural ambiguity in the control group ($p = 0.149$) and in the treatment group ($p = 0.157$). Moreover, Table 9 shows that the correlation between the two forms of ambiguity aversion is large and significant both in the control group ($r = 0.53$, $p < 0.001$) and in the treatment group ($r = 0.62$, $p < 0.001$).

TABLE 9: Correlation between aversion to artificial and natural ambiguity

	Control	Treatment
	Artificial Ambiguity	Artificial Ambiguity
Natural	0.53***	0.62***
Ambiguity	(0.11)	(0.10)

Notes: Reported in this table are the correlations between aversion to artificial ambiguity and aversion to natural ambiguity. For Pearson correlations, standard errors are given in the parentheses. *** indicates significance (from a correlation of 0) at the 0.01 level, ** at the 0.05 level, and * at the 0.10 level.

These results lend support to the view that attitudes towards artificial and natural ambiguity share common psychological underpinnings that are independent of compound risk aversion.

4 Concluding Remarks

A considerable literature robustly documents a high correlation between ambiguity aversion and compound risk aversion which gives rise to intriguing questions regarding their psychological underpinnings. Is ambiguity aversion merely a consequence of people's compound risk aversion? Do people perceive ambiguous prospects as compound risk such that aversion to compound risk automatically spills over to aversion against ambiguous prospects? Or is it the other way round? To what extent is compound risk aversion a genuine preference that prevails even if people fully understand the nature of compound risk including the mathematical fact that each compound lottery can be reduced to an equivalent simple lottery in terms of probabilities of outcomes? Or are compound risk aversion and ambiguity aversion simply the consequences of the inability to reduce compound to simple lotteries? How does this inability affect attitudes towards compound risks and ambiguous prospects?

In this paper, we provide answers to these questions with the help of an experiment that examines the impact of an exogenous rise in the ability to reduce compound to simple risks. The evidence unambiguously suggests that subjects do *not* perceive ambiguous prospects as compound risk such that aversion to compound risk automatically spills over to aversion against ambiguous prospects. If that were the case, we should have observed that the teaching of ROCL either does not affect both compound risk aversion and ambiguity aversion, or reduces both compound risk aversion and ambiguity aversion. However, the evidence indicates that the teaching of ROCL causes large reductions in compound risk aversion (Result 1) but does not significantly affect the levels of ambiguity aversion (Result 2).

Thus, ambiguity aversion is not merely a consequence of compound risk aversion. Rather, our results are consistent with the view that ambiguity aversion may be a driver of compound risk aversion. If, e.g., the probabilities of outcomes in compound lotteries become blurry if subjects lack the ability to apply ROCL, then subjects perceive compound prospects as ambiguous. And if, in addition, subjects have an aversion against ambiguity *per se*, as indicated by Result 2, then this aversion is likely to spill over to choices over compound risks.

Taken together, Result 1 and 2 thus suggest that compound risk aversion and ambiguity aversion are driven by very different psychological forces. Result 1, in particular, indicates that compound risk aversion is not a genuine preference that prevails even if people fully understand the nature of compound risk. It rather suggests that compound risk aversion is largely due to a form of bounded rationality – the inability to reduce compound to simple lotteries. In contrast, Result 2 is consistent with the view (i) that ambiguity aversion is not derived from compound risk aversion, (ii) that is not "correctable" by an increased ROCL ability, and (iii) constitutes an independent phenomenon of its own kind. This interpretation is further corroborated by the fact that the teaching of ROCL almost completely eradicates the correlation between compound risk aversion and ambiguity aversion for the case of artificial ambiguity (Result 3a) and becomes low and insignificant for the case of natural ambiguity (Results 3b).

Finally, we find (Result 4) that subjects display similar attitudes towards artificial and natural ambiguity. The aversion against artificial ambiguity is statistically indistinguishable from their aversion against natural ambiguity both in the control group *and* in the treatment group. Thus, changes in subjects' ROCL ability do not affect the relationship between natural and artificial ambiguity aversion – a finding that is further corroborated by the fact that the correlation between the two ambiguity attitudes is rather high and statistically indistinguishable between the control group and the treatment group. Thus, while the teaching of ROCL breaks up the tight relationship between compound risk aversion and ambiguity aversion, it leaves the relationship between artificial and natural ambiguity attitudes intact, which can be taken as further evidence for the conclusion that compound risk aversion and ambiguity aversion have very different psychological underpinnings.

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Appendix

A1 Further Results

TABLE A1: Compound Risk Aversion across Blocks

Matching probabilities	Control – Block 1	Control – Block 2	Treatment – Block 1	Treatment – Block 2
Aversion to symmetric compound risk	14.45%	14.41%	0.78%	3.76%
	(2.44%)	(2.46%)	(0.63%)	(1.25%)
Aversion to asymmetric compound risk	15.15%	12.72%	5.17%	3.33%
	(2.14%)	(2.31%)	(1.18%)	(1.47%)

TABLE A2: Ambiguity Aversion across Blocks

Matching probabilities	Control – Block 1	Control – Block 2	Treatment – Block 1	Treatment – Block 2
Aversion to artificial ambiguity	22.18%	25.71%	17.73%	20.34%
	(2.68%)	(3.14%)	(2.97%)	(2.99%)
Aversion to natural ambiguity	22.15%	26.60%	17.78%	22.52%
	(3.15%)	(3.16%)	(3.24%)	(3.06%)

A2 Experimental Instructions and Protocol

(Translated from German)

A2.1 Teaching instructions: learning about probabilities

In part 1 of today's session, you can learn to combine probabilities. On the next pages, you will find 3 examples on how to combine probabilities. In all examples, you play a lottery where you can either win a prize or not win the prize. The basic setting for all 3 examples is the same:

There is a bag filled with 11 tickets. The 11 tickets are numbered from 0 to 10. In addition to the bag, there is a box.

The box is filled with 10 balls. Each of the 10 balls is either labelled W for "winning" or L for "losing". Note that we do not yet know how many of the balls in the box are W-balls, and how many are L-balls. This is determined as follows: One ticket is randomly drawn from the bag, and its number is observed. This number determines how many of the balls in the box are W-balls, and how many are L-balls. The exact rule differs across the three examples.

Finally, to determine whether you win, one ball is randomly drawn from the box. If the ball is a W-ball, you win the lottery.

Please study the 3 examples carefully. Along the explanations of these examples, there are some blank spaces marked like this: _______. Please fill in the numbers that are missing in these blank spaces. This will help you to get a better understanding of these examples. If, at any time, you have a question, please raise your hand and an assistant will come and help you.

Once you have understood everything, and filled out all blank fields, please raise your hand. An assistant will then check your answers.

Example 1

Exact Rule on how the Box is filled

In this example, the number of W-balls in the box is determined as follows:

(1) If the ticket drawn from the bag is from the interval 0-5, then there are 5 W-balls in the box.

(2) If the ticket drawn from the bag is from the interval 6-10, then there are 7 W-balls in the box.

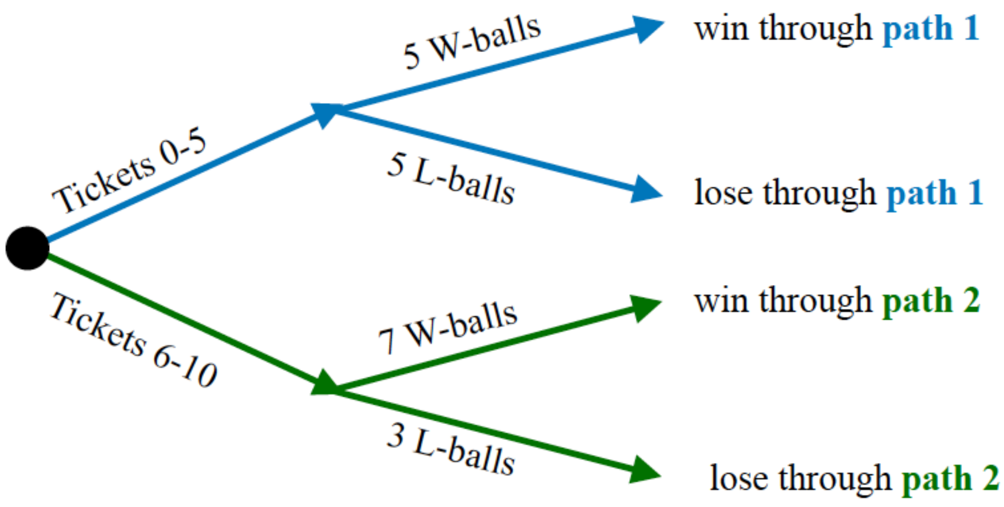
Problem

What is the probability of winning in this lottery?

Solution

There are two ways in which one can win this lottery, which we represent with paths **1** and **2** as shown in figure 1.

Figure 1: Paths to win the lottery in example 1



Step 1: Calculating the probability of winning through path 1

Initially, we find ourselves at the black dot on the very left and now draw one ticket from the bag. If the number written on it is from the interval 0-5, then we are in **path 1**, represented by the **blue** arrow from the black dot. Note that the interval from 0 to 5 contains 6 numbers (0,1,2,3,4,5). Since the bag contains 11 tickets and each of them is drawn with equal probability, the chance of drawing a ticket from the interval 0 to 5, and thus being on the blue path is $\frac{6}{11}$. Once we are on **path 1**, there will be 5 W-balls in the box. Since the box contains 10 balls and each of them is drawn with equal probability, the chance that this happens is $\frac{5}{10}$.

We can now calculate the probability of winning the lottery through **path 1**. As we calculated above, the chance of being on **path 1** is $\frac{6}{11}$, and, once we find ourselves on **path 1**, the chance of winning is

$\frac{5}{10}$. Thus, the probability of winning through **path 1** is $\frac{5}{10}$ of $\frac{6}{11}$. To calculate this, we multiply the two probabilities with each other: $\frac{5}{10} \times \frac{6}{11} = \frac{30}{110}$. The probability of winning through **path 1** is hence $\frac{30}{110}$.

Step 2: Calculating the probability of winning through path 2

Now consider the case where we draw a ticket with a number in the interval 6-10, which means we are on the green **path 2**. There are 11 tickets, and 5 numbers between 6 and 10 (6,7,8,9,10), hence this will happen with a chance of $\frac{5}{11}$. We would now win if the ball drawn from the box is one of the 7 W-balls. The chance that this happens is $\frac{7}{10}$.

To calculate the probability that one wins the lottery through **path 2**, we multiply the probability of getting on **path 2**, $\frac{5}{11}$, with the probability of winning once being on **path 2**, which we calculated to be $\frac{7}{10}$. The probability that one wins through **path 2** is hence: $\frac{5}{11} \times \frac{7}{10} = \frac{35}{110}$.

Step 3: Calculating the total probability of winning the lottery

We can win the lottery either through path **1** or **2** and therefore the total probability of winning this lottery is obtained by adding the probabilities of winning through paths **1** and **2**: $\frac{30}{110} + \frac{35}{110} = \frac{65}{110}$. Later, to enter such answers in the computer, we need to convert the fraction into a rounded percentage. Dividing 65 by 110 gives 0.5909.. hence we round to 59%.

Example 2

Exact Rule on how the Box is filled

In this example, the number of W-balls in the box is determined as follows:

(1) If the ticket from the bag is **0 or 1**, then there is no W-ball in the box.

(2) If the ticket from the bag is 2, then there are 2 W-balls in the box.

(3) If the ticket from the bag is 3, then there are 3 W-balls in the box.

(4) If the ticket from the bag is 4, then there are 4 W-balls in the box.

(5) If the ticket from the bag is 5, then there are 5 W-balls in the box.

(6) If the ticket from the bag is 6, then there are 6 W-balls in the box.

(7) If the ticket from the bag is 7, then there are 7 W-balls in the box.

(8) If the ticket from the bag is 8, then there are 8 W-balls in the box.

(9) If the ticket from the bag is 9, then there are 9 W-balls in the box.

(10) If the ticket from the bag is 10, then there are 10 W-balls in the box.

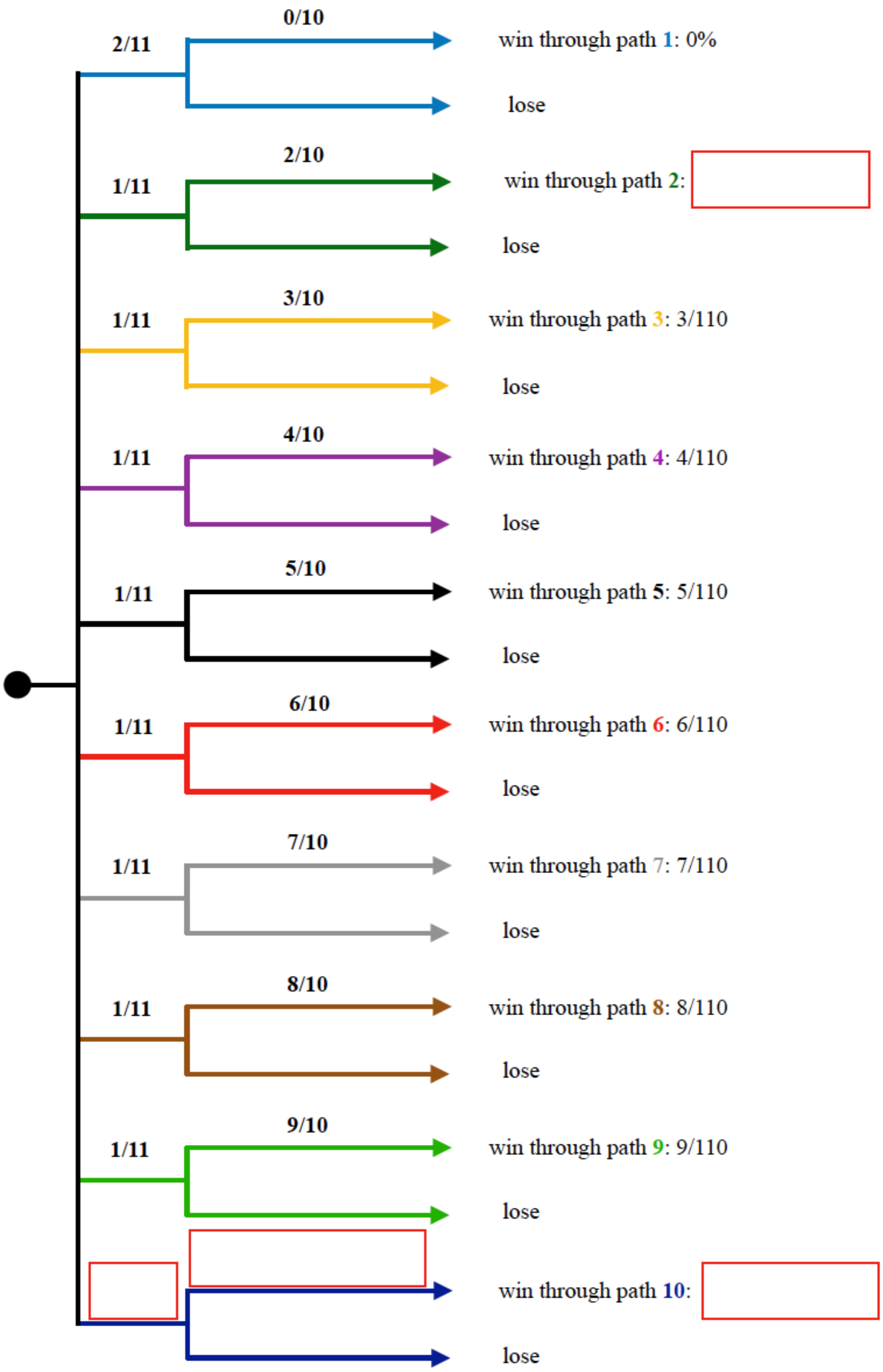
Problem

What is the probability of winning in this lottery?

Solution

We can represent all the paths to win this lottery in probability terms in Figure 3.

Figure 3: Paths and probabilities in example 3



The probability of winning the lottery is given by calculating the probability of winning through each of the 10 paths and summing them up. As there are 11 tickets in the bag, the probability of drawing each ticket is $\frac{1}{11}$. Thus, the probability of getting onto path 1 is $\frac{2}{11}$, and the probability of getting onto each of the other 9 paths is $\frac{1}{11}$.

Step 1: Calculating the probability of winning through path 1

We are on **path 1** if we draw number 1 from the bag, which happens with a probability of $\frac{2}{11}$. We now win with probability 0 because there is no W-ball in the box.

Step 2: Calculating the probability of winning through path 2

We have a $\frac{1}{11}$ chance of being on **path 2**, which occurs if we draw ticket 2 from the bag. The probability of now drawing a W-ball from the box is $\frac{2}{10}$. Therefore, the probability of winning through **path 2** is $\frac{1}{11} \times \frac{2}{10} =$ ________.

Step 3-10: Calculating the probability of winning through paths 3-10

We see that an analogous calculation applies to the remaining paths, that is, the probability of winning through paths **3**, **4**, **5**, **6**, **7**, **8**, **9** and **10** are respectively $\frac{3}{110}, \frac{4}{110}, \frac{5}{110}, \frac{6}{110}, \frac{7}{110}, \frac{8}{110}, \frac{9}{110}$, and $\frac{10}{110}$.

Just to be sure that you understand this, please fill out below how the probability of winning through **path 7** can be calculated:

We end up on **path 7** with a probability of ________. The probability of then drawing a W-ball from the box is ________.

Hence, the probability of winning through **path 7** is: ________ × ________ = ________.

Step 11: Calculating the total probability of winning the lottery

Please now calculate find the total probability of winning the lottery (on this sheet) as a percentage.

Best if you first calculate it as a fraction: $\frac{\quad}{110}$

And now use your calculator to find the percentage, as always round to a whole number:

The total probability of winning the lottery is: ________%

Example 3

Exact Rule on how the Box is filled

In this example, the number of W-balls in the box is determined as follows:

(1) If the ticket from the bag is 0-2, then there is 1 W-ball in the box.

(2) If the ticket from the bag is 3-4, then there are 3 W-balls in the box.

(3) If the ticket from the bag is 5, then there are 5 W-balls in the box.

(4) If the ticket from the bag is 6-7, then there are 7 W-balls in the box.

(5) If the ticket from the bag is 8-10, then there are 9 W-balls in the box.

Problem

What is the probability of winning in this lottery?

Solution

The probability of winning the lottery is given by calculating the probability of winning through each of the 5 paths and summing them up. As there are 11 tickets in the bag, the probability of drawing each ticket is $\frac{1}{11}$.

(1) If a ticket between 0 – 2 is drawn we are on path 1. So the probability of being on path 1 is $\frac{3}{11}$. If we are on path 1, then 1 of the 10 balls will be a W-ball, hence the probability of drawing a W-ball on path 1 is $\frac{1}{10}$. Therefore, the probability of winning through path 1 is $\frac{3}{11} \times \frac{1}{10} = \frac{3}{110}$.

(2) If a ticket between 3 – 4 is drawn we are on path 2. So the probability of being on path 2 is $\frac{2}{11}$. If we are on path 2, then 3 of the 10 balls will be W-balls, hence the probability of drawing a W-ball on path 2 is $\frac{3}{10}$. Therefore, the probability of winning through path 1 is $\frac{2}{11} \times \frac{3}{10} = \frac{6}{110}$.

(3) If the ticket with the number 5 is drawn we are on path 3. So the probability of being on path 3 is ___. If we are on path 3, then 5 of the 10 balls will be W-balls, hence the probability of drawing a W-ball on path 3 is __ . Therefore, the probability of winning through path 3 is ___ _______× _____= _____.

4) If a ticket between 6 – 7 is drawn we are on path 4. So the probability of being on path 4 is $\frac{2}{11}$. If we are on path 4, then 7 of the 10 balls will be W-balls, hence the probability of drawing a W-ball on path 4 is $\frac{7}{10}$. Therefore, the probability of winning through path 4 is ________ ____ ____$\frac{2}{11} \times \frac{7}{10}$ $= \frac{14}{110}$.

(5) If a ticket between 8 – 10 is drawn we are on path 5. So the probability of being on path 5 is $\frac{3}{11}$. If we are on path 5, then _____ of the 10 balls will be W-balls, hence the probability of drawing a W-ball on path 5 is ____. Therefore, the probability of winning through path 5 is ________________ × = _____ .

Calculating the total probability of winning the lottery

We can win the lottery either through either of the 5 paths, and therefore the total probability of winning this lottery is obtained by adding the probabilities of winning through paths 1 through 5: +______+______+______+________= _____ . Now simplify this fraction or use your calculator what percentage this probability to win equals: 50%.

Why is the probability of winning 50% in this example?

Why is the probability of winning 50% in this example? Let us write the example a little bit more clearly, by writing down how many W- balls *and* L-balls there are in the box, and reordering:

(1) If the ticket from the bag is 0 - 2, then there are 1 W-balls, and 9 L-balls in the box.

(5) If the ticket from the bag is 8-10, then there are 9 W-balls, and 1 L-ball in the box.

(2) If the ticket from the bag is 3-4, then there are 3 W-balls, and 7 L-balls in the box.

(4) If the ticket from the bag is 6-7, then there are 7 W-balls, and 3 L-balls in the box.

(3) If the ticket from the bag is 5, then there are 5 W-balls, and 5 L-balls in the box.

First look at paths 1 and 5:

Both happen with the same probability (in this case for each path $\frac{3}{11}$).

Path 1 has W-ball and 9 L-balls, while **path 5** is just the reverse, namely 1 L-ball and 9 W-balls. So, the low probability of winning on **path 1** ($\frac{1}{10}$) is exactly offset by the high probability of winning on **path 5** ($\frac{9}{10}$), because $\frac{1}{10}$ and $\frac{9}{10}$ are symmetric around $\frac{5}{10} = 50\%$ (that is, the average of $\frac{1}{10}$ and $\frac{9}{10}$ is 50%).

Then look at paths 2 and 4:

We reach paths **2** and **4** with the same probability (in this case for each path $\frac{2}{11}$).

Path 2 has 3 W-balls and 7 L-balls, while **path 4** is just the reverse.

So, the low probability of winning on **path 2** ($\frac{3}{10}$) is exactly offset by the high probability of winning on **path 4** ($\frac{7}{10}$), because the average of $\frac{3}{10}$ and $\frac{7}{10}$ is also ______.

Finally, look at path 3:

The probability of winning on **path 3** is 50%.

In conclusion:

The probability of winning through **path 3** is 50%.

For each of the other paths (e.g. path 2), there is always another path (e.g. path 4) which (i) we reach with equal probability, and (ii) where the probability of winning on that path and the probability of winning on the original path average to 50%. Therefore, the overall probability of winning of this symmetric lottery is just 50%.

A.2.2 Information sheets during attitude elicitations

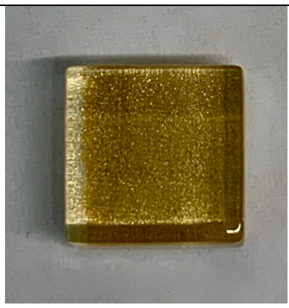
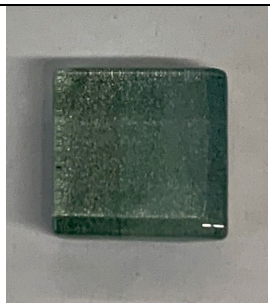
This package contains the detailed descriptions of the four envelopes you are given.

Transparent Envelope

The transparent envelope contains 100 chips, which are numbered from 1 to 100. There is exactly one chip for each number between 1 and 100 in this envelope. Hence, the probability to draw a particular number is 1%.

Black Envelope 1

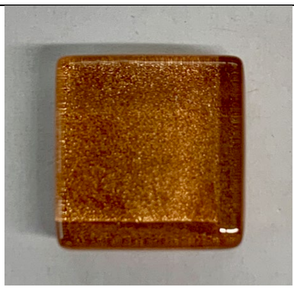
The black envelope 1 contains exactly 10 stones. Each stone is either golden or silver:

Golden	Silver
	

The exact composition of the envelope is unknown.

Black Envelope 2

The black envelope 2 contains exactly 10 stones. Each stone is either brown or copper.

Copper	Brown
	

The number of copper and brown stones in the envelope was determined as follows: A bowl was filled with 11 tickets, which were numbered from 0 to 10. One ticket was drawn at random. According to the number on that ticket, Black Envelope 2 was filled as follows:

If the ticket was 0, then 0 copper and 10 brown stones were put in the envelope.

If the ticket was 1, then 1 copper and 9 brown stones were put in the envelope.

If the ticket was 2, then 2 copper and 8 brown stones were put in the envelope.

If the ticket was 3, then 3 copper and 7 brown stones were put in the envelope.

If the ticket was 4, then 4 copper and 6 brown stones were put in the envelope.

If the ticket was 5, then 5 copper and 5 brown stones were put in the envelope.

If the ticket was 6, then 6 copper and 4 brown stones were put in the envelope.

If the ticket was 7, then 7 copper and 3 brown stones were put in the envelope.

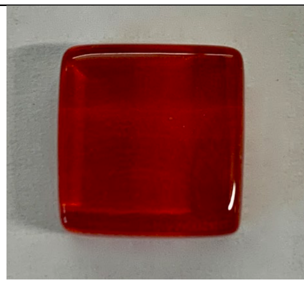
If the ticket was 8, then 8 copper and 2 brown stones were put in the envelope.

If the ticket was 9, then 9 copper and 1 brown stones were put in the envelope.

If the ticket was 10, then 10 copper and 0 brown stones were put in the envelope.

Black Envelope 3

Black Envelope 3 contains exactly 10 stones. Each stone is either green or red:

Green	Red
	

The number of green and red stones in the envelope was determined as follows: A bowl was filled with 17 tickets, which were numbered from 0 to 16. One ticket was drawn at random. According to the number on that ticket, Black Envelope 3 was filled as follows:

If the ticket was from the interval 0-4, then 0 green and 10 red stones were put in the envelope.

If the ticket was 5, then 1 green and 9 red stones were put in the envelope.

If the ticket was 6, then 2 green and 8 red stones were put in the envelope.

If the ticket was 7, then 3 green and 7 red stones were put in the envelope.

If the ticket was 8, then 4 green and 6 red stones were put in the envelope.

If the ticket was 9, then 5 green and 5 red stones were put in the envelope.

If the ticket was 10, then 6 green and 4 red stones were put in the envelope.

If the ticket was 11, then 7 green and 3 red stones were put in the envelope.

If the ticket was from the interval 12-14, then 8 green and 2 red stones were put in the envelope.

If the ticket was 15, then 9 green and 1 red stones were put in the envelope.

If the ticket was 16, then 10 green and 0 red stones were put in the envelope.

2017 Financial Information

Tencent Holdings Ltd. (TCEHY)

All of the following information refers to the company's fiscal year 2017, which coincides with the calendar year.

Tencent Holdings Ltd.[11] is listed on the Hong Kong Stock exchange. Tencent realized revenues of HKD[12] 274 billion. Earnings per share (EPS) were HKD 8.76. Tencent Holdings Ltd. paid an annual dividend of HKD 0.88 per share.

As you may know, this information can be used to estimate the stock price of Tencent Holdings Ltd. At the end of the session, you can look up the stock price of Tencent Holdings Ltd. on the official website of the Hong Kong stock exchange.

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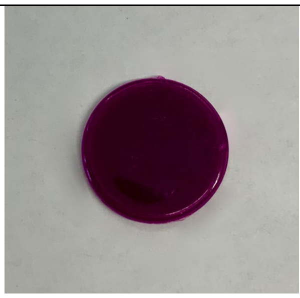
[11] Tencent Holdings Ltd. and its wholly-owned subsidiaries offer internet, mobile, and value added telecommunications services.

[12] ISO 4217 abbreviation for the Hong Kong Dollar.

Black Envelope 4

Black Envelope 4 contains exactly 8 chips. Each chip is either purple or orange:

Purple	Orange
	

The number of purple and orange chips in the envelope was determined as follows: A bowl was filled with 17 tickets, which were numbered from 0 to 16. One ticket was drawn at random. According to the number on that ticket, Black Envelope 6 was filled as follows:

If the ticket was 0-5, then 0 purple and 8 orange chips were put in the envelope.

If the ticket was 6, then 1 purple and 7 orange chips were put in the envelope.

If the ticket was 7, then 2 purple and 6 orange chips were put in the envelope.

If the ticket was 8, then 3 purple and 5 orange chips were put in the envelope.

If the ticket was 9, then 4 purple and 4 orange chips were put in the envelope.

If the ticket was 10, then 5 purple and 3 orange chips were put in the envelope.

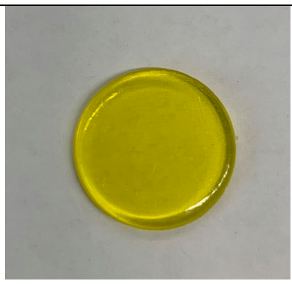
If the ticket was 11, then 6 purple and 2 orange chips were put in the envelope.

If the ticket was from the interval 12-15, then 7 purple and 1 orange chips were put in the envelope.

If the ticket was 16, then 8 purple and 0 orange chips were put in the envelope.

Black Envelope 5

The black envelope 5 contains exactly 8 chips. Each chip is either blue or yellow:

Blue	Yellow
	

The exact composition of the envelope is unknown.

Black Envelope 6

The black envelope 6 contains exactly 8 chips. Each chip is either white or black.

White	Black
	

The number of white and black chips in the envelope was determined as follows: A bowl was filled with 9 tickets, which were numbered from 0 to 8. One ticket was drawn at random. According to the number on that ticket, Black Envelope 5 was filled as follows:

If the ticket was 0, then 0 white and 8 black chips were put in the envelope.

If the ticket was 1, then 1 white and 7 black chips were put in the envelope.

If the ticket was 2, then 2 white and 6 black chips were put in the envelope.

If the ticket was 3, then 3 white and 5 black chips were put in the envelope.

If the ticket was 4, then 4 white and 4 black chips were put in the envelope.

If the ticket was 5, then 5 white and 3 black chips were put in the envelope.

If the ticket was 6, then 6 white and 2 black chips were put in the envelope.

If the ticket was 7, then 7 white and 1 black chips were put in the envelope.

If the ticket was 8, then 8 white and 0 black chips were put in the envelope.

2017 Financial Information

AIA Group Ltd. (1299.HK)

All of the following information refers to the company's fiscal year 2017, which coincides with the calendar year.

AIA Group Ltd.[13] is listed on the Hong Kong Stock exchange. AIA realized revenues of HKD[14] 301 billion. Earnings per share (EPS) were HKD 4.577. AIA Group Ltd. paid an annual dividend of HKD 0.89 per share.

As you may know, this information can be used to estimate the stock price of AIA Group Ltd. At the end of the session, you can look up the stock price of AIA Group Ltd. on the official website of the Hong Kong stock exchange.

[13] AIA Group Ltd. offers insurance and financial services.

[14] ISO 4217 abbreviation for the Hong Kong Dollar.