The Welfare Consequences of Processing Compound Risk*

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ABSTRACT: For consumers to make efficient financial decisions, the mapping of beliefs about probabilities of states of the world with potential outcomes is an important cognitive process. Many financial decisions, as a part of this mapping, require consumers to be able to process compound risk. This ability, and an individual's potential violations of the Reduction of Compound Lotteries (ROCL) axiom could play an important role in explaining demand and welfare for these financial products. We investigate this link in the context of insurance with compound risk, and show that individuals who violate ROCL excessively purchase insurance, leading to welfare losses. However, when these ROCL violators are given a decision aid that helps them process compound risk, they purchase less insurance and do no worse in terms of welfare than individuals who do not violate ROCL. An important policy implication of our findings is that average consumer welfare should increase if providers of financial products such as insurance, pensions and warranties, are required to inform consumers, transparently, and in a balanced manner, about the compounded probabilities of all potential states that the product does and does not cover.

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1 Introduction

The rapid expansion of access to finance, low levels of financial literacy of consumers, and increasing complexity of financial products raises serious concerns about the extent to which consumers are able to select a product that increases their welfare. Individuals making choices about insurance, for example, frequently choose products that appear financially inefficient from a consumer surplus perspective based on standard insurance demand models.[1] These findings are problematic from the perspective of the welfare of specific consumers because, *ceteris paribus*, they can improve their welfare by making different product choices. It also raises concerns about the functioning of insurance markets, where price and quality signals of insurance products are important for competition.[2] To explain the seemingly inefficient choices consumers make, a recent literature focuses on insurance demand models with non-standard preferences.[3] An alternative explanation may, however, be the inability of consumers to understand the often complex products that are offered to them.[4]

To be able to make efficient insurance choices, consumers need to be able to map beliefs about probabilities of states of the world to realized outcomes that occur when these states materialize. Consumers could have difficulty evaluating if, and under which conditions, an insurance contract will provide claim payments, for example because of misperceptions of coverage or obstacles in the claim procedure.[5] In this case, the insured needs to evaluate the likelihood of a loss as well as the likelihood that the insurance will cover the loss, conditional on its occurence. This, by definition, implies that the risk of loss to the consumer is a compound risk, as a result of perceptions of contractual non-performance (Doherty and Schlesinger, 1990). We focus on one specific cognitive challenge that is critical for this process: the ability to process compound risk. Behaviourally, the processing of compound risk and potential violations of the Reduction of Compound Lotteries (ROCL) axiom[6] could play an important role in explaining demand

[1] Sydnor (2010), Abaluck and Gruber (2011), Handel (2013) and Bhargava et al. (2017)

[2] See, for example, Heidhues and Kőszegi (2014) and Ho et al. (2017).

[3] See, for example, Casaburi and Willis (2018), Bleichrodt and Bruggen (2022).

[4] See, for example, Loewenstein et al. (2013), Handel and Kolstad (2015), Bhargava et al. (2017) and Handel and Schwartzstein (2018).

[5] Kling et al. (2012); Loewenstein et al. (2013) and Handel and Kolstad (2015).

[6] Many associate violations of ROCL with decision-making under uncertainty or ambiguity. This is correct, but not necessary. Consistent with the opening line of *Anna Karenina*, "All happy families are alike; each unhappy family is unhappy in its own way," when ROCL is violated there

and welfare for insurance products with risks of non-performance.

We show that individuals who struggle with processing compound risk, measured directly by violations of the ROCL axiom, excessively purchase insurance products with a risk of (perceived) contractual non-performance. However, when these ROCL violators are given a decision aid that helps them process compound risk, they purchase less insurance. We structurally estimate individual consumer welfare of each insurance decision in terms of individual preferences. As a prior for these individual preferences we elicit the decisions of each individual over numerous financial options that vary simple risk and compound risk, and estimate preferences at the individual level. We show that ROCL violators generate welfare losses. When the ROCL violators receive the decision aid, however, they do no worse in terms of welfare than individuals who do not violate ROCL. The aid that we use is simple: we multiply probabilities of the layers of risk, and explicitly inform subjects about the eventual likelihood of each outcome. An important policy implication of our findings is that average consumer welfare should increase if insurance supervisors and regulators require insurers to inform consumers, transparently, and in a balanced manner, about the compounded probabilities of all potential states that an insurance does and does not cover. While we focus on compound risk in insurance, generated by non-performance, results are likely to generalize to other decisions where contractual non-performance is relevant, such as pensions and warranties.

To be able to study the effect of variation in non-performance risk across many insurance products and to account for selection into information treatments that may effect both individual-level insurance purchase and welfare, we conducted a laboratory experiment with 101 student subjects at Georgia State University. Each individual was asked to make 54 insurance purchase decisions in which we varied the risk of contractual non-performance, as well as other actuarial parameters of the contract. The insurance decisions consisted of a compound risk, with the realization of an idiosyncratic personal risk of loss, and a separate realization of claim payments, which was correlated with the personal risk of loss. As a result, in the process of mapping outcomes to probabilities, subjects would have to multiply

are a lot of ways to model risk preferences. One involves just saying that people have different risk preferences for simple risks than they do for compound risks, but that those preferences are EUT-consistent apart from the nature of the risk. This was actually how Smith (1969) critiqued the claim that the thought experiments of Ellsberg (1961) *exclusively* reflected uncertainty or ambiguity. Other models might posit some (uncertainty or ambiguity) aversion to the multiple priors over compound risks that ROCL removes, and sharply differentiate this from risk aversion over simple risks: Harrison (2011, §4) explains with reference to popular models in the literature.

the personal risk of loss with the probability of a claim payment, conditional on a loss. Half of our subjects were randomly assigned to a treatment where they received, in addition to this standard representation of the compound risk, the decision aid. In the decision aid, which was presented as a pie-chart, we multiplied the probabilities of personal losses and the likelihood of a match of the claim payment for the subject, potentially helping them process compound risk. Actual realizations of risk were, however, exactly the same for all subjects, implying that the decision aid only provided those randomly assigned subjects with additional information.

Before making the insurance choices, subjects participated in an experiment where they made 100 decisions between two risky lotteries. These 100 decisions allow us to do two things. First, in these 100 decisions we included 10 lottery choices between a simple lottery and a compound lottery, as well as 10 corresponding lottery choices between the same simple lottery and a simple lottery that is actuarially-equivalent to the compound lottery in the paired choices. These 20 lottery pairs give us 10 direct, data-based tests of choice violations that we can use to measure the intensity with which people violate ROCL. It then allows us to investigate if the 54 decisions of each individual to purchase or not purchase insurance with compound risk are associated with individual violations of ROCL, and to assess if the decision aid that helps with processing of the compound risk leads to different purchase behaviour. To mitigate concerns about our measure of ROCL picking up random choice inconsistency or preferences for randomness,[7] we demonstrate that our results are robust to a measure of ROCL violations that only classifies individuals that choose to consistently avoid compound risk as ROCL violators (Section 6.3).

Second, these 100 choices between two risky lotteries also allow us to structurally estimate, at the individual-level, the risk preferences over simple and compound lotteries, as well as the *type* of risk preferences, including probability weighting, of the individual. Based on these estimated risk preferences we calculate the expected consumer surplus from each of the 54 decisions each individual makes to purchase or not to purchase the product, allowing us to calculate the welfare gains or losses from the observed decisions. This also allows us to relate these individual welfare gains and losses to the extent to which they violate ROCL,

[7]There is some tendency for subjects in experiments to exhibit choice inconsistency even when faced with pairs of literally identical simple lotteries (e.g., Becker et al. (1964), Hey (2001) or Agranov and Ortoleva (2017)), and some of the ROCL violations could be due to that underlying inconsistency. Our econometric estimates of risk preferences account for this underlying choice inconsistency by means of a behavioural (Fechner) error parameter, popularized by Hey and Orme (1994).

and to consider if our decision aid can play a role in enhancing welfare.

Out of the 5,454 decisions to purchase insurance or not that our subjects make, we find that 57% are decisions to purchase insurance. When subjects are presented with the decision aid that helps them process compound risk, this purchase rate is significantly lowered by 7%. This effect of the decision aid on insurance purchase is comparable to the effect of some of the traditional actuarial characteristics of the insurance contract. For example, as expected when assuming EUT, an increase in the premium loading between -12% to +12% in our experiment decreases purchase by about 6 percentage points. Subjects respond as expected to variations in the insurance premium loading, reducing purchase when the loading increases. However, they only respond to the likelihood of non-performance when they receive the decision aid that helps them process compound risk. With the decision aid they purchase less insurance, on average, if the likelihood of contract non-performance increases. We observe that 20% of the individuals in our sample consistently violate ROCL. When ROCL violators do not receive the decision aid, they are 20 percentage points more likely to purchase insurance than non-ROCL violators. However, with the decision aid ROCL violators do not appear to behave significantly differently from non-ROCL violators.

Despite actual purchase being observed in 57% of purchase decisions, our structural welfare evaluations show that, based on their risk preferences, subjects *should* only decide to purchase insurance in 13% of purchase decisions. A large share of welfare losses thus appears to be created by *excess purchase*. On average, there are no significant differences in welfare for individuals who receive the decision aid, as compared to those who do not receive the decision aid. However, the distributions of our individual-level welfare measures exhibit significant heterogeneity, which indeed appears driven by heterogeneity of ROCL violations. We find that ROCL violators, who purchase excessively in the frame without decision aid, generate significantly lower welfare by 26 percentage points, while ROCL violators do not generate lower welfare compared to non-ROCL violators in the frame with the decision aid. We show that these welfare results are robust to a welfare measure that assumes individuals are EUT maximizers (Section 5.1); a welfare measure that uses either EUT or Rank Dependent Utility (RDU) risk preferences for the individual, conditional on the model that best characterizes their choices (Section 6.1); or a welfare measure that allows individuals to have different preferences over simple and compound risk (source-dependent EUT), and therefore does not assume individuals behave consistently with ROCL (Section 6.2).

The insurance with compound risk we consider is index insurance. With an index insurance contract the insured gets coverage for an idiosyncratic personal risk of loss that they face that is positively correlated with an observable and verifiable public index, such as a weather index, and payments are only made on the basis of the index exceeding some trigger. Index insurance is a product which is compounded with a risk of non-performance, because the insured can experience a personal loss and not receive a payout (downside basis risk), or the insured can not experience a loss but receive a payout (upside basis risk). The imperfect correlation of personal loss *and* index loss is not present in traditional indemnity insurance contracts, but any indemnity insurance with the risk of default or non-performance by the insurance company exhibits downside basis risk as a result of compound risk, as modelled by Doherty and Schlesinger (1990) and Clarke (2016).

Index insurance has great potential to provide protection against aggregate risks such as weather risk, climate change, or pandemics because claims are based on observable and independently verifiable indices which are correlated with idiosyncratic losses, and thereby reduce moral hazard and adverse selection.[8] Index insurance has been an important component of the United States (US) Federal Crop Insurance programme[9] and the Common Agricultural Policy of the European Union (EU).[10] It is widely used as a risk management tool in developing countries, with large scale national programmes already being implemented in countries such as Kenya[11] and India.[12]

We make three contributions to the literature. First, we connect to a literature on the welfare of insurance.[13] We specifically contribute to a strand of this literature that investigates the role of information search and processing, insurance literacy and

[8] Moral hazard is reduced because there is little that the insured can do to affect the index outcome and hence the chance of a claim payment. Adverse selection is reduced because the contract does not differentiate between the correlation of the idiosyncratic risk and the index outcome, hence not making the contract more valuable conditional on the risk of personal losses.

[9] See `https://rma.usda.gov/en/Policy-and-Procedure/Insurance-Plans/Area-Risk-Protection-Insurance`

[10] See `https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/trade/documents/agri-market-brief-12_en.pdf`

[11] See the Kenyan Livestock Insurance Programme: `https://ibli.ilri.org/2019/03/19/the-kenya-government-declares-a-pay-out-of-ksh87-million-to-cushion-6000-pastoralists-from-the-effects-of-drought/`

[12] See the Weather-Based Crop Insurance Scheme that is part of the Government of India's national crop insurance "Pradhan Mantri Fasal Bima Yojana (PMFBY)" `https://pmfby.gov.in/pdf/FINAL_WBCIS_OGs_23.03.2016.pdf`

[13] See Cardon and Hendel (2001); Cohen and Einav (2007); Abaluck and Gruber (2011); Bundorf et al. (2012); Handel (2013); Harrison and Ng (2016); Harrison et al. (2020b) and Hendren (2021).

competence, and incorrect beliefs about coverage to explain suboptimal insurance choice.[14] Several studies have focused on interventions to enhance the quality of consumers' insurance decisions through providing information about the expected value, the distribution of expected expenditure, and expected utility of insurance plans.[15] We contribute to this literature by focusing on an individual's ability to process compound risk, measured through ROCL violations, and by designing and testing a decision aid that helps mitigate welfare losses that result from the inability to process compound risk.

We also make a methodological contribution to the welfare evaluation of insurance. A common structural approach in this literature backward-inducts risk preferences based on insurance decisions from administrative data[16] to conduct welfare analysis.[17] Handel and Kolstad (2015), Bhargava et al. (2017) and Samek and Sydnor (2020) have stressed the limitations of this approach if the insurance decision context is poorly understood by potential consumers. Recent structural approaches, to which we contribute, use individual-specific information as a prior, such as data on risk preferences, subjective beliefs, or historical losses, combined with models of behaviour, for the welfare evaluation of insurance, to then estimate the extent to which observed choices represent a welfare gain or welfare loss in terms of the individual-specific information.[18] This implies that even if products are not well-understood, as is the case in our setting, it is still possible to make statements about welfare gains and losses that are informative, and policies to improve decision quality can be tested.

We also connect to an approach in behavioural welfare economics that is not structural and remains agnostic about preferences and beliefs, but makes the assumption that a social planner is able to identify cognitive challenges that matter for welfare (Bernheim and Rangel, 2008, 2009; Ambuehl et al., 2022). One can then design interventions, or so-called choice frames, that remove or reduce these cognitive constraints while otherwise keeping the product that decision makers choose exactly the same. Changed decisions as a result of choice frames that removed cognitive constraints are then assumed,

[14] Handel (2013); Handel and Kolstad (2015); Bhargava et al. (2017); Handel and Schwartzstein (2018) and Harrison et al. (2022).

[15] See, for example, Kling et al. (2012), Samek and Sydnor (2020), Gruber et al. (2020), and Bundorf et al. (2019).

[16] To be able to infer risk preferences these studies assume that subjective expectations of risk are the same as actuarial estimates of risk.

[17] For example, Cardon and Hendel (2001); Cohen and Einav (2007); Bundorf et al. (2012); Handel (2013) and Hendren (2021).

[18] See Harrison and Ng (2016), Harrison et al. (2020a), Handel et al. (2020), and Ghili et al. (2021).

by direct revealed preference, to be welfare enhancing. In our setting with compound risk, a natural cognitive constraint that is *a priori*, likely to be welfare-relevant is the ROCL axiom. Our decision aid was designed so that a subject could choose to use the information that helped them with processing compound risk, thereby offering them a simpler choice set. We indeed observe that individuals who struggle with compound risk are less likely to purchase the insurance contract when presented with the decision aid intervention, suggesting that a lower likelihood of purchase is a welfare-enhancing choice for them. We contribute by showing that both the structural approach as well as the behavioural revealed preference approach proposed by Bernheim and Rangel (2008) and Ambuehl et al. (2022) point in the same direction in this application.

Our third contribution is to the understanding of index insurance as a policy mechanism. Despite its potential, demand for index insurance *appears* low and many interventions have focused on increasing index insurance take-up.[19] The contractual modifications inherent in index insurance imply, however, that the take-up of index insurance does not necessarily lead to an improvement in welfare for everyone. If that is the case, *low* demand may merely be a reflection of the fact that some consumers may be *better off* not purchasing the product. We contribute to this literature by demonstrating that indeed *excess* purchase of index insurance is an important driver of welfare losses. Many individuals who *do* take-up index insurance are actually worse-off in terms of welfare than they would have been without the insurance.[20] In terms of implications for consumer protection and supervision of index insurance and other financial products with compound risk, the use of choice architectures that communicate clearly the compound risk inherent in the product can play a substantial role in enhancing welfare, especially of those who struggle to process compound risk.

In Section 2 we present a conceptual framework with a simple model of the demand for insurance where information about compound probabilities that is presented to subjects differs. In Section 3 we lay out our experimental design motivated by this framework. Section 4 presents descriptives of ROCL violations, and the effects of our treatments on insurance purchase. We present our structural model of the welfare of insurance with compound risk in Section 5, and our welfare results in Section 5.1. In Section 6 we extend

[19]See Gaurav et al. (2011), Cole et al. (2013), Cole et al. (2014), Norton et al. (2014), Takahashi et al. (2016), Casaburi and Willis (2018), Belissa et al. (2019) and Ceballos and Robles (2020).

[20]The same welfare-focused perspective is provided by Carter and Chiu (2018) and Flatnes et al. (2018), using EUT assumptions on risk preferences.

our analysis by allowing for heterogeneity in welfare based on the *type* of risk preferences, by allowing for risk preferences that relax ROCL in our welfare evaluations, and considering behaviour and welfare if individuals consistently violate ROCL. In Section 7 we conclude and provide suggestions for policy and future research.

2 Conceptual Framework

We first present a simple model of a demand function for insurance where the information that is available to subjects about compound risk differs. This simple framework guides the design of our treatment with the decision aid. Next we discuss our experimental design in detail.

Assume an individual with a wealth endowment E and a personal loss event probability p_L. If there is a loss it has value L, leaving the individual with outcome $E - L$. If the individual does not purchase insurance, she faces a prospect $\{E - L,\, p_L;\, E,\, (1 - p_L)\}$ in the usual notation.

An index insurance contract differs from a standard indemnity insurance product because the contract might pay when the individual does not suffer a loss, and it might not pay when the individual does suffer a loss, depending on whether the index matches the actual loss of the individual. The probability that the index matches the outcome of the individual is m. This matching probability implies a correlation ρ between the individual's loss and the index outcome equal to $1 - (2 \times (1 - m))$. Therefore, in the case of the index insurance contract there are 4 possible outcomes, which we spell out in full to be explicit about the compound risks involved:

1. The individual pays the premium π, *experiences a loss* of L, and *the index differs* from the outcome of the individual. Hence the insurance does not pay out and the individual ends up with $E - \pi - L$. The compound risk of the individual having a loss and the index differing is $p_L \times (1 - m)$.

2. The individual pays the premium π, *experiences a loss* of L, and *the index matches* the outcome of the individual. Hence the insurance pays out L and the individual ends up with $E - \pi - L + L$. The compound risk of the individual having a loss and the index matching is $p_L \times m$.

3. The individual pays the premium π, *experiences no loss*, and *the index matches* the outcome of the individual. Hence the insurance does not pay out and the individual ends up with $E - \pi$. The compound risk of the individual not having a loss and the index matching is $(1 - p_L) \times m$

4. The individual pays the premium π, *experiences no loss*, and *the index differs* from the outcome of the individual. Hence the insurance pays out L and the individual ends up with $E - \pi + L$. The compound risk of the individual not having a loss and the index differing is $(1 - p_L) \times (1 - m)$.

If the index insurance product is presented in its compound form, with the p_L and m probabilities separately identified, we can assume a demand function D that is a function of the parameters:

$$D(p_L, m, \pi, E, L) \tag{1}$$

The first two arguments of this demand function reflect the fact that the information given to the subject consists of the two layers of the compound risk in the index insurance: the probability of a personal loss and the probability of the index matching the personal loss.

Alternatively, we can offer the individual a simple decision aid where we present the probabilities of the states after multiplying the probability of the personal loss with the probability of the index matching. This implies providing information to the subject about the reduced form of the compound risk, the actuarially equivalent, of the index insurance product:

$$D((p_L \times (1 - m)), (mp_L), ((1 - p_L) \times m), ((1 - p_L) \times (1 - m)), \pi, E, L) \tag{2}$$

Our experimental design is based on the assumption that individuals who do not violate the ROCL axiom will display the same insurance purchase behaviour independently of the representation of the compound risk in its compound form or if presented with a decision aid that provides the actuarially equivalent of the index insurance contract. Thus, with no violations of the ROCL axiom, (1)=(2).

However, if the person does not satisfy ROCL, this equality is not necessarily satisfied, and the insurance purchase behaviour in the representation with the decision aid can be higher or lower compared to an index insurance contract that presents probabilities in compound form. We are only varying information that the subject receives about probabilities. The actual presence of compound risk remains unchanged by the presence of the decision aid. In other words, the incentives remain the same across treatments because losses are still determined by a separate random process of the probability of loss and the matching probability. Our experimental design is guided by this simple and general framework that is based on the null hypothesis that index insurance purchase behaviour is not affected by our decision aid that presents the actuarially equivalent of the compound risk in the index insurance contract.[21] In effect, of course, our null hypothesis is that individuals correctly apply ROCL when evaluating these insurance choices.

3 Experimental Design

We conduct experiments with 101 student subjects at Georgia State University. Our primary decision task is an experiment where subjects make 54 insurance choices. Subjects can choose to purchase the insurance or not, and at the end of the experiment one choice is randomly selected for payment. We provide an endowment E of \$60 for each choice. Loss amounts L are either \$20 or \$35, and loss probabilities p_L are either 0.1 or 0.2. Premium loadings on actuarially-fair premia could be -30%, 0% or +30%, resulting in a premium π. We include negative loadings because index insurance premia are often subsidized. Finally, the index matching probability m could be 1, 0.8, 0.6, 0.4, 0.2 and 0. For the loss probability of 0.1, we considered all variants of loss amounts, matching probabilities, and premium amounts. For the loss probability of 0.2 we considered all variations of matching probabilities and premium amounts for the loss amount of \$35.

Before subjects make their 54 insurance choices they are randomly assigned to one of two treatments. In one treatment 53 subjects participate in the treatment called Index Insurance (II), where they make index insurance decisions while only receiving the information presented in Eq. (1), that is, probabilities are presented in compound form. In the other treatment 48 subjects participate in the treatment called Actuarially Equivalent (AE), where they see exactly the same information on the screen as the subjects in II, but

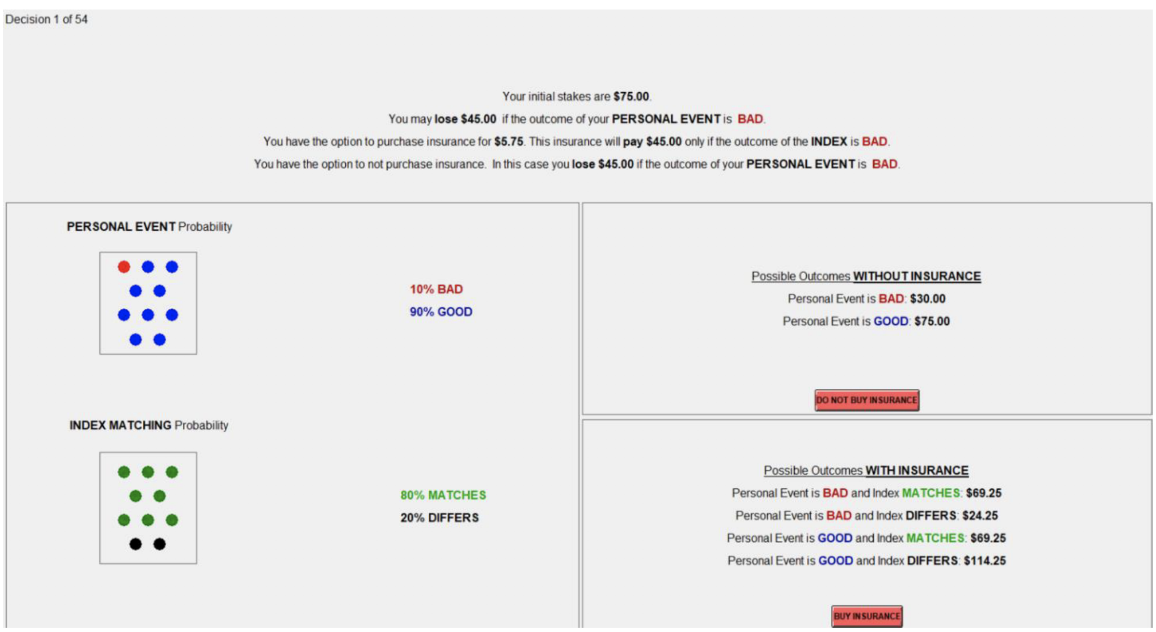
[21] In principle the provision of the decision aid could add some sort of "information overload," and generate other effects on purchase decisions. Our subjects already had experience with simple lottery representations using exactly the form of the decision aid, so we do not believe that such overload would be plausible.

they also receive the decision aid that provides them information about the actuarially equivalent probabilities as presented in (2). Instructions are provided in Appendix C (online).

3.1 Index Insurance without the decision aid

In this treatment, before subjects make their insurance purchase decisions they receive instructions about the insurance. The index insurance decisions are presented as shown in Figure 1. The probability of a personal event and the probability of the index matching are presented separately to the subjects. The monetary outcomes are also presented, based on the outcomes of the personal event and the index matching. At the top of the screen the initial endowment, the personal loss amount, the premium, and the claim payment in the event that the index is triggered, are also presented.

Figure 1: Example Screen of Index Insurance without Decision Aid



There are several important components of the logic of this task and the interface. The first is the use of the matching probability, m, between the personal loss and the index loss.[22] The second component of the task, and the interface, is the use of distinct colors for

[22]One might have assumed that a simpler implementation would have been to specify a target correlation of the two, and randomly generate a personal and index realization consistent with

the personal event (red and blue) and for the index matching (green and black). These colors are used to link the urns on the left to the payoffs on the right. To ensure credibility of the random processes described, realizations were implemented by drawing appropriately coloured chips from a "personal event" bag and an "index matching" bag. A third component of this task is the clear display of the two possible outcomes if the insurance is *not* purchased, and the four possible outcomes if the insurance *is* purchased. The four outcomes translate into only three distinct payoffs, but that redundancy is, we believe, valuable to help fully convey the operation of the product.[23]

3.2 Index Insurance with the decision aid

In the **Actuarially-Equivalent (AE)** task the index insurance decisions, as well as the realizations based on drawing coloured chips from a "personal event" bag and an "index matching" bag, are identical to the II task. The only difference in this treatment is the display on the screens, where we added "pie displays" showing the equivalent AE lotteries implied, where the probabilities of the personal event and index matching are multiplied and presented in the pie display along with the corresponding outcome. An example screen is presented in Figure 2. The instructions in the AE treatment were the same as for the II treatment, but complemented by extra information explaining the pie displays. The logic of the contract and underlying risk is explained in the same manner in the instructions for the II and AE treatments, so the natural context remains the same as in the II treatment.

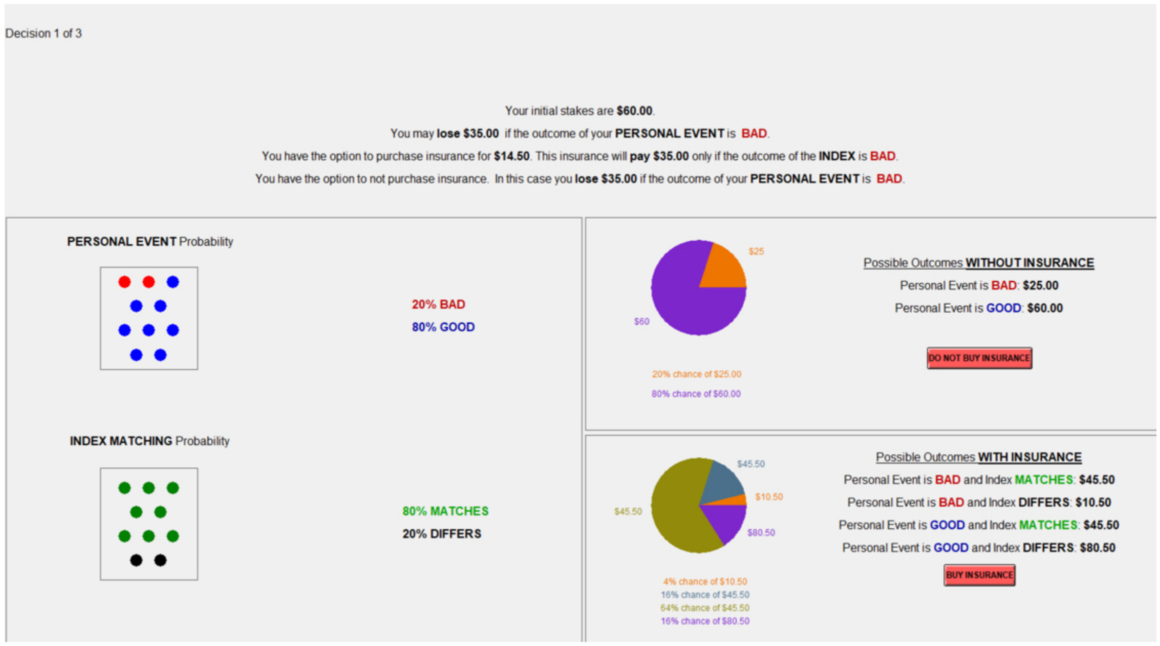
All of the insurance choices came after a risky lottery task, and were presented in random order.[24] The average payoff per subject for the II and AE insurance task was $57.88, with a standard deviation of $12.49.

that correlation. The logical difficulty is that one would need many such realizations for the subject to "experience" the intended sample correlation, and there would be some sample standard error around the experienced average correlation, raising additional issues of compound risk. Correlation is obviously a key actuarial parameter for this product. The method used here allows us to induce specific values for the correlation, and indeed to vary that from choice to choice.

[23]The only other experimental interface focused on index insurance that we are aware of was used in artefactual field experiments in Peru by Carter et al. (2008). Their design and interface was deliberately structured to mimic the field setting it was applied in, as a literacy treatment, whereas ours is deliberately structured to be more abstract, to allow evaluation of theoretical propositions. Each emphasis has a valid, and complementary, inferential role to play, as stressed by Harrison and List (2004). Carter et al. (2008) do not report results of the use of their literacy intervention.

[24]The insurance choices were programmed with the z-Tree software developed by Fischbacher (2007).

Figure 2: Example Screen with Actuarially-Equivalent Probabilities



3.3 Risky Lottery Choices

To be able to estimate the risk preferences of individuals over simple risk and compound risk, we use a task in which subjects are asked to make choices between 100 pairs of risky lotteries. In addition to its presentation of risk in a simple risk or compound risk form, we consider it to be attractive because it allows us to structurally estimate risk preferences for both EUT and non-EUT models, also taking into consideration that individuals make behavioural errors that we account for.

The 100 pairs of lotteries were designed to provide evidence of risk aversion as well as the tendency to make decisions consistently with EUT or Rank Dependent Utility Theory (RDU) models. The battery is based on designs from Loomes and Sugden (1998) to test the Independence Axiom, designs from Harrison and Swarthout (2022) to evaluate Cumulative Prospect Theory (CPT)[25] models of risk preferences, designs from Harrison et al. (2015) to test violations of the ROCL axiom, and a series of lotteries that are actuarially-equivalent

[25] Although we have risk lotteries that allow estimation of models of EUT, RDU, and a model of Cumulative Prospect Theory (CPT), we focus on the implications of estimating risk preferences using EUT and RDU. One reason is that there is little evidence of CPT behavior in this population, documented by Harrison and Swarthout (2022). Another reason is that we want to focus on different issues concerning the type of risk preference: whether one is an EUT or RDU decision-maker, and whether one obeys ROCL or not.

versions of some of our index insurance choices.

3.4 Measuring ROCL Violations

To measure if individuals violate ROCL, Harrison et al. (2015) designed a revealed preference battery to non-parametrically test for violations of the ROCL axiom. Each subject was given 10 lottery choices between a simple lottery and a compound lottery, as well as 10 corresponding lottery choices between the same simple lottery and a simple lottery that was actuarially-equivalent to that compound lottery. The two lotteries in these pairs were randomly assigned for presentation, and were not presented contiguously.

Our ROCL battery is designed to generate trade-offs in terms of foregone Expected Value (EV) that an individual that behaves consistently with ROCL would not care about. For instance, consider lottery pair *rdon12* and lottery pair *rae12* in our battery.[26] The Left (Right) lottery in both *rdon12* and *rae12* are exactly the same, except that in *rdon12* the Right lottery is presented in compound form while in *rae12* it is presented in reduced form. Moreover, both in *rdon12* and *rae12*, the Left lottery has an EV of 43.75 and the Right lottery has an EV of 52.5, with an EV difference of 8.75. A person that satisfies ROCL would make consistent choices both in *rdon12* and *rae12*: if the person chooses the Left (Right) lottery in *rdon12*, then the person should choose Left (Right) lottery in *rae12*.

An individual that violates ROCL, however, will not have consistent choices when comparing *rdon12* and *rae12*. For example, say the individual chooses the Right lottery in the *rae12* lottery pair, but then chooses the Left lottery when presented with *rdon12*. This is a choice pattern inconsistent with ROCL. This behavior implies that the person is willing to forego $8.75 in EV to avoid the Right (compound) lottery in favor of the Left (simple) lottery. This would be a violation of ROCL consistent with people displaying risk aversion towards compound risk that can be identified by observing how much the person is willing to forego in terms of EV to avoid a compound lottery that was previously preferred but when presented in reduced form.

Our ROCL battery has 10 such lottery pair comparisons to identify ROCL violations, where we vary the difference in EV between the compound lottery and the simple lottery to provide trade-offs that allow us to identify the strength of attitudes towards compound

[26] These are described numerically in Tables E.2 and E.4 in Appendix E. The numerical values are not needed for the point being made here.

risk.[27] We count the number of the 10 pairs where each subject does not make ROCL-consistent choices and we use this as a measure of the degree to which each subject deviates from the ROCL axiom.[28] This measure is agnostic about the reason for the choice inconsistency. There is some tendency for subjects in experiments to exhibit choice inconsistency even when faced with pairs of literally identical simple lotteries, and some of the ROCL violations could be due to that underlying inconsistency. Nonetheless, they are still violations of ROCL. Our econometric estimates of risk preferences account for this underlying choice inconsistency by means of a behavioural (Fechner) error parameter, popularized by Hey and Orme (1994). For robustness, we also use a measure of ROCL violations that only classifies individuals that choose to consistently avoid compound risk as ROCL violators. These results are presented in Section 6.3.

4 Descriptives and Insurance Purchase

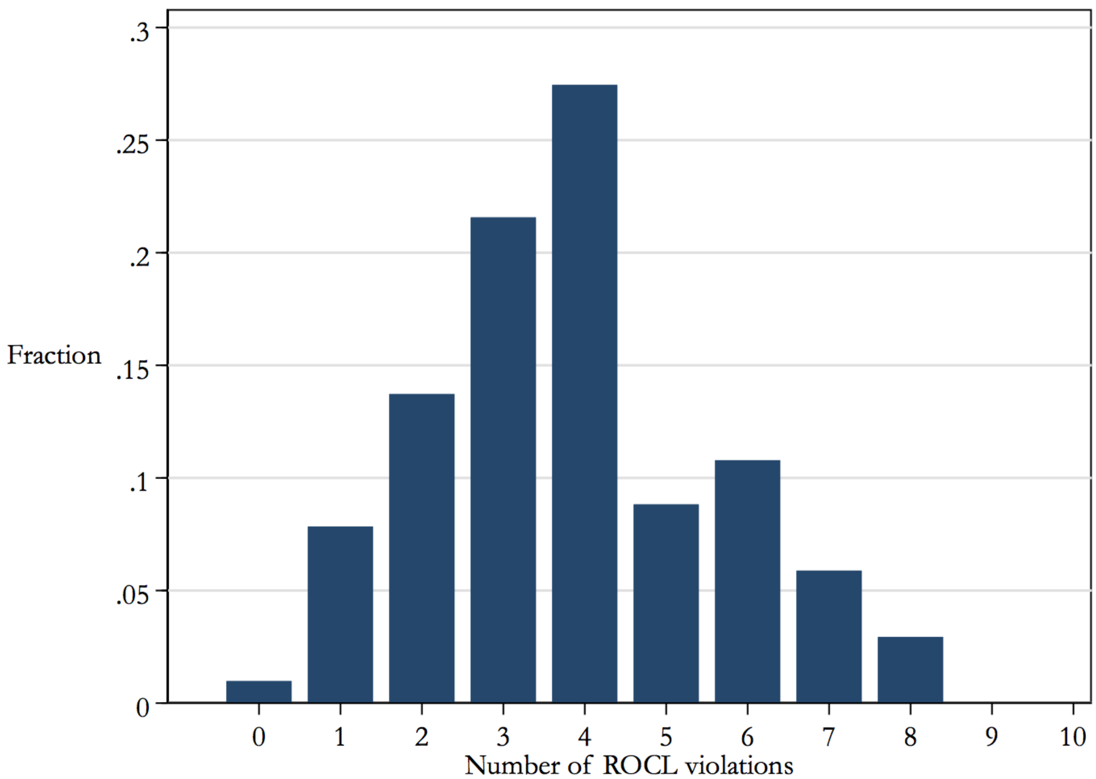
Figure 3 shows that our subjects violate ROCL between zero and eight times and that 72% makes 4 or fewer ROCL violations out of 10. We characterize individuals as ROCL-violators if they violate the ROCL consistent choice in more than half out of the ten ROCL violation tests. Based on this categorization, 20% of the individuals in our sample are characterized as ROCL-violators.

Table 1 shows that our randomization to the II and AE treatments was successful in terms of observable characteristics. Columns 1 and 2 in Table 1 show the means and standard deviations of key covariates of the subjects in our sample by treatment assignment. The column "*t*-test difference" presents the difference in means between each of the treatments, and none of the differences is statistically significant. The last column presents the normalized differences in means following Imbens and Rubin (2015, §14.2). The F-test of joint significance is presented in the bottom row and is also not significant.

[27]The EV differences of the compound lottery and simple lottery are: -17.5, 0, 1.25, 2.5, 7.5, 8.25, 20 and 25.

[28]The compound lotteries are constructed by visually presenting two simple lotteries, but having some "double or nothing" option for one of them: Appendix E documents these 20 lottery pairs.

Figure 3: Histogram of the Number of ROCL Violations per Subject



Note: Histogram of the number of ROCL violations per subject (N=101) out of 10, based on a revealed preference measure of ROCL violations where each subject was given 10 lottery choices between a simple lottery and a compound lottery, as well as 10 corresponding lottery choices between the same simple lottery and a simple lottery that was actuarially-equivalent to that compound lottery. For each subject we count the number of pairs out of the 10 where the subject does not make ROCL-consistent choices.

Table 1: Covariate Means and Balance

Variable	(1) AE Mean/SD	(2) II Mean/SD	T-test Difference (1)-(2)	Normalized difference (1)-(2)
Female	0.583	0.528	0.055	0.110
	(0.498)	(0.504)		
Age in years (> 18)	6.354	7.057	-0.702	-0.187
	(3.522)	(3.954)		
Black	0.812	0.849	-0.037	-0.097
	(0.394)	(0.361)		
Single	0.958	1.000	-0.042	-0.298
	(0.202)	(0.000)		
Household members	2.875	2.868	0.007	0.004
	(1.709)	(1.676)		
Business major	0.250	0.283	-0.033	-0.074
	(0.438)	(0.455)		
High GPA	0.542	0.528	0.013	0.027
	(0.504)	(0.504)		
Working part-time or full-time	0.792	0.698	0.094	0.213
	(0.410)	(0.463)		
Money spent per day	16.875	16.189	0.686	0.056
	(13.122)	(11.619)		
Christian	0.688	0.755	-0.067	-0.149
	(0.468)	(0.434)		
ROCL violations	4.146	3.566	0.580	0.325
	(1.798)	(1.738)		
N	48	53		
F-test of joint significance (F-stat)			0.952	
F-test, number of observations			101	

Notes: The value displayed for t-tests are the differences in the means across the groups. The value displayed for F-tests are the F-statistics. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Note: The value displayed for t-tests are the differences in the means across the groups. The value displayed for F-tests are the F-statistics. The last column present the normalized differences proposed by Imbens and Rubin (2015, §14.2): the difference in the sample means of experimental arms divided by the square root of the sum of the sample variances. "Household members" refers to the number of household members in the household. "High GPA" represents a Grade Point Average score higher than 3.25 out of 4. "ROCL violations" refers to the number of ROCL violations out of 10.

4.1 Insurance Purchase

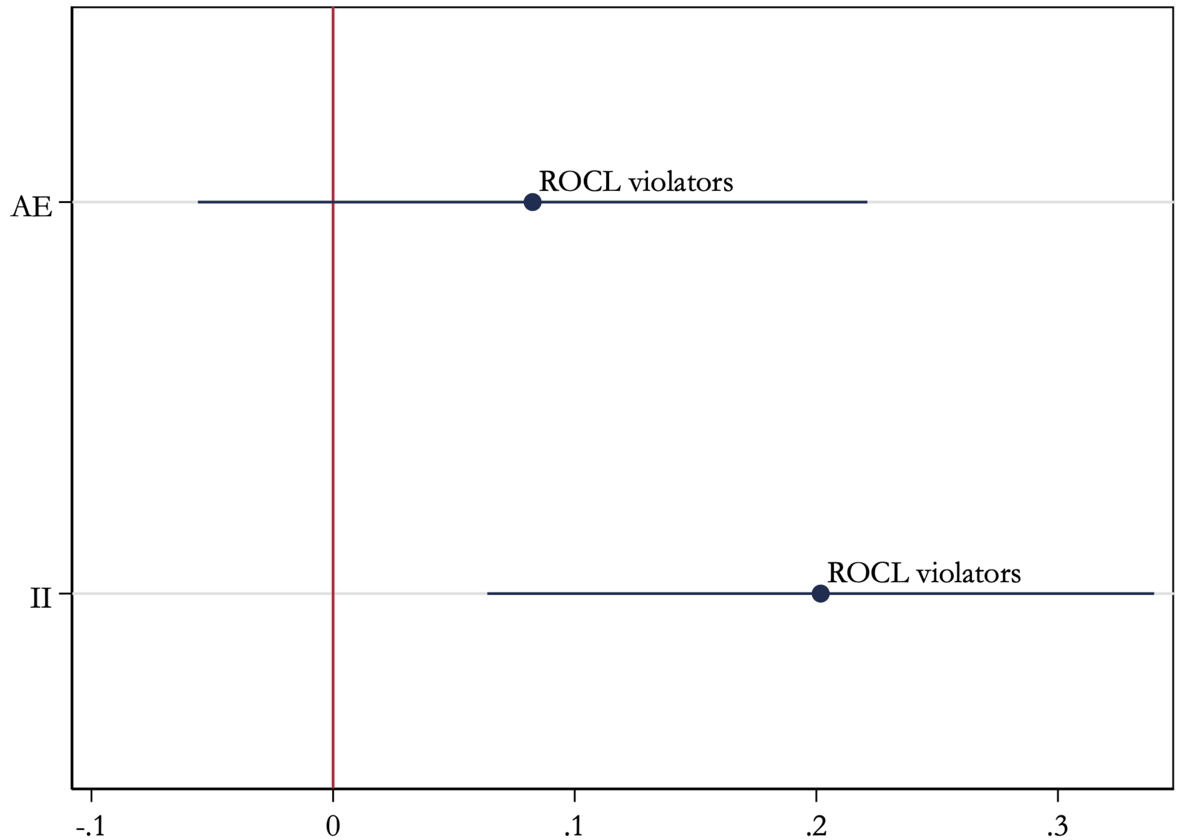
In the II treatment we observe that 58% of the decisions are decisions to purchase insurance, rather than not purchase insurance. In the AE treatment where subjects are also presented with the reduced form version of the risk, we observe a 4 percentage points reduction in the purchase rate. This difference in purchase across the II and AE frame is significant at the 1 percent level. This effect of the AE treatment on insurance purchase is comparable to the effect of some of the traditional actuarial characteristics of the insurance contract. For example, in terms of actuarial characteristics, as expected when assuming EUT preferences, an increase in the loading, which was experimentally varied between -12% to +12%, decreases purchase by about 6 percentage points in both the II and the AE frame. From the perspective of insurance as a risk management product, an increase in the matching probability, and thus a decrease in the likelihood of contractual non-performance, should increase the likelihood of purchase. In the experiment the matching probability was varied between 0 and 1, and its effect on purchase has a different sign in the II and the AE treatment. Its effect on purchase is negative but not significant in the II treatment, but is positive and marginally significant in the AE treatment, suggesting that insurance contract quality does not affect purchase in the II treatment, but does affect purchase in the AE treatment in the expected direction.

ROCL violations significantly affect the purchase of index insurance. ROCL violators are significantly more likely to purchase index insurance by 13 percentage points (p-value 0.025). Figure 4 shows that this effect is driven by the purchase decisions of individuals in the II frame, where ROCL violators are 20 percentage points more likely to purchase insurance in the II frame than individuals who are not characterized as being ROCL violators. This difference is statistically significantly different from zero (p-value 0.016). Although ROCL violators appear more likely to purchase index insurance in the AE frame, the difference from non-ROCL violators is not significant (p-value 0.327). The effect is not significantly different across the AE and II treatment.

5 Welfare of Insurance with Compound Risk

The objective of insurance is, *ex ante* any actual loss, to reduce the expected variability of consumption, by having the individual pay an insurance premium now, in

Figure 4: Insurance Purchase and ROCL violations



Note: Predicted probability of purchase and 90% confidence intervals from panel logit regressions of the interactions of "ROCL violator's' (versus "non-ROCL violators") and treatment on purchase. An individual is characterized as a ROCL violator if they violate ROCL in more than 5 out of the 10 tests for ROCL violations. 20% of our subjects are classified as a ROCL violator. AE refers to the Actuarially Equivalent treatment (N=48) and II refers to the Index Insurance treatment (N=53). For each of the regressions the number of individuals is N=101 and the number of observations is N=5,454. Regressions control for demographic and actuarial characteristics, and standard errors are clustered at the individual level.

exchange for a claim payment later, in case the future state is realised where there is a loss. Therefore we focus on an assessment of the expected welfare of buying insurance to an individual compared to the expected welfare of not buying insurance for the same individual. We refer to this measure as the Expected Consumer Surplus (ECS) of insurance decisions. We use this measure because insurance is an *ex ante* risk management product, and from that perspective should be evaluated in terms of the value of its *ex ante* protection, rather than in terms of its realised consumer surplus conditional on the realisation of states. To explain the calculation of ECS from the observed choice to purchase insurance or not to purchase insurance we use one of the specific examples given to our subjects (displayed as Figure 1).

Let there be an endowment of \$60, and a loss probability to the individual of 20%. If there is a loss, it has value \$39, leaving the individual with \$21 = \$60 - \$39. This is a lottery {\$21, 0.2; \$60, 0.8} in the usual notation, for an individual that *does not purchase* insurance. This lottery has an Expected Value (EV) of \$52.20 = \$21 × 0.2 + \$60 × 0.8.

Assume for now that the individual behaves consistently with EUT, and has a Power utility function $u(x) = x^r$ with parameter r = 0.507, the estimated average of our sample. Then the Expected Utility (EU) of this lottery in which the individual *does not purchase* insurance is defined by:

$$EU_{NP} = u(\$21) \times 0.2 + u(\$60) \times 0.8 = (\$21)^{0.507} \times 0.2 + (\$60)^{0.507} \times 0.8 = 7.31$$

The Certainty Equivalent (CE) of this lottery is the CE_{NP} value that solves $u(CE_{NP}) = EU_{NP}$. With the assumed utility function, the CE is defined by:

$$CE_{NP} = (EU_{NP})^{(1/0.507)} = (7.31)^{(1/0.507)} = \$50.62$$

We now repeat the logic of this calculation to obtain the CE when *purchasing* an index insurance contract. We can represent this lottery following the usual notation as {\$8.50, 0.04; \$47.50, 0.16; \$47.50, 0.64; \$86.50, 0.16}. This lottery has an EV of \$52.18, slightly lower than the EV of the lottery in which no insurance is purchased. This lottery has an EU defined by:

$$
\begin{aligned}
EU_P &= u(\$8.50) \times 0.04 + u(\$47.50) \times 0.16 + u(\$47.50) \times 0.64 + u(\$86.50) \times 0.16 \\
&= (\$8.50)^{0.507} \times 0.04 + (\$47.50)^{0.507} \times 0.16 + (\$47.50)^{0.507} \times 0.64 + (\$86.50)^{0.507} \times 0.16 \\
&= 7.32
\end{aligned}
$$

For an individual that follows this preference representation, deciding to purchase the index insurance has a CE of $CE_P = \$50.69$.

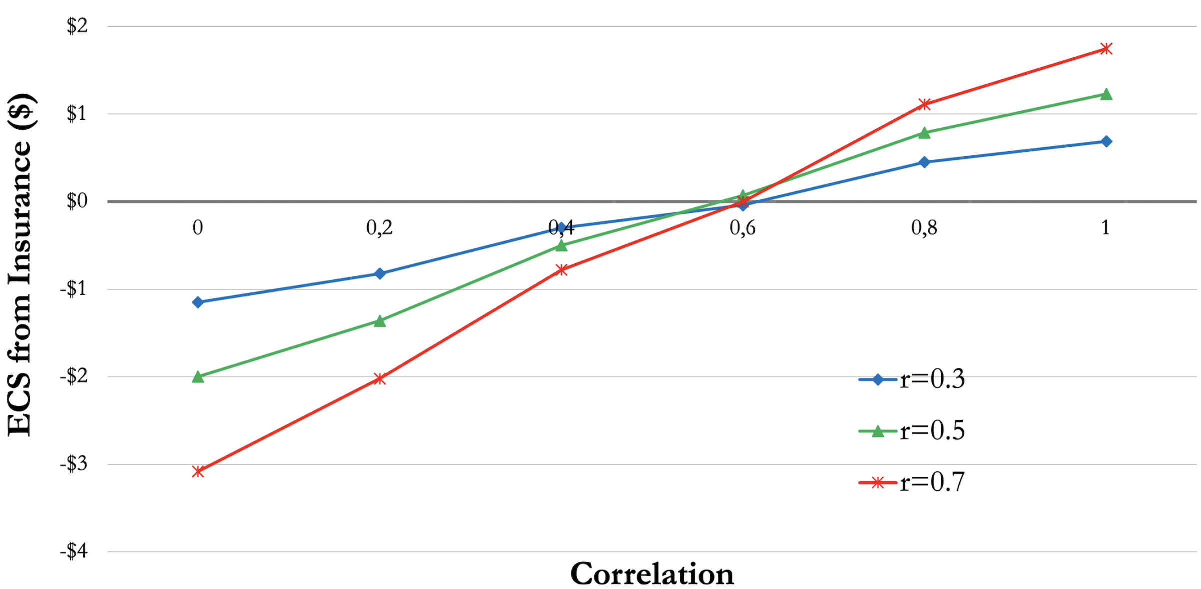
Comparing the two lotteries defined by buying index insurance and by not buying insurance with this degree of risk aversion, the individual gains an ECS of $\$0.07 = CE_P - CE_{NP} = \$50.69 - \$50.62$ from purchase. Again, this is the *Expected* CS, since it refers to all payouts from all possible events when they are weighted by their probabilities of occurring. It is unrelated to the actual realization of the loss or the index.

The same calculation can be repeated for different levels of risk aversion. We already know from the EV calculations that the ECS for a risk-neutral individual would be slightly negative, and equal to $-\$0.02 = \$52.18 - \$52.20$. If the individual was more risk averse than the average, with $r = 0.3$ say, then the ECS would increase to \$0.12; and if the individual was less risk averse than the average, with $r = 0.7$ say, then the ECS would decrease to \$0.02. Hence if we know the risk aversion of each subject, we can calculate the ECS from making either the purchase decision or the non-purchase decision.

To provide concrete illustrations, assume utility follows a constant relative risk aversion (CRRA) specification so that $U(x) = \frac{x^{(1-r)}}{(1-r)}$, where x is the monetary outcome and $r \neq 1$ is a parameter to be estimated. Thus r is the coefficient of CRRA under EUT, such that $r = 0$ corresponds to risk neutrality, $r < 0$ to risk loving, and $r > 0$ to risk aversion. The CE for lottery α is then $CE_\alpha = [EU_\alpha \times 1 - r]^{1/(1-r)}$. Values between 0.3 and 0.7 are typical for our subjects.

Figure 5 shows how the ECS varies for this index insurance product across the risk parameter r, assuming the individual has EUT preferences. We assume an endowment of \$60, a loss amount of \$35, and a loss probability of 0.2. When there is perfect correlation and $m = 1$, so the outcome of the individual always matches the outcome of the index, the ECS is larger if the individual is more risk averse. This follows from the fact that more risk averse individuals are willing to pay more for insurance. This is a special case of the index insurance contract, where there is no basis risk and the compound lottery collapses into a simple indemnity contract. As correlation decreases, so the probability of the outcome of the individual matching the index outcome decreases, the downside basis risk causes the ECS to decrease. A sufficiently large decrease in correlation for this insurance product results in negative ECS. This shows that the *level* of EUT risk preferences of the individual, as measured by the utility parameter r, and the correlation, can affect whether the individual's decision to purchase insurance would result in an expected welfare gain or loss, as stressed by Clarke (2016). The intuition is simple: for an EUT individual with high enough risk aversion, a decrease in correlation between the index and the individual loss is equivalent to an increase in risk, which translates in turn into lower welfare for the individual. Rather than having an insurance product that *reduces* variability of final outcomes for a fixed premium, the index insurance product *increases* variability of final outcomes.

Figure 5: Expected Consumer Surplus Under EUT Risk Preferences

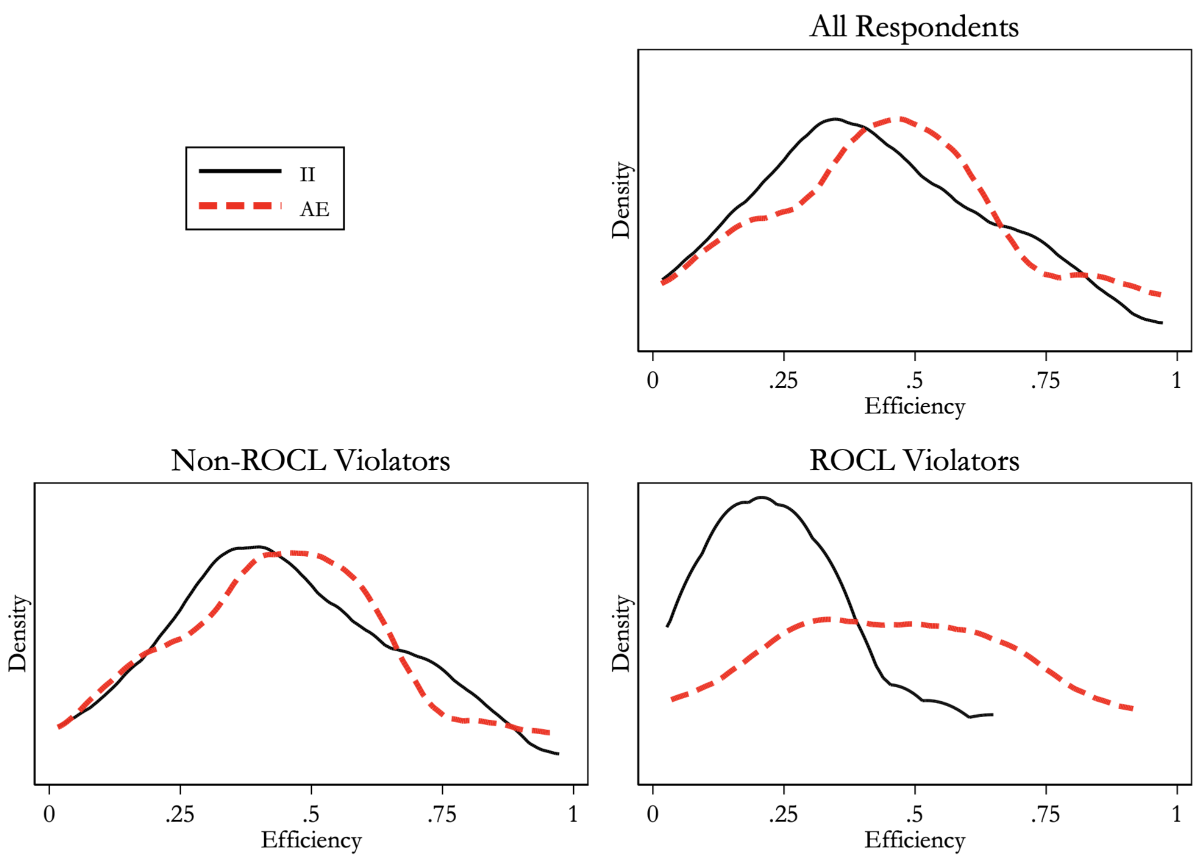


Note: The horizontal axis represents the correlation between the index and the personal loss. The vertical axis represents the ECS from insurance as we vary the coefficient, r, of the CRRA utility function under EUT.

5.1 Structural Welfare Evaluation

Based on the risk preferences we elicited from our subjects, as well as the actuarial parameters of the insurance contracts on offer, take-up was only predicted to occur 13% of the time, while take-up actually occurred 57% of the time. This alerts us to the fact that "excess purchase" likely generated welfare losses.

Figure 6: Efficiency Distribution for ROCL Violators and non-ROCL Violators

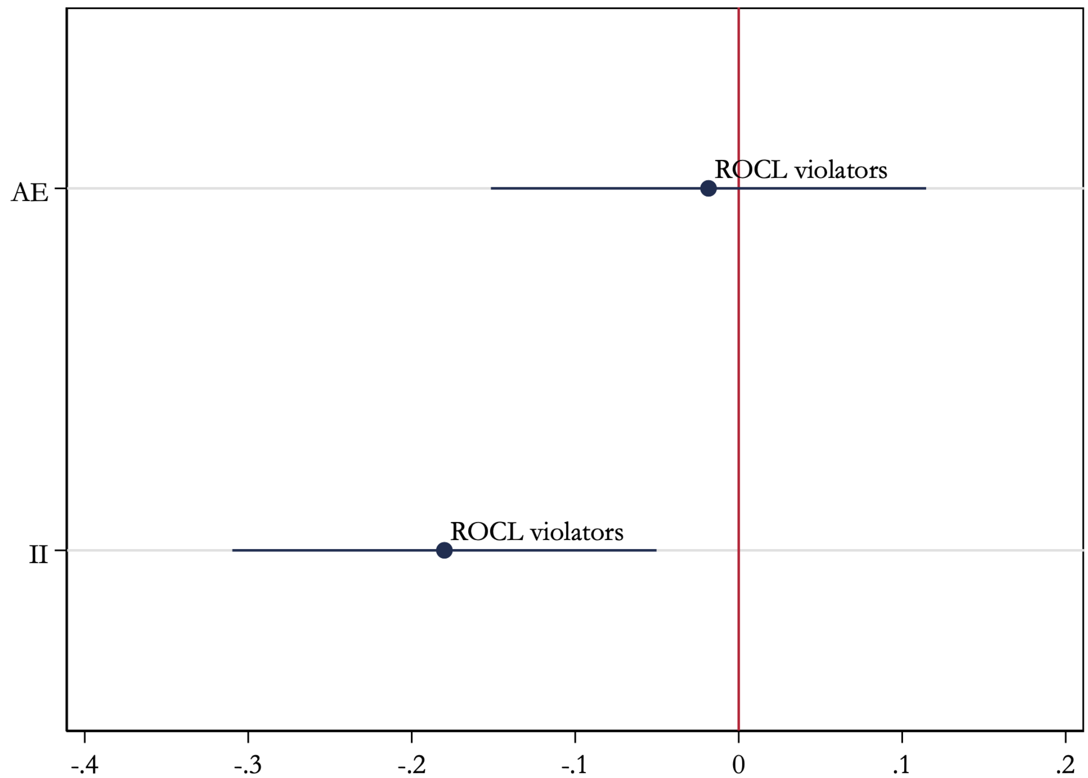


Note: II refers to Index Insurance treatment and AE refers to Actuarial Equivalent treatment. Each subject makes 54 decisions to purchase insurance or not. The Efficiency measure is calculated at the level of the individual using their estimated EUT risk preferences.

The building block of our evaluation of welfare is the ECS gained or foregone when an individual makes a decision to purchase or not purchase insurance. Our primary welfare measure for the *individual* is Efficiency defined over all 54 insurance choices. The top panel in Figure 6 displays the Efficiency distributions of the II treatment and the AE treatment.

Average Efficiency for the AE treatment is 49% and average Efficiency for the II treatment is 48%. While we generally observe a shift of the distribution towards higher Efficiency in the AE frame, the means in the two frames are not statistically significantly different from each other. However, when we analyze the Efficiency distributions for ROCL violators and non-ROCL violators we can observe that ROCL violators in the II treatment appear to generate lower Efficiency than those in the AE treatment.

Figure 7: Welfare and ROCL violations



Note: Predicted marginal effect on Efficiency and 90% confidence intervals from Beta regressions on Efficiency calculated with EUT preferences of individuals who are classified as "ROCL violators" and "no ROCL violators." An individual is characterized as ROCL violator if they violate ROCL in more than 5 out of the 10 tests for ROCL violations. AE refers to the Actuarially Equivalent frame (N=48) and II refers to the Index Insurance frame (N=53). For each of the regressions the number of individuals is N=101. Regressions control for demographic and actuarial characteristics, and standard errors are clustered at the individual level.

Figure 7 shows that the significantly higher levels of purchase in the II frame by ROCL violators than we observed in Figure 4 translate into *significantly* lower levels of welfare for ROCL violators. In the AE frame there is no significant difference between

ROCL violators and non-ROCL violators (p-value 0.820) while there is a large and significant difference in terms of welfare in the II frame. ROCL violators experience 18 percentage points lower Efficiency in the II frame, and this effect is significantly different from zero at the 5 percent level (p-value 0.022).

6 Welfare and Heterogeneity in Risk Preferences

6.1 Heterogeneity in Type of Risk Preferences

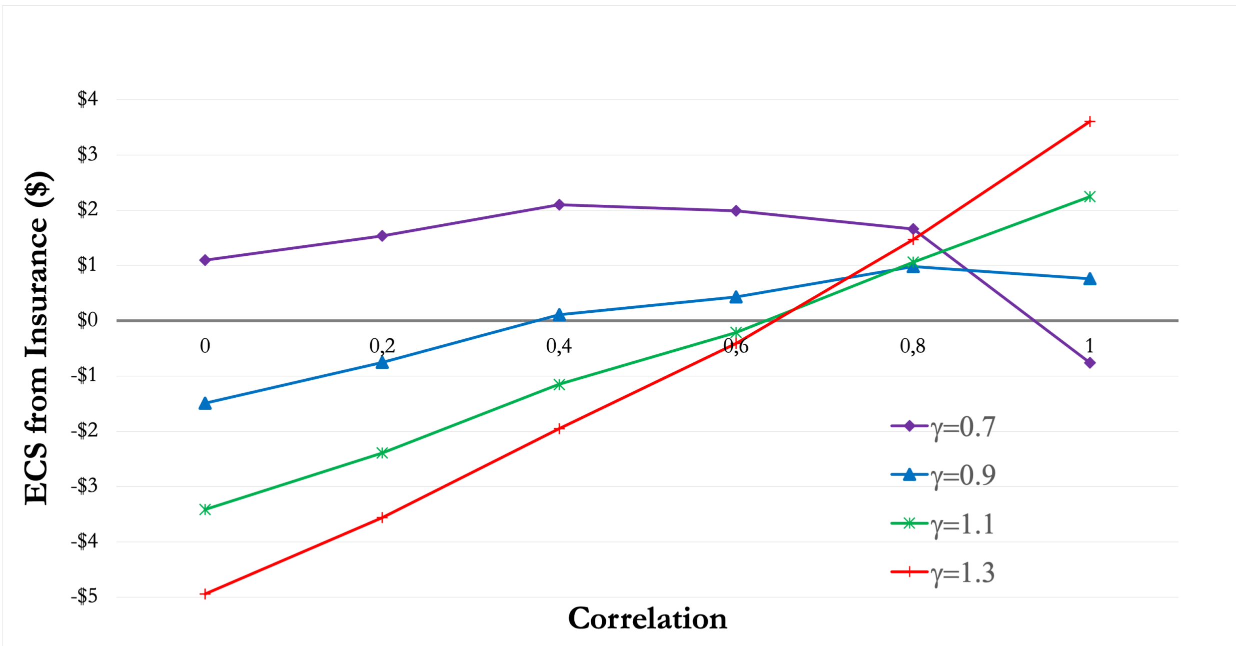
In our structural welfare evaluation we assumed that individuals behave consistently with EUT risk preferences, and heterogeneity was captured by the *level* of risk aversion of the individual. We can explore the welfare implications if we also allow for heterogeneity in the *type* of individual risk preferences by allowing for characterization, at the individual-level, of EUT or RDU preferences. We classify the risk preferences of each individual in Appendix B, based on with tests of the null hypothesis that there is no probability weighting $\omega(p) = p$ and a 5% significance level for this test.[29] These estimates and hypothesis tests are undertaken for each subject. Just over 50% of the subjects are classified as RDU with a Prelec (1998) probability-weighting function $\omega(p) = exp(-\eta(-\ln p)^{\phi})$, defined for $0 < p \leq 1$, $\eta > 0$ and $\phi > 0$. EUT is the next most common model, reflecting the behavior of 44% of the subjects. The remaining subjects are best characterized by RDU with a Power or an Inverse-S probability weighting function.

When we recognize that a substantial fraction of subjects behave consistently with RDU rather than EUT we need to recognize that the RDU utility function and the probability weighting functions have implications for the ECS. Therefore we evaluate the RDU^1 and RDU^0 of the lottery using the estimated U^{RDU} utility function and the estimated probability weighting function.We can then evaluate the corresponding CE^1 and CE^0 using this U^{RDU} function. It is apparent that the RDU preferences can have very different effects on the valuation of the risky prospects than the EUT preferences,even for the same individual.

Figure 8 shows how ECS varies as correlation decreases, but now assuming, for ease of exposition, an RDU decision-making model with a Power probability weighting function

[29] Appendix B (online) repeats the detailed results.

Figure 8: Expected Consumer Surplus Under RDU Risk Preferences



Note: The horizontal axis represents the correlation between the index and the personal loss. The vertical axis represents the ECS from insurance as we vary the probability weighting parameter, γ, under RDU, with $\gamma > 1$ is said to reflect "pessimism" and $\gamma < 1$ is said to reflect "optimism." In Panel B we assume that the CRRA coefficient is $r = 0.6$.

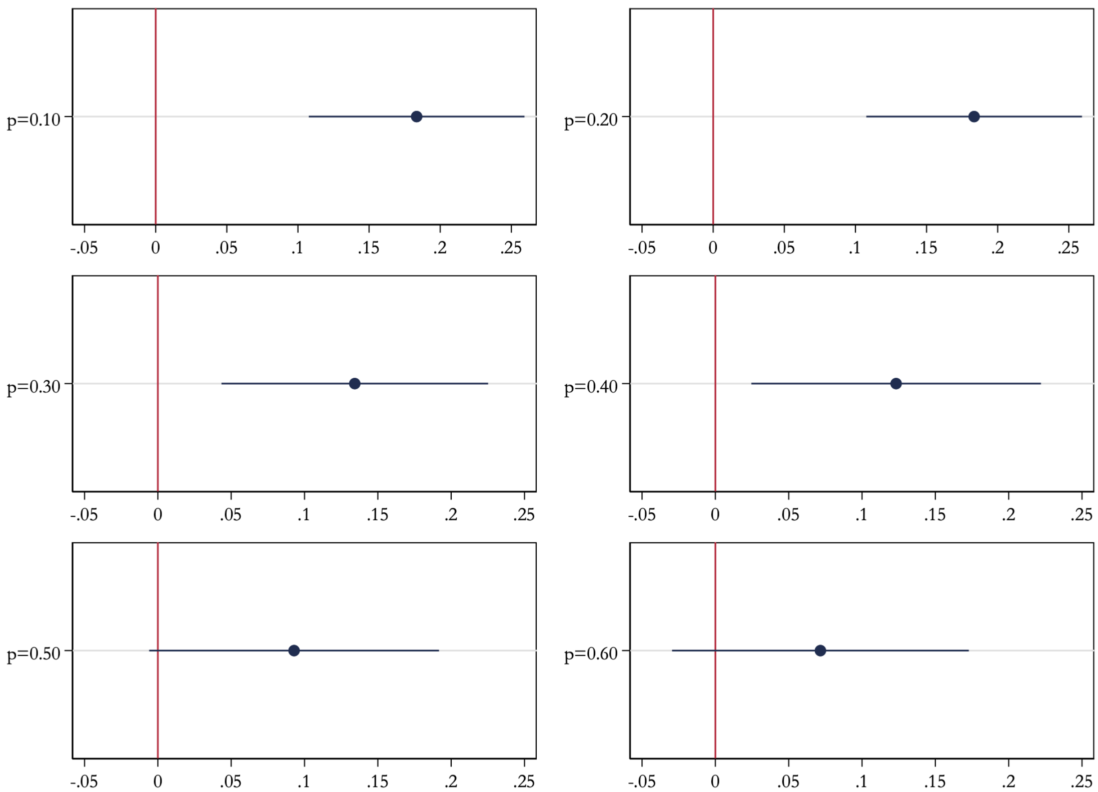
$\omega(p) = p^{\gamma}$ and the same CRRA utility function described above. This simplified example makes the point that people who care about probability weighting in an optimistic way can see their welfare *reduced* by *improvements* in correlation between the index and the individual loss. In this case $\gamma \neq 1$ is consistent with a deviation from the conventional EUT representation. The probability weighting parameter γ spans our expected range of 0.7 to 1.3, and the CRRA coefficient r is held constant at 0.6. Convexity of the probability weighting function, with $\gamma > 1$, is said to reflect "pessimism" and generates, if one assumes a linear utility function, a risk premium.The converse is true for $\gamma < 1$, and is said to reflect "optimism." When there is perfect correlation, $\rho = 1$, and the insurance purchase lottery collapses to a two-outcome lottery, each with the same monetary outcome since there is no chance of basis risk. In this case the presence of *optimism* causes the ECS of purchasing insurance to be *lower*, since the probability of no loss occurring is over-weighted, and this makes the insurance *non-purchase lottery* more attractive.[30] As the correlation decreases, this optimism increases the impact of underweighting of the downside basis risk and overweighting of the upside basis risk when purchasing insurance, which causes the expected welfare gain of purchasing insurance to *increase* as correlation *decreases* for optimistic individuals. Hence one can generate, under RDU, results that seem counterintuitive under EUT: improved correlation *reducing* the demand for index insurance. The converse is true for pessimistic individuals with $\gamma > 1$.

This added "lottery" feature of index insurance is reduced and then lost as correlation increases and approaches 1, and therefore individuals with optimistic probability weighting experience a reduction in welfare. As the correlation ρ decreases, their optimism increases the impact of underweighting of the downside basis risk as well as the impact of the overweighting of the upside basis risk when purchasing insurance, which causes the expected welfare gain of purchasing insurance. The converse is true for pessimistic individuals with $\gamma > 1$. The effect of probability weighting is subtle, particularly for correlations less than 1, because then the index insurance contract generates three distinct monetary outcomes, and rank-ordering plays a critical role in evaluation of the purchase lottery.[31]

[30] Since the only two outcomes of the insurance-purchase lottery have the same monetary value when $\rho = 1$, under RDU they receive the same decision weight since they have the same rank. However, the only two outcomes of the no-purchase lottery have distinct values, with the no loss outcome being the highest-ranked.

[31] Appendix A explores the subtle effects of allowing for probability weighting on the demand for index insurance. Even within RDU, differences arise from the type of probability weighting: globally concave *or* convex weighting can be quite different from locally concave *and* locally convex weighting.

Figure 9: Insurance Purchase, RDU, and Probability Optimism



Note: Predicted probability of purchase and 90% confidence intervals from panel Probit regressions on purchase of individuals who are characterized as substantially overweighting (based on a median split) of probabilities of 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6. Individuals who are characterized as EUT decision-makers, based on a probability weighting function that is not significantly different from zero at the 5% level are classified as not overweighting probabilities. For each of the regressions the number of individuals is N=101 and the number of observations is N=5,454. Regressions control for demongraphic and actuarial characteristics, and standard errors are clustered at the individual level.

We have empirical support for our hypothesis that indeed overweighting of the probability of upside basis risk may lead RDU optimistic individuals to purchase more index insurance. Figure 9 shows that RDU individuals who substantially *overweight* small probabilities between 0.1 and 0.4, are significantly more likely to purchase index insurance than individuals who do not overweight probabilities.[32] The effects are strongest for probabilities of 0.1 and 0.2, which are both at 18 percentage points (p-value<0.01), and which are the exact probabilities of the majority of the downside basis risk and upside basis risk states.

Figure 10 shows that the welfare outcomes we obtained under the assumption that individuals behave consistently with EUT are qualitatively similar to the welfare outcomes obtained if we allow for the risk preferences to be best characterized by either of the models. In the AE frame there is no significant difference between ROCL violators and non-ROCL violators (p-value 0.994), while there is a substantial difference in terms of welfare between ROCL violators and non-ROCL violators in the II frame. Specifically, ROCL violators experience 26 percentage points lower Efficiency in the II frame, and this effect is significantly different from zero at the 1 percent level (p-value < 0.001), and also significantly different across the frames (p-value 0.012).

6.2 Risk Preferences Without Assuming ROCL

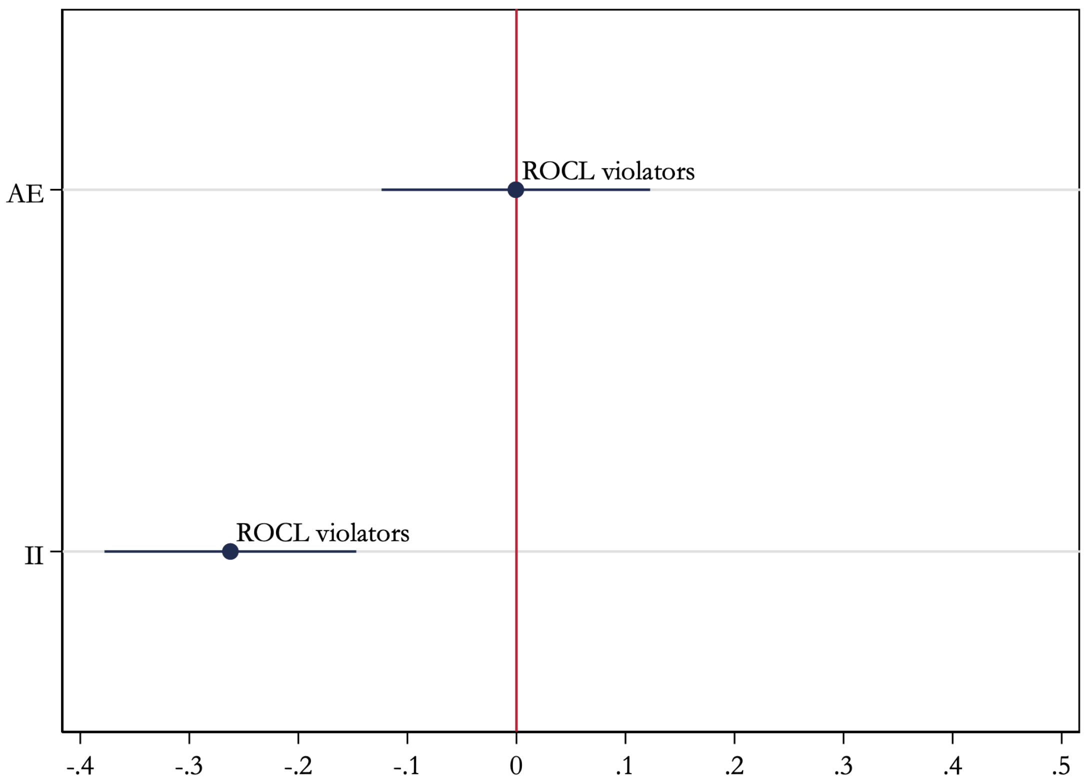
One conceptual limitation of the current methodology for calculating the expected welfare benefits from insurance is that we assume the subject calculates CS by using ROCL. We therefore consider a variant of the EUT model that does not assume ROCL.

We follow Harrison et al. (2015) and consider a "source-dependent" model in which the individual has one risk attitude for simple lotteries and potentially another risk attitude for compound lotteries. In historical context, Smith (1969) proposed this specification as one that was consistent with the evidence from several of the thought experiments underlying the (two-color) Ellsberg paradox. If we view these types of lotteries as defining different sources of risk, this specification deviates from ROCL to the extent that these risk attitudes differ.[33] Given the importance of the source-dependent EUT model, it is useful to

[32] Effects are shown for both frames combined because there are no significant differences across the frames.

[33] In a handful of cases the source-dependent EUT model does not solve for an individual, but the traditional EUT model does solve. In that case we assume the latter specification for this

Figure 10: Welfare and ROCL Violations Assuming RDU or EUT



Note: Predicted marginal effect on Efficiency and 90% confidence intervals from Beta regressions on Efficiency calculated with EUT or RDU preferences, depending on the best-fitting model for the individual, for individuals who are classified as "ROCL violators" and "no ROCL violators." An individual is characterized as ROCL violator if they violate ROCL in more than 5 out of the 10 tests for ROCL violations. AE refers to the Actuarially Equivalent frame (N=48) and II refers to the Index Insurance frame (N=53). For each of the regressions the number of individuals is N=101. Regressions control for demographic and actuarial characteristics, and standard errors are clustered at the individual level.

identify how significant the deviations from ROCL are. Figure B.3 in Appendix B shows the distribution of p-values, one per subject, testing the null hypothesis that the risk attitude for simple lotteries (r^{simple}) is the same as the risk attitude for compound lotteries ($r^{compound}$). We find that 14.7% of the subjects are estimated to violate ROCL in this manner at the 10% significance level (i.e., where the null hypothesis is EUT and the alternative hypothesis is source-dependent EUT), which is not far off from the 20% we observed based on our choice violation measure.

Figure 11 shows that calculation of expected welfare without assuming ROCL still leads to the same conclusion: on average the expected welfare gain is higher in the AE treatment than in the II treatment. In the AE frame there is no significant difference between ROCL violators and non-ROCL violators (p-value 0.663), while there is a substantial difference in terms of welfare between ROCL violators and non-ROCL violators in the II frame. ROCL violators experience 17 percentage points lower Efficiency in the II frame, and this effect is significantly different from zero at the 5 percent level (p-value 0.039), and also significantly different across the frames (p-value 0.078).

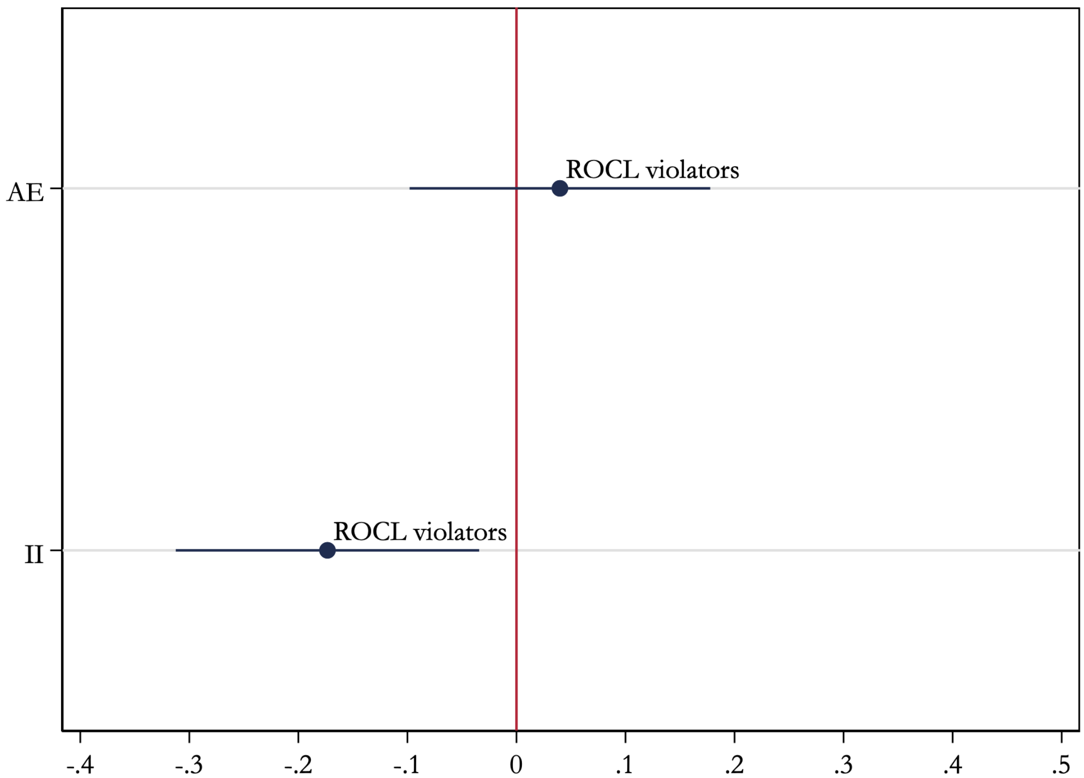
6.3 Consistent ROCL Violators?

Individuals who violate ROCL can either do so randomly, by sometimes preferring the simple risk over the compound risk and other times preferring the compound risk over the simple risk. However, subjects may also consistently violate ROCL in one direction, by either consistently choosing the simple risk over the compound risk in the lottery task, or by consistently choosing the compound risk over the simple risk in the lottery task. We categorize individuals who violate ROCL and consistently prefer the simple risk over the compound risk as *Compound Risk Averse* and those who violate ROCL and consistently prefer the compound risk over the simple risk as *Compound Risk Loving.*[34] Based on this categorization, 40% of individuals classified as ROCL violators are Compound Risk Averse, so 60% are Compound Risk Loving. Whether individuals who are Compound Risk Averse or Compound Risk Loving purchase more or less insurance in the II and AE frame is an empirical question, since this depends on the way that these preferences interact with the

individual, at least as the best EUT characterization.

[34] The maximum number of ROCL violations that individuals make is 8, so we classify individuals as either Compound Risk Averse or Compound Risk Loving if they exhibit this particular behaviour more than 4 times. Appendix B (online) documents these classifications.

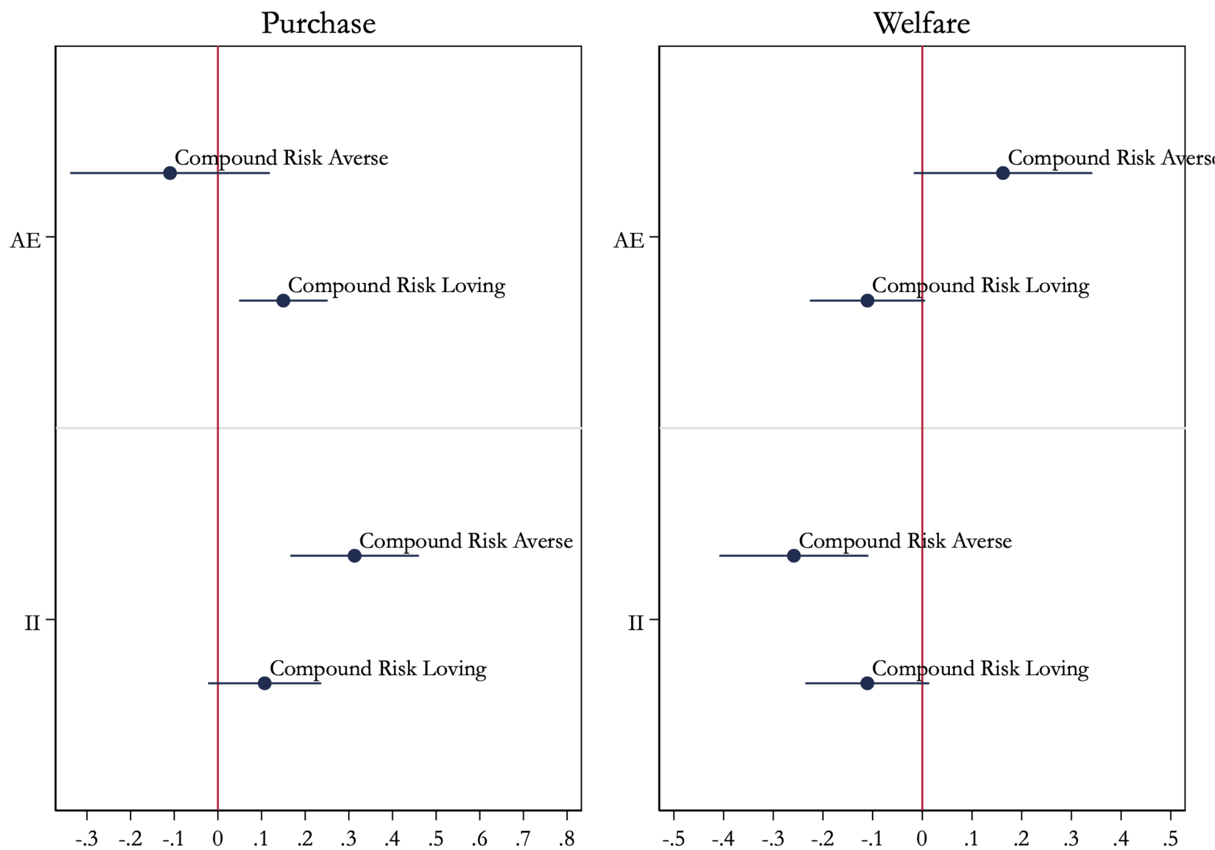
Figure 11: Welfare and ROCL Violations without Assuming ROCL



Note: Predicted marginal effect on Efficiency and 90% confidence intervals from Beta regressions on Efficiency calculated with source-dependent EUT preferences of individuals who are classified as "ROCL violators" and "no ROCL violators." An individual is characterized as ROCL violator if they violate ROCL in more than 5 out of the 10 tests for ROCL violations. AE refers to the Actuarially Equivalent frame (N=48) and II refers to the Index Insurance frame (N=53). For each of the regressions the number of individuals is N=101. Regressions control for demographic and actuarial characteristics, and standard errors are clustered at the individual level.

information we provide in each of the frames.

Figure 12: Insurance Purchase, Welfare and Compound Risk Aversion



Note: The left panel shows the predicted probability of purchase and 90% confidence intervals from panel Logit regressions on purchase of individuals who are classified as “Compound Risk Averse” and “Compound Risk Loving.” The right panel shows the predicted marginal effect on Efficiency and 90% confidence intervals from Beta regressions on Efficiency calculated with EUT preferences of individuals who are classified as “Compound Risk Averse” and “Compound Risk Loving.” An individual is characterized as “Compound Risk Averse” if they violate ROCL and prefer simple risk over compound risk in more than half of the maximum number of ROCL violations. An individual is characterized as “Compound Risk Loving” if they violate ROCL and prefer compound risk over simple risk in more than half of the maximum number of ROCL violations. AE refers to the Actuarially Equivalent frame (N=48) and II refers to the Index Insurance frame (N=53). For each of the purchase regressions the number of individuals is N=101 and the number of observations is N=5,454. For each of the Efficiency regressions there is one Efficiency measure per individual (N=101). Regressions control for demographic and actuarial characteristics, and standard errors are clustered at the individual level.

The left panel in Figure 12 shows that Compound Risk Averse individuals are significantly more likely to purchase index insurance in the II frame but not in the AE frame, and the difference across the frames is significant (p-value of 0.02). In the II frame this effect is large, with an increase in purchase of 31 percentage points, and is significantly different from zero at the 1 percent level. The fact that Compound Risk Averse individuals consistently choose the simple lottery over the compound lottery in a risky lottery frame, even when they choose the actuarially equivalent of the compound lottery when presented with two simple lotteries, suggests that these individuals struggle with processing compound risks, are aware of this, and therefore consistently choose the option without compound risk. This interpretation is strengthened by the fact that, when presented with pie-charts representing the simple risk of the compound insurance decisions these individuals behave similar to individuals who are not Compound Risk Averse. However, when presented with the index insurance choice in its compound risk form only, they have no option to avoid dealing with the compound risk, make mistakes, and purchase the index insurance excessively frequently. Since both the AE and II frame still contain compound risk, but only vary the information, and subjects respond to this by significantly changing behaviour, we suggest that Compound Risk Aversion is a reflection of a cognitive challenge that individuals face when confronted with compound risk.

The right panel in Figure 12 shows that Compound Risk Averse individuals generate substantial welfare losses in the II frame, and that there is a significant difference in Efficiency across the AE and II frame, significant at the 1 percent level, where those in the II frame experience a 26 percentage points lower level of Efficiency, while those in the AE frame do no worse than individuals who are not Compound Risk Averse. The fact that results for the Compound Risk Averse sub-sample, which reflect consistent ROCL violations in the direction of avoiding compound risk, are qualitatively similar to the results for ROCL violators, mitigates concerns about our measure of ROCL merely picking up random choice inconsistency or preferences for randomness.

7 Conclusion

The rapid expansion of access to finance, low levels of financial literacy of some consumers, and increasing complexity of financial products, raises serious concerns about whether consumers are able to select a product that increases their expected welfare. To be able to make efficient financial decisions, consumers need to be able to map beliefs about probabilities of states of the world to realized outcomes that occur when these states materialize. We focus on one general cognitive challenge that individuals may face in this process, the ability to process compound risk. We show that individuals who struggle with processing compound risk, measured directly by violations of the ROCL axiom, excessively purchase insurance products with compound risk leading to expected welfare losses. However, when these ROCL violators are given a decision aid that helps them process compound risk, they purchase less insurance and do no worse in terms of expected welfare than individuals who do not violate ROCL. The aid that we use is simple: we multiply out probabilities of the compound layers of risk, and explicitly inform subjects about the eventual likelihood of each outcome. An important policy implication of our findings is that average consumer welfare should increase if insurance supervisors and regulators require insurers to inform consumers about the compounded probabilities of all potential states that an insurance product does and does not cover. Our results and these policy implications apply more broadly to any contract with compound risk, such as pensions and warranties.

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A The Effects of Probability Weighting (NOT FOR PUBLICATION)

When probability weighting makes decision-makers globally optimistic or pessimistic for all probabilities, as is the case with the Power probability weighting function, the effects are relatively straightforward. Particularly interesting complications arise, however, when probability weighting allows for locally optimistic and locally pessimistic behavior towards different probabilities.

Figure A.1 shows how the CS is affected if we vary the parameter of an Inverse-S probability weighting function $\omega(p) = p^\gamma/(p^\gamma + (1-p)^\gamma)^{1/\gamma}$ for an RDU decision-making model while decreasing the correlation σ. This function exhibits inverse-S probability weighting (optimism for small p, and pessimism for large p) for $\gamma < 1$, and S-shaped probability weighting (pessimism for small p, and optimism for large p) for $\gamma > 1$. Once again the probability weighting parameter γ spans our expected typical range of 0.7 to 1.3, and the CRRA coefficient r is held constant at 0.6. A smaller $\gamma < 1$ reflects an overweighting of the probabilities of extreme outcomes, while a larger $\gamma > 1$ reflects an underweighting of the probabilities of extreme outcomes.

Figure A.2 shows the effect of $\gamma = 1.4 > 1$ on decision weights in the case that concerns us. When no insurance is purchased there are just two outcomes. When correlation is anything less than 100%, the Index Insurance contract with full indemnity has three *rank-ordered* monetary outcomes: the "carrot" of no loss but a payout from the index, initial wealth minus the premium when the index matches the loss outcome (whether it is good or bad), and the "stick" of a loss but no payout from the index. In the right panel of Figure A.2 we assume equi-probable 2-outcome lotteries or 3-outcome lotteries, to show the pure effect of probability weighting. From Figure A.2 we see that the effect of S-shaped probability weighting, *ceteris paribus* the effect from $U'' < 0$, is to make the decision maker risk averse with respect to the implied lottery when deciding not to purchase insurance. The worst outcome, a loss, is given greater weight, and the best outcome, no loss, is given less weight.

Figure A.1: Consumer Surplus Across Inverse-S Probability Weighting Parameter (r=0.6)

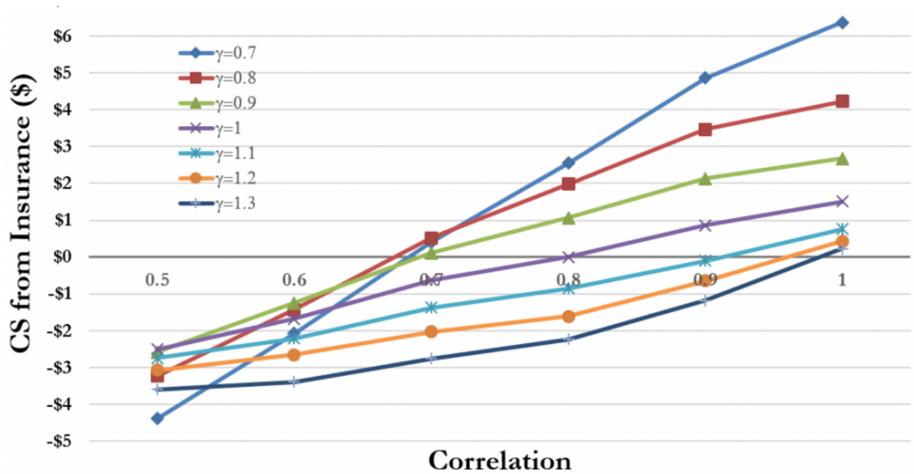
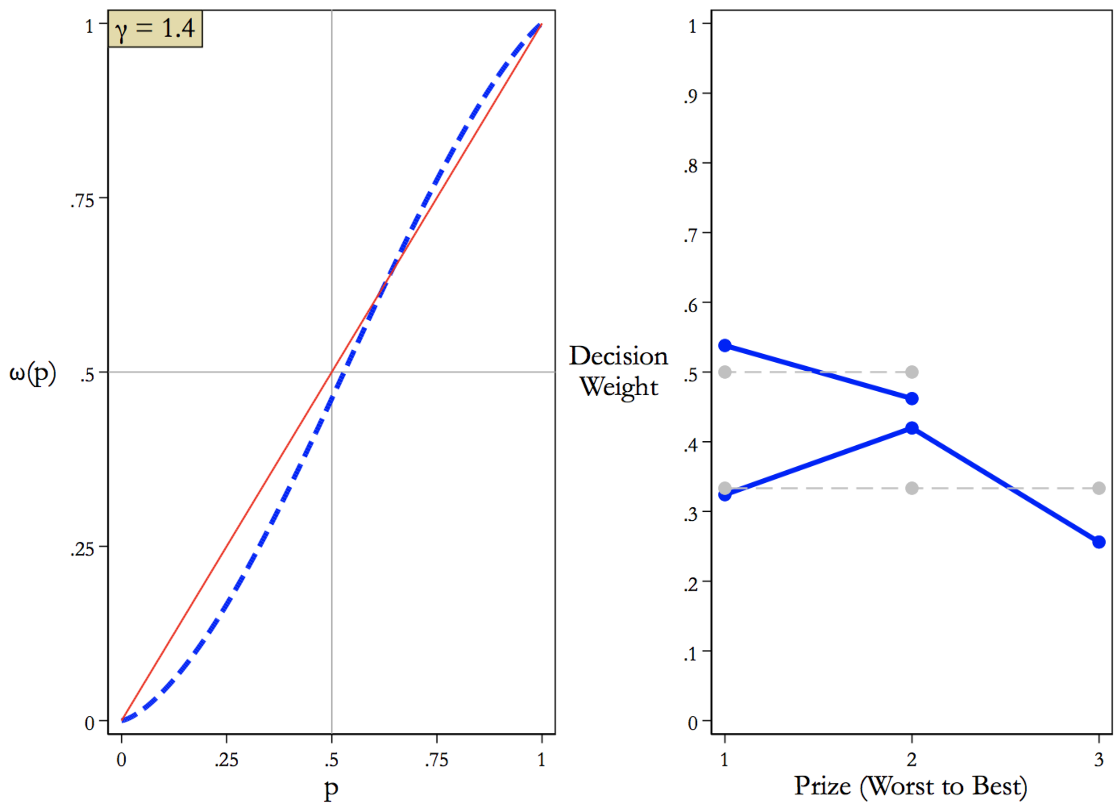


Figure A.2 tells a more nuanced story when it comes to the implied lottery when deciding to purchase index insurance. The intermediate outcome, when the index matches the loss outcome, is given greater weight because of probability weighting. The worst outcome is given slightly smaller weight, in this case almost imperceptibly smaller. But the best outcome, the carrot of index insurance, is given much lower weight. This is due to the general over-weighting of extremes noted above, but highlights the asymmetric weighting of extremes in this instance.[35] Hence we have what we call a "rotten carrot" effect from probability weighting: the lure of the good extreme outcome from basis risk is given less weight than it should have from the actuarial probabilities alone, and is also given less weight in a *proportional* sense than the curse of the bad extreme outcome from basis risk. Both effects of probability weighting serve to make the index insurance contract less attractive to somebody with these risk preferences, irrespective of the effects from $U'' < 0$. It is quite possible, even with low aversion to extremes from U'', that the effect of probability weighting is to make the index insurance contract less attractive than facing the loss uninsured. And we know from Clarke (2016) that if there is also high enough aversion to extremes from U'', that the index contract could already be less attractive than being uninsured.

Figures A.3 and A.4 draw an important policy implication from these observations.

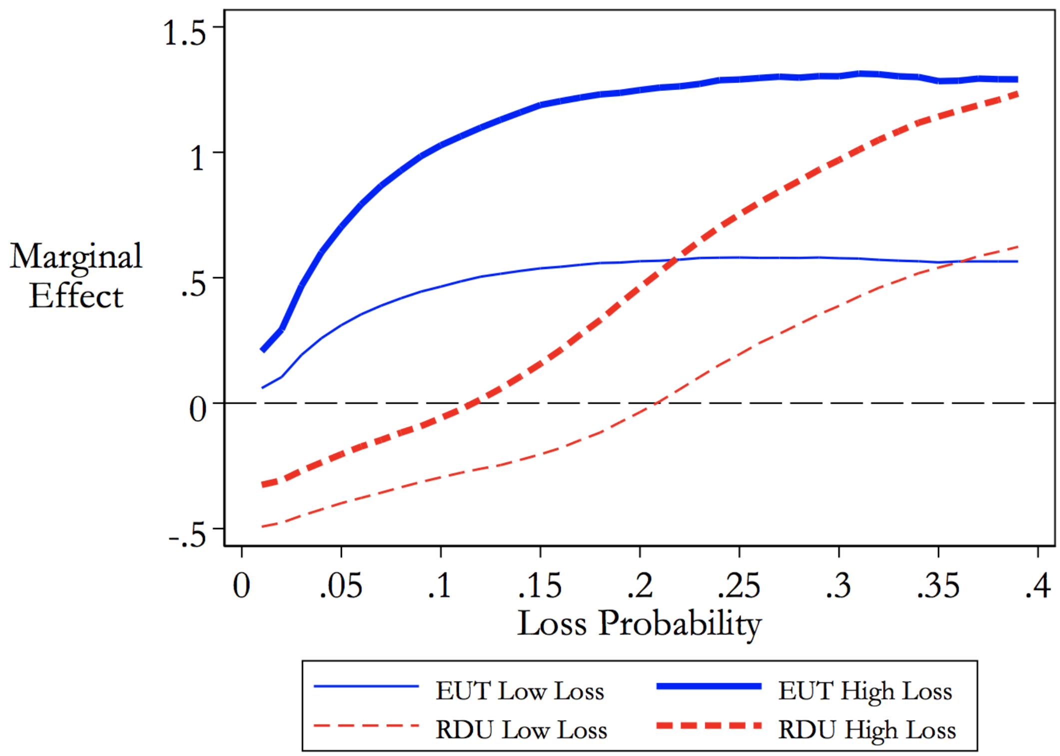
[35] To some extent this asymmetry is an artefact of the Inverse-S functional form, which can only have a fixed point at $\frac{2}{3}$ when $\gamma > 1$. In more general functional forms, which we employ, one can have S-shaped probability weighting with fixed points below 0.5, reversing this particular asymmetry. We only use the familiar Inverse-S function for exposition.

Figure A.2: The Rotten Carrot Effect from S-Shaped Probability Weighting and Implied Decision Weights



Notes: Decision weights based on equi-probable reference lotteries, with probabilities 0.5 for the 2-outcome case annd 0.33 for the 3-outcome case in light grey.

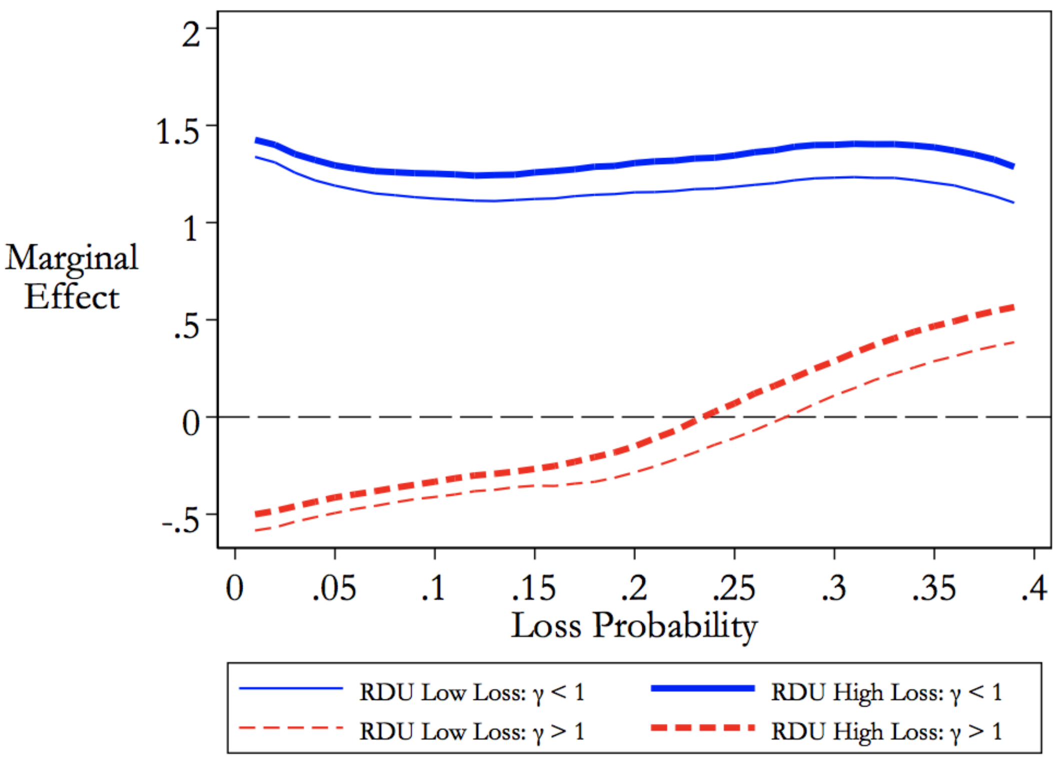
Figure A.3: Healthy and Rotten Carrot Effects



Note: Marginal effect of the matching probability, conditional on the loss probability, on the probability of choosing the Index Insurance contract. Simulations assuming different RDU risk preferences, a relatively high (low) loss of \$35 (\$20) from a \$60 endowment, and parameters of the contrract in the experiment

In each case we consider the marginal effect on the probability of purchasing the index insurance contract as the correlation between the idiosyncratic loss outcome and the index outcome goes up. Enhancing this correlation is widely viewed as desirable from the perspective of making the index insurance contract more attractive, and considerable research is underway to employ remote-sensing technologies to complement local indices: for example, see Leeuw et al. (2014) and Chantarat et al. (2013). Figure A.3 confirms that such efforts will indeed enhance the attractiveness of the product if risk preferences are characterized by EUT. But it also shows that there are circumstances where such efforts will *reduce* the attractiveness of the product for certain RDU risk preferences. Specifically, Figure A.4 shows that the type of RDU preferences that lead to this "rotten carrot" effect are those displayed in Figure A.2, and only when the idiosyncratic loss probability is low.

Figure A.4: The Rotten Carrot Effect with RDU Risk Preferences



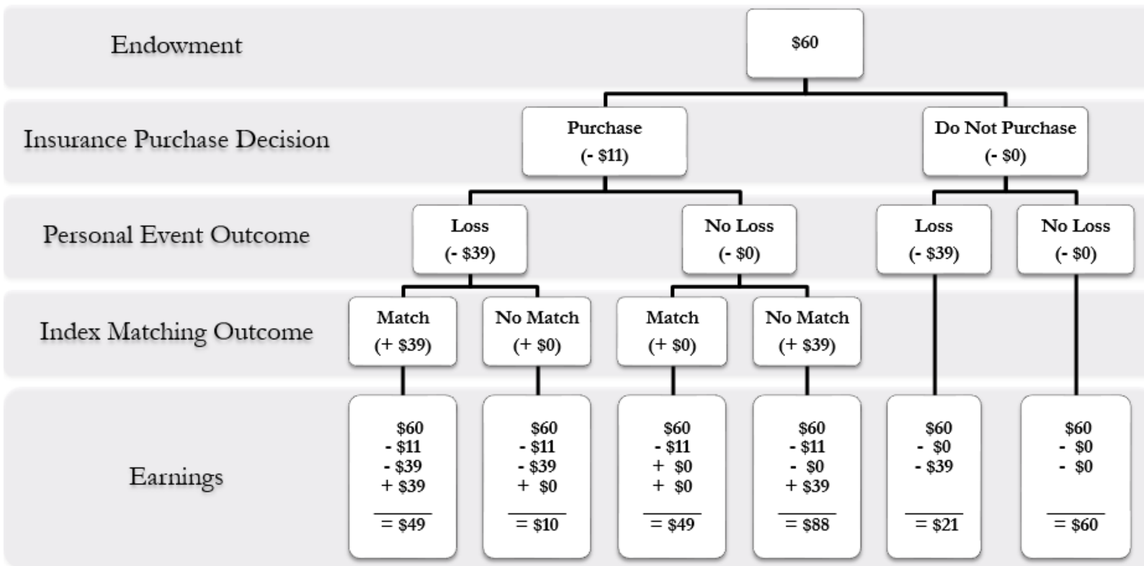
Note: Marginal effect of the matching probability, conditional on the loss probability, on the probability of choosing the Index Insurance contract. Simulations assuming different RDU risk preferences, a relatively high (low) loss of $35 ($20) from a $60 endowment, and parameters of the contrract in the experiment

What is the intuition for this counter-intuitive result? Building on the earlier explanation of the effect of S-shaped probability weighting on the three monetary outcomes under the index insurance contract, we expect less weight on the carrot outcome, relatively less weight on the carrot outcome than the stick outcome, and greater weight on the intermediate outcome. When the idiosyncratic loss probability is low, the complementary probability of no idiosyncratic loss is high, and this means that the carrot gets has greater actuarial probability since it is one of the compound outcomes that depends on this complementary probability. Thus the effect of probability weighting, to proportionately reduce this actuarial probability of the carrot outcome, has more (negative) impact on the overall evaluation of the lottery induced by purchasing the index insurance contract. When the loss probability gets large enough, as shown most clearly in Figure 7, this complementary probability gets smaller, hence the actuarial probability of the carrot outcome gets smaller, and hence the rotten carrot effect does not affect the overall evaluation of the lottery induced by purchasing the index insurance contract as much.

The bottom line is that one needs to know the level of risk aversion, the risk premium, under both EUT and RDU, to know if the index insurance product is attractive to purchase. But one also has to know the type of risk preference, in order to determine how much of the given risk premium derives from U'' or the effect of probability weighting. Absent these two types of information, and one cannot say a priori whether take-up of a given index insurance product is welfare-enhancing for the individual.

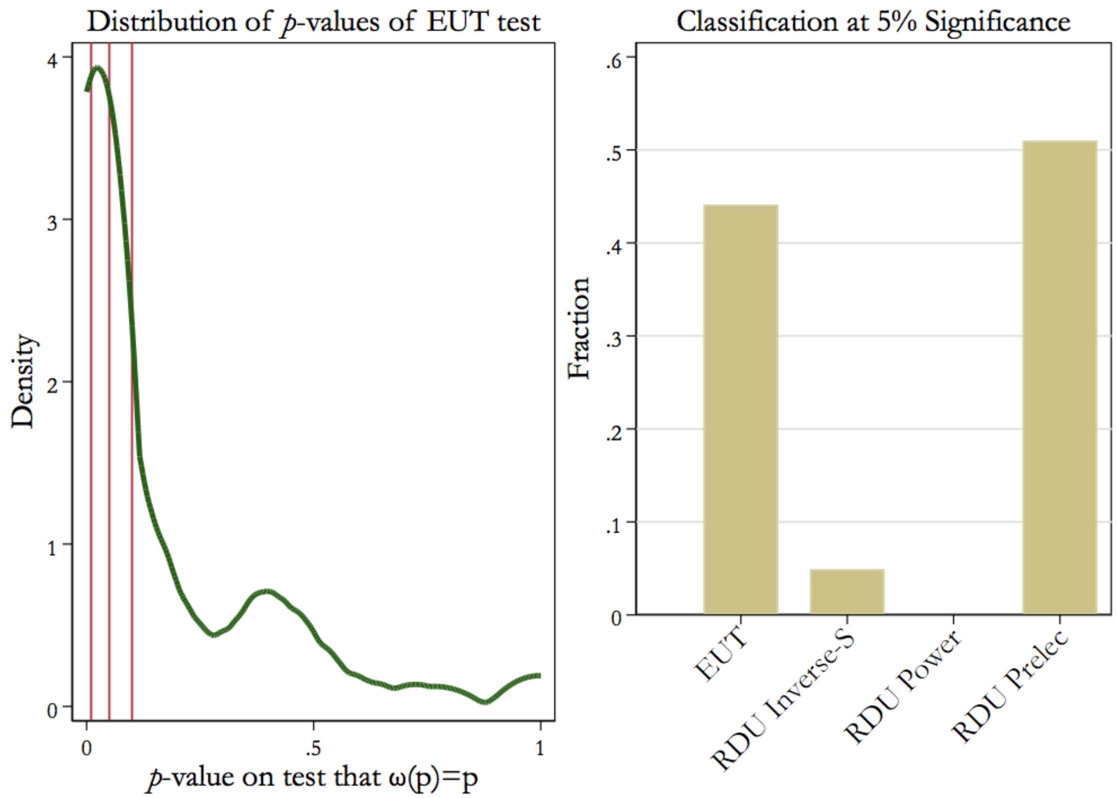
B Additional Figures and Tables (NOT FOR PUBLICATION)

Figure B.1: Decision Tree for Index Insurance Product



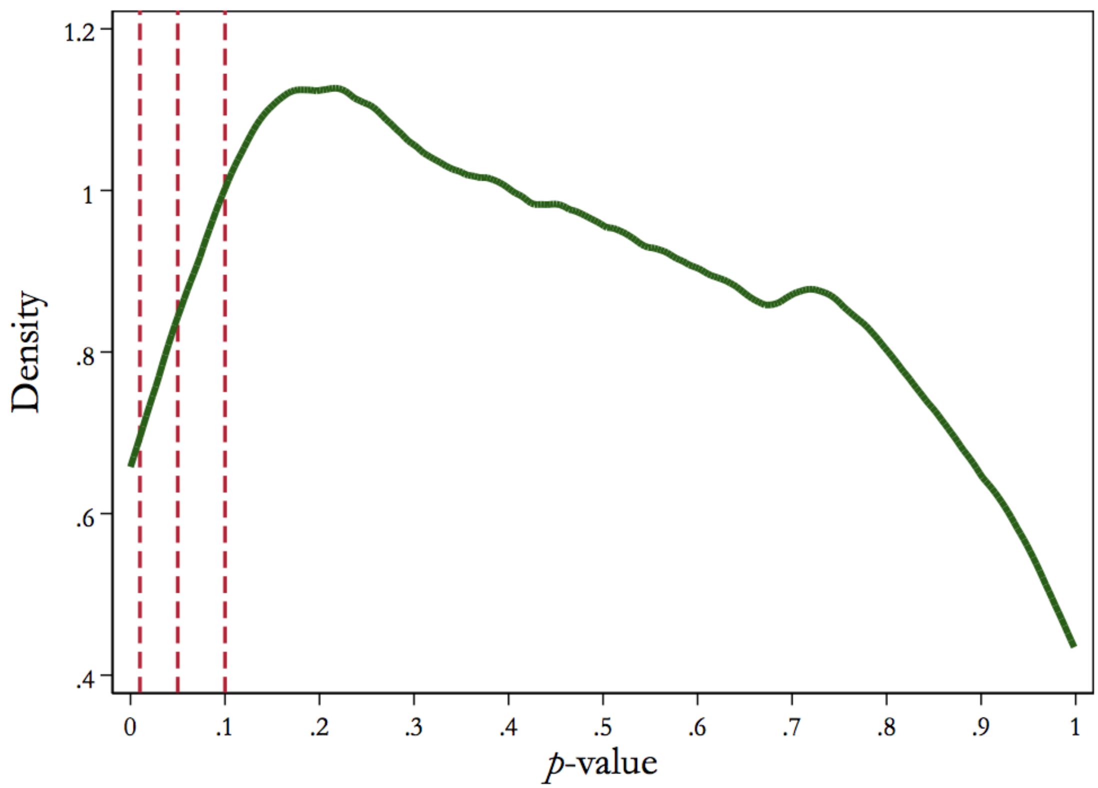
Note: This figure displays the decision tree and subsequent earnings for an index insurance product purchase assuming an endowment of $60, a potential personal loss of $39, and a premium of $11 to purchase insurance to protect against that loss if the index matches.

Figure B.2: Classifying Subjects as EUT or RDU



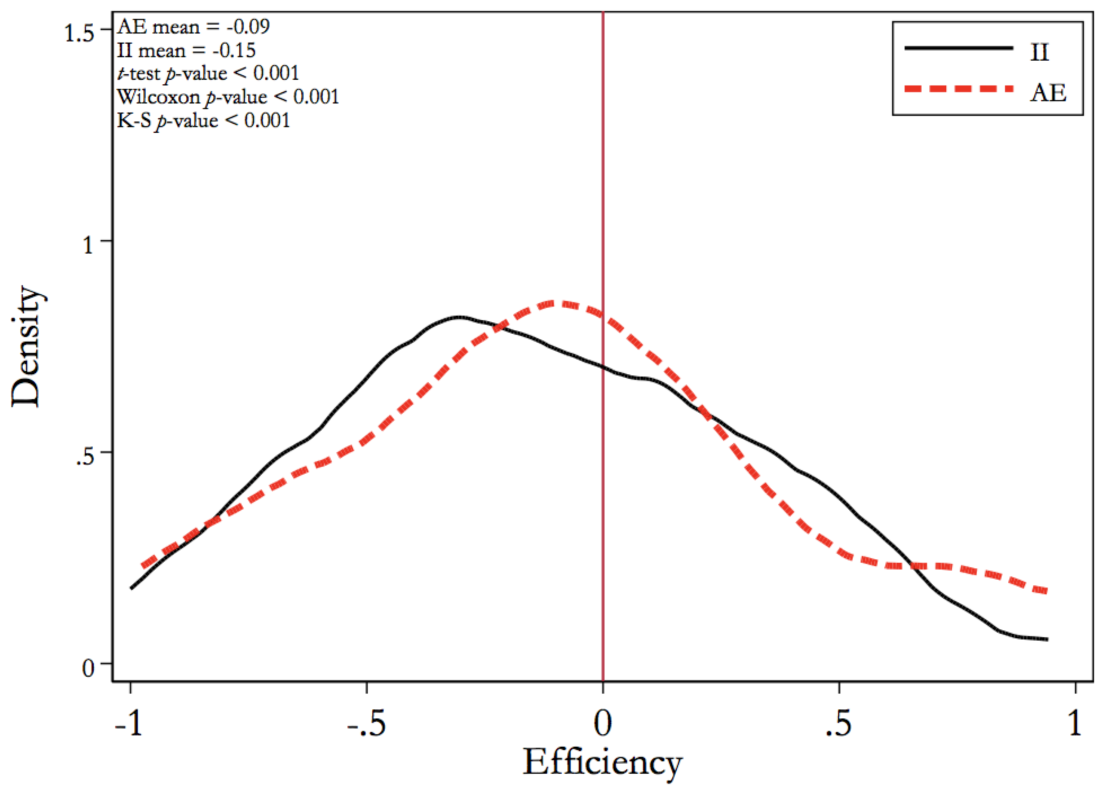
Note: N=101. The left panel shows the distribution of p-values of the test that there is no probability weighting, $\omega(p) = p$. The red solid lines present the 1%, 5%, and 10% significance levels. The right panel presents the classification of subjects to the EUT and RDU models. These estimates and hypothesis tests are undertaken for each subject.

Figure B.3: Tests of Source-Independence of EUT



Note: The green line presents the distribution of p-values of the null hypothesis that the simple risk preferences are equal to the compound risk preferences. The distributions reflects one p-value per individual and the total number of individuals is 101. The dashed red lines show the p-values 0.01, 0.05, and 0.1. The fraction of people below each of these threshold p-values is 4.9%, 8.8%, and 14.7 % respectively.

Figure B.4: Efficiency Distributions for II and AE Treatments, Without Assuming ROCL



Note: II refers to Index Insurance treatment and AE refers to Actuarial Equivalent treatment. The number of subjects is 53 in the II treatment and 48 in the AE treatment. Each subject makes 54 insurance decisions to purchase insurance or not. The Efficiency measure is calculated at the level of the individual. The p-values test the hypothesis that the Efficiency distribution for the II treatment is significantly different from the Efficiency distribution in the AE treatment.

C Instructions (NOT FOR PUBLICATION)

C.1 II treatment

Choices Over Insurance Prospects

In this task you will make choices about whether to insure against possible monetary loss. In each choice you will start out with an initial amount of money and, in the event of a loss, the loss amount will be taken from this initial stake. In each choice you will have the option to buy insurance to protect you against the possible loss, although you are not required to buy the insurance.

You will make 54 choices in this task. You will actually get the chance to play one of the choices you make, and you will be paid in cash according to the outcome of that choice. So you should think carefully about how much each insurance choice is worth to you.

Each choice has two random events: a Personal Event and an Index Event. Each event has two possible outcomes: Good or Bad. If the Personal Event outcome is Bad, then you will suffer a loss. Before you know the outcome of the Personal Event, you must decide whether to purchase insurance against this possible loss. However, the insurance only pays a claim if the Index Event outcome is Bad.

If you do not purchase insurance, then only the outcome of the Personal Event will decide your earnings:

Personal Event	Your Earnings
Bad	Initial stake - Loss
Good	Initial stake

If you do purchase insurance, it is important for you to understand that an insurance claim is not paid according to whether you actually suffer a loss. Instead, an insurance claim is paid only according to the Index Event. Both events will decide your earnings:

Personal Event	Index Event	Your Earnings
Bad	*Bad*	Initial stake - Insurance cost – Loss + Insurance coverage
Bad	*Good*	Initial stake - Insurance cost – Loss
Good	*Good*	Initial stake - Insurance cost
Good	*Bad*	Initial stake - Insurance cost + Insurance coverage

So there are four possible outcomes if you purchase insurance. You might suffer a loss and receive an insurance claim payment. Or you might suffer a loss but not receive an insurance claim payment. You might not suffer a loss and also receive no insurance claim payment. Finally, you might receive an insurance claim payment even when you do not suffer a loss.

Each event is determined by randomly drawing a colored chip from a bag. In general, each draw will involve two colors, and each decision you make will involve different amounts and mixtures of two colors. When making each decision, you will know the exact amounts and mixtures of colored chips associated with the decision. After you have decided whether or not to purchase insurance, the two events will be determined as follows.

First, the Personal Event will be determined with blue and red chips.

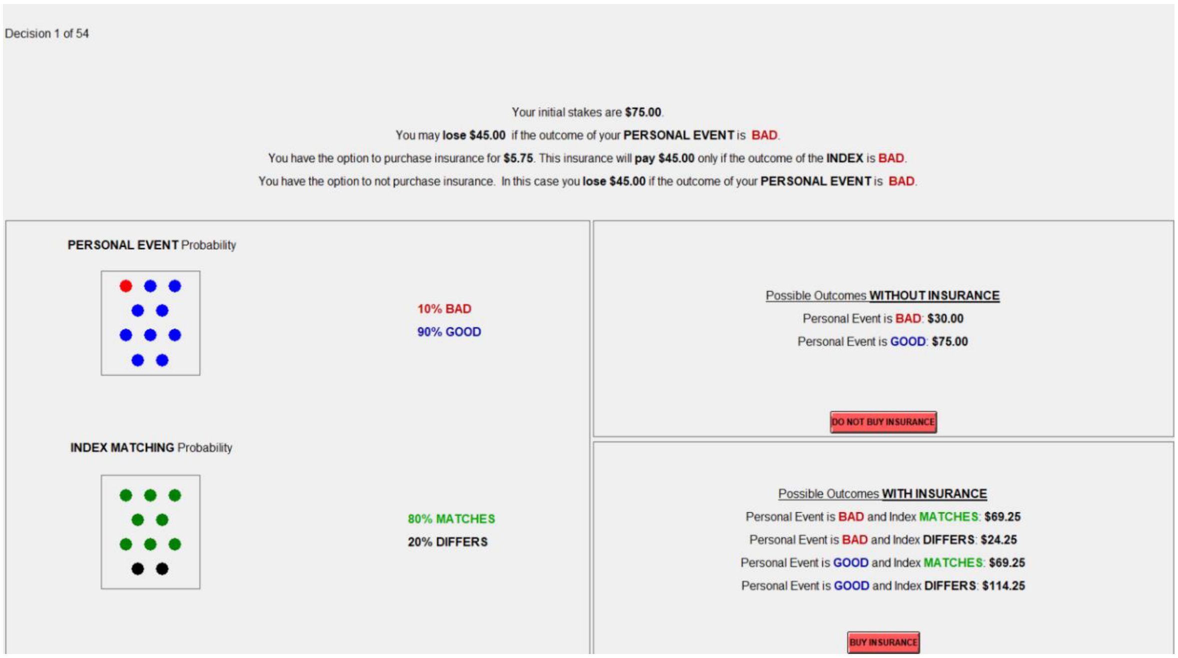
- If you draw a blue chip, then the Personal Event outcome is Good and you do not suffer a loss.
- If you draw a red chip, then the Personal Event outcome is Bad and you suffer a loss.

Next, if you purchased insurance, the Index Event will be determined with green and black chips.

- If you draw a green chip, then the Index Event outcome Matches the Personal Event outcome
- If you draw a black chip, then the Index event outcome Differs from the Personal Event outcome

Here is an example of what your decision would look like on the computer screen. The display on your screen will be bigger and easier to read.

Figure C.1



In this example you start out with an initial stake of $75. If the outcome of the Personal Event is Bad you will lose $45, and if the outcome of the Personal Event is Good you will not lose any money. If you faced the choice in this example and chose to purchase insurance, you would pay $5.75 from your initial stake. You would pay this $5.75 before you drew any chips, so you would pay it regardless of the outcomes of your draws.

You will be drawing colored chips from bags to determine the outcomes of both events. First, you will draw a chip to determine the Personal Event outcome. The image on the left shows that there is a 10% chance that the Personal Event outcome is Bad, and a 90% chance that the Personal Event outcome is Good. This means there will be 9 blue chips and 1 red chip in a bag, and the color of the chip you randomly draw from the bag represents the outcome of the Personal Event. If a blue chip is drawn, the Personal Event outcome is Good, and if a red chip is drawn the Personal Event outcome is Bad.

Next, you will draw a chip to determine the Index Event outcome. There is an 80% chance that the Index Event outcome Matches the Personal Event outcome and a 20% chance that the Index Event outcome Differs from the Personal Event outcome. This means there will be 8 green chips and 2 black chips in a bag. If a green chip is drawn the Index

Event outcome Matches the Personal Event outcome, and if a black chip is drawn the Index Event outcome Differs from the Personal Event outcome.

The possible outcomes if you choose not to purchase insurance are therefore as follows:

Personal Event outcome	Your Earnings
Red (*Bad*)	\$75 - \$45 = \$30
Blue (*Good*)	\$75 - \$0 = \$75

- If a red chip is drawn from the Personal bag your Personal Event outcome is Bad. You will lose \$45 and be left with \$30.
- If a blue chip is drawn from the Personal bag your Personal Event outcome is Good. You will lose nothing and be left with \$75.

You can choose to purchase insurance, which will cost you \$5.75, and if you chose to purchase insurance you would pay this \$5.75 regardless of the outcomes of your draws. The possible outcomes if you choose to purchase insurance are therefore as follows:

Personal Draw	Index Draw	Your Earnings
Red (*Bad*)	Green (*Matches → Bad*)	\$75 - \$5.75 - \$45 + \$45 = \$69.25
Red (*Bad*)	Black (*Differs → Good*)	\$75 - \$5.75 - \$45= \$24.25
Blue (*Good*)	Green (*Matches → Good*)	\$75 - \$5.75 = \$69.25
Blue (*Good*)	Black (*Differs → Bad*)	\$75 - \$5.75 + \$45 = \$114.25

- If a red chip is drawn from the Personal bag and a green chip from the Index bag, you will lose \$45 but the insurance claim payment will cover the loss. You will keep \$69.25.
- If a red chip is drawn from the Personal bag and a black chip from the Index bag, you will lose \$45 but you will not receive an insurance claim payment from insurance. You will keep \$24.25.
- If a blue chip is drawn from the Personal bag and a green chip from the Index bag, you will not lose any money. You will keep \$69.25.
- If a blue chip is drawn from the Personal bag and a black chip from the Index bag, you will not lose any money, but you receive a claim payment from insurance. You will keep \$114.25.

You will indicate your choice to purchase, or not purchase, the insurance by clicking on your preferred option on the computer screen.

There are 54 decisions like this one to be made, each shown on a separate screen on the computer. Each decision might have different chances for the Personal Event outcome, the Index Event outcome, the initial stake, or the cost of insurance, so pay attention to each screen. After you have worked through all of the insurance decisions, please wait in your seat and an experimenter will come to you. You will then roll two 10-sided dice to determine which insurance decision will be played out. Since there are only 54 decisions, you will keep rolling the dice until a number between 1 and 54 comes up. There is an equal chance that any of your 54 choices will be selected, so you should approach each decision as if it is the one that you will actually play out to determine your payoff. Once the decision to play out is selected, you will draw chips from the Index bag and the Personal bag to determine the outcome.

In summary:

- You will decide whether or not to purchase insurance in each of the 54 scenarios.
- One of your decisions will be randomly selected to be played for cash.
- You will suffer the specified monetary loss only if the Personal Event outcome is Bad.
- If you purchase insurance, it will pay a claim payment only if the Index Event outcome is Bad. This can happen in two ways:
    1. Your Index draw Matches a bad Personal Event outcome;
    2. Your Index draw Differs from a good Personal Event outcome.

Whether or not you prefer to buy the insurance is a matter of personal taste. You may choose to buy insurance on some or all of your 54 choices, or none of the choices. The people next to you may be presented with different choices, insurance prices, and may have different preferences, so their responses should not matter to you. Please work silently, and make your choices by thinking carefully about each prospect.

Your payoff from this task is in cash and is in addition to the show-up payment that you receive just for being here, as well as any other earnings in other tasks. If you have a question, raise your hand and someone will come over and answer it.

C.2 AE treatment

Choices Over Insurance Prospects

In this task you will make choices about whether to insure against possible monetary loss. In each choice you will start out with an initial amount of money and, in the event of a loss, the loss amount will be taken from this initial stake. In each choice you will have the option to buy insurance to protect you against the possible loss, although you are not required to buy the insurance.

You will make 54 choices in this task. You will actually get the chance to play one of the choices you make, and you will be paid in cash according to the outcome of that choice. So you should think carefully about how much each insurance choice is worth to you.

Each choice has two random events: a Personal Event and an Index Event. Each event has two possible outcomes: Good or Bad. If the Personal Event outcome is Bad, then you will suffer a loss. Before you know the outcome of the Personal Event, you must decide whether to purchase insurance against this possible loss. However, the insurance only pays a claim if the Index Event outcome is Bad.

If you do not purchase insurance, then only the outcome of the Personal Event will decide your earnings:

Personal Event	Your Earnings
Bad	Initial stake - Loss
Good	Initial stake

If you do purchase insurance, it is important for you to understand that an insurance claim is not paid according to whether you actually suffer a loss. Instead, an insurance claim is is paid only according to the Index Event. Both events will decide your earnings:

Personal Event	Index Event	Your Earnings
Bad	*Bad*	Initial stake - Insurance cost – Loss + Insurance coverage
Bad	*Good*	Initial stake - Insurance cost – Loss
Good	*Good*	Initial stake - Insurance cost
Good	*Bad*	Initial stake - Insurance cost + Insurance coverage

So there are four possible outcomes if you purchase insurance. You might suffer a loss and receive an insurance claim payment . Or you might suffer a loss but not receive an insurance claim payment . You might not suffer a loss and also receive no insurance claim payment. Finally, you might receive a claim payment even when you do not suffer a loss.

Each event is determined by randomly drawing a colored chip from a bag. In general, each draw will involve two colors, and each decision you make will involve different amounts and mixtures of two colors. When making each decision, you will know the exact amounts and mixtures of colored chips associated with the decision. After you have decided whether or not to purchase insurance, the two events will be determined as follows.

First, the Personal Event will be determined with blue and red chips.

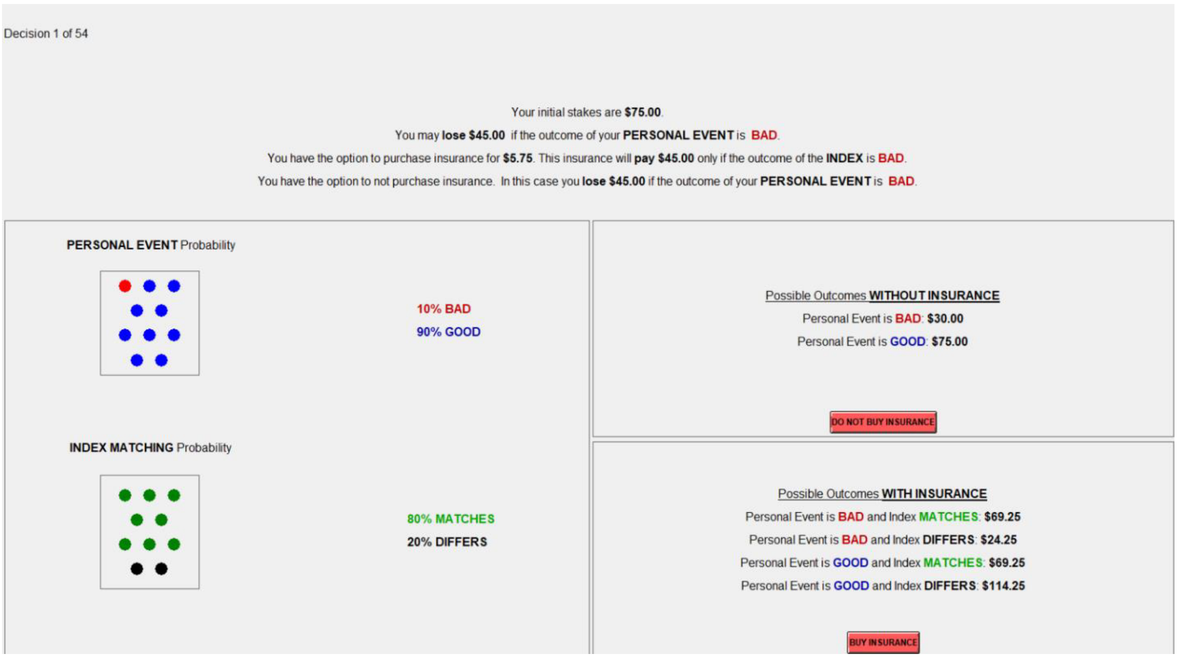
- If you draw a blue chip, then the Personal Event outcome is Good and you do not suffer a loss.
- If you draw a red chip, then the Personal Event outcome is Bad and you suffer a loss.

Next, if you purchased insurance, the Index Event will be determined with green and black chips.

- If you draw a green chip, then the Index Event outcome Matches the Personal Event outcome
- If you draw a black chip, then the Index event outcome Differs from the Personal Event outcome

Here is an example of what your decision would look like on the computer screen. The display on your screen will be bigger and easier to read.

Figure C.2



In this example you start out with an initial stake of $75. If the outcome of the Personal Event is Bad you will lose $45, and if the outcome of the Personal Event is Good you will not lose any money. If you faced the choice in this example and chose to purchase insurance, you would pay $5.75 from your initial stake. You would pay this $5.75 before you drew any chips, so you would pay it regardless of the outcomes of your draws.

You will be drawing colored chips from bags to determine the outcomes of both events. First, you will draw a chip to determine the Personal Event outcome. The image on the left shows that there is a 10% chance that the Personal Event outcome is Bad, and a 90% chance that the Personal Event outcome is Good. This means there will be 9 blue chips and 1 red chip in a bag, and the color of the chip you randomly draw from the bag represents the outcome of the Personal Event. If a blue chip is drawn, the Personal Event outcome is Good, and if a red chip is drawn the Personal Event outcome is Bad.

Next, you will draw a chip to determine the Index Event outcome. There is an 80% chance that the Index Event outcome Matches the Personal Event outcome and a 20% chance that the Index Event outcome Differs from the Personal Event outcome. This means there will be 8 green chips and 2 black chips in a bag. If a green chip is drawn the Index

Event outcome Matches the Personal Event outcome, and if a black chip is drawn the Index Event outcome Differs from the Personal Event outcome.

The possible outcomes if you choose not to purchase insurance are therefore as follows:

Personal Event outcome	Your Earnings
Red (*Bad*)	\$75 - \$45 = \$30
Blue (*Good*)	\$75 - \$0 = \$75

- If a red chip is drawn from the Personal bag your Personal Event outcome is Bad. You will lose \$45 and be left with \$30.
- If a blue chip is drawn from the Personal bag your Personal Event outcome is Good. You will lose nothing and be left with \$75.

You can choose to purchase insurance, which will cost you \$5.75, and if you chose to purchase insurance you would pay this \$5.75 regardless of the outcomes of your draws. The possible outcomes if you choose to purchase insurance are therefore as follows:

Personal Draw	Index Draw	Your Earnings
Red (*Bad*)	Green (*Matches → Bad*)	\$75 - \$5.75 - \$45 + \$45 = \$69.25
Red (*Bad*)	Black (*Differs → Good*)	\$75 - \$5.75 - \$45= \$24.25
Blue (*Good*)	Green (*Matches → Good*)	\$75 - \$5.75 = \$69.25
Blue (*Good*)	Black (*Differs → Bad*)	\$75 - \$5.75 + \$45 = \$114.25

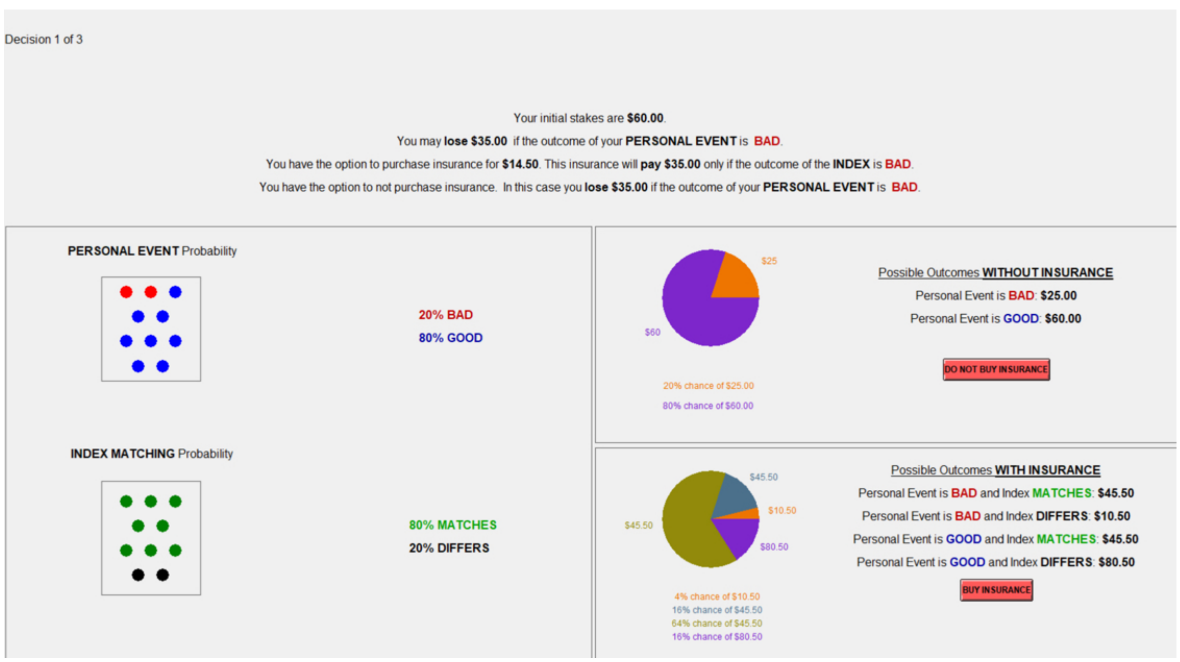
- If a red chip is drawn from the Personal bag and a green chip from the Index bag, you will lose \$45 but the insurance claim payment will cover the loss. You will keep \$69.25.
- If a red chip is drawn from the Personal bag and a black chip from the Index bag, you will lose \$45 but you will not receive an insurance claim payment from insurance. You will keep \$24.25.
- If a blue chip is drawn from the Personal bag and a green chip from the Index bag, you will not lose any money. You will keep \$69.25.
- If a blue chip is drawn from the Personal bag and a black chip from the Index bag, you will not lose any money, but you receive a claim payment from insurance. You will keep \$114.25.

You will indicate your choice to purchase, or not purchase, the insurance by clicking on your preferred option on the computer screen.

There are 54 decisions like this one to be made, each shown on a separate screen on the computer. Each decision might have different chances for the Personal Event outcome, the Index Event outcome, the initial stake, or the cost of insurance, so pay attention to each screen.

The screen that you will actually see has one additional piece of information, shown in this display. In this case you should note that the initial stakes are now \$60, that the loss is now \$35, and that the cost of the insurance is now \$14.50. This shows how these values might change from screen to screen, as mentioned earlier. The additional information is contained in the two "pie displays" on the right hand side. These additional displays are just another way to view the same information, and may or may not help you make your choice to purchase insurance or not to purchase insurance.

Figure C.3



In this example you start out with an initial stake of \$60. If the outcome of the Personal Event is Bad you will lose \$35, and if the outcome of the Personal Event is Good you will not lose any money. If you faced the choice in this example and chose to purchase insurance, you would pay \$14.50 from your initial stake. You would pay this \$14.50 before you drew any chips, so you would pay it regardless of the outcomes of your draws.

In this example there is a 20% chance that the outcome of the Personal Event is Bad, and an 80% chance that the Personal Event outcome is Good. There is an 80% chance that the Index Event outcome Matches the Personal Event outcome and a 20% chance that the Index Event outcome Differs from the Personal Event outcome. Based on these probabilities, the pie charts show the overall probabilities of the possible earnings and their respective amounts.

The top pie chart shows the possible earnings if you choose not to purchase insurance. Without insurance, the payouts depend only on the outcome of the Personal Event. Given that there is a 20% chance that the Personal Event outcome is Bad and an 80% chance that the Personal Event outcome is Good, the pie chart shows that there is a 20% chance you earn \$25 (= \$60 - \$35) and an 80% chance that you earn \$60.

The bottom pie chart shows the possible earnings if you choose to purchase insurance. Since the insurance claim is only paid out according to the outcome of the Index Event, outcomes from both the Index Event and the Personal Event will decide your earnings. There is an 80% chance that the Index Event outcome Matches the Personal Event outcome. Hence there is an 80% chance you will either receive a claim payment when you suffer a loss or not receive a claim payment when you do not suffer a loss. If either of these happen your payout will be \$45.50: your initial stake of \$60 less the \$14.50 cost of insurance. In the case in which you receive a claim payment when you suffer a loss the payout of \$35 completely offsets the loss of \$35.

According to the bottom pie chart the chance that the Personal Event outcome is Bad, but the Index Event outcome Differs, is 4% (= 20%$\times$ 20%). This means that there is a 4% chance that the Personal Event outcome is Bad without receiving an insurance claim payment . In this case you will receive \$10.50: your initial stake of \$60 less the \$14.50 cost of insurance less the \$35 loss. The chance that the Personal Event outcome is Good, and the Index Event outcome Differs, is 16% (= 80% $\times$ 20%). This means that there is a 16% chance that the Personal Event outcome is Good and you still receive an insurance claim payment. In this case you will receive \$80.50: your initial stake of \$60 less the \$14.50 cost of insurance plus the \$35 claim payment from the insurance.

After you have worked through all of the insurance decisions, please wait in your seat and an experimenter will come to you. You will then roll two 10-sided dice to determine which insurance decision will be played out. Since there are only 54 decisions, you will keep rolling the dice until a number between 1 and 54 comes up. There is an equal chance that any of your 54 choices will be selected, so you should approach each decision as if it is the one that you will actually play out to determine your payoff. Once the decision to play out is selected, you will draw chips from the Index bag and the Personal bag to determine the outcome.

In summary:

- You will decide whether or not to purchase insurance in each of the 54 scenarios.
- One of your decisions will be randomly selected to be played for cash.
- You will suffer the specified monetary loss only if the Personal Event outcome is Bad.
- If you purchase insurance, it will pay a claim payment only if the Index Event outcome is Bad. This can happen in two ways:
    1. Your Index draw Matches a bad Personal Event outcome;
    2. Your Index draw Differs from a good Personal Event outcome.

Whether or not you prefer to buy the insurance is a matter of personal taste. You may choose to buy insurance on some or all of your 54 choices, or none of the choices. The people next to you may be presented with different choices, insurance prices, and may have different preferences, so their responses should not matter to you. Please work silently, and make your choices by thinking carefully about each prospect.

Your payoff from this task is in cash and is in addition to the show-up payment that you receive just for being here, as well as any other earnings in other tasks. If you have a question, raise your hand and someone will come over and answer it.

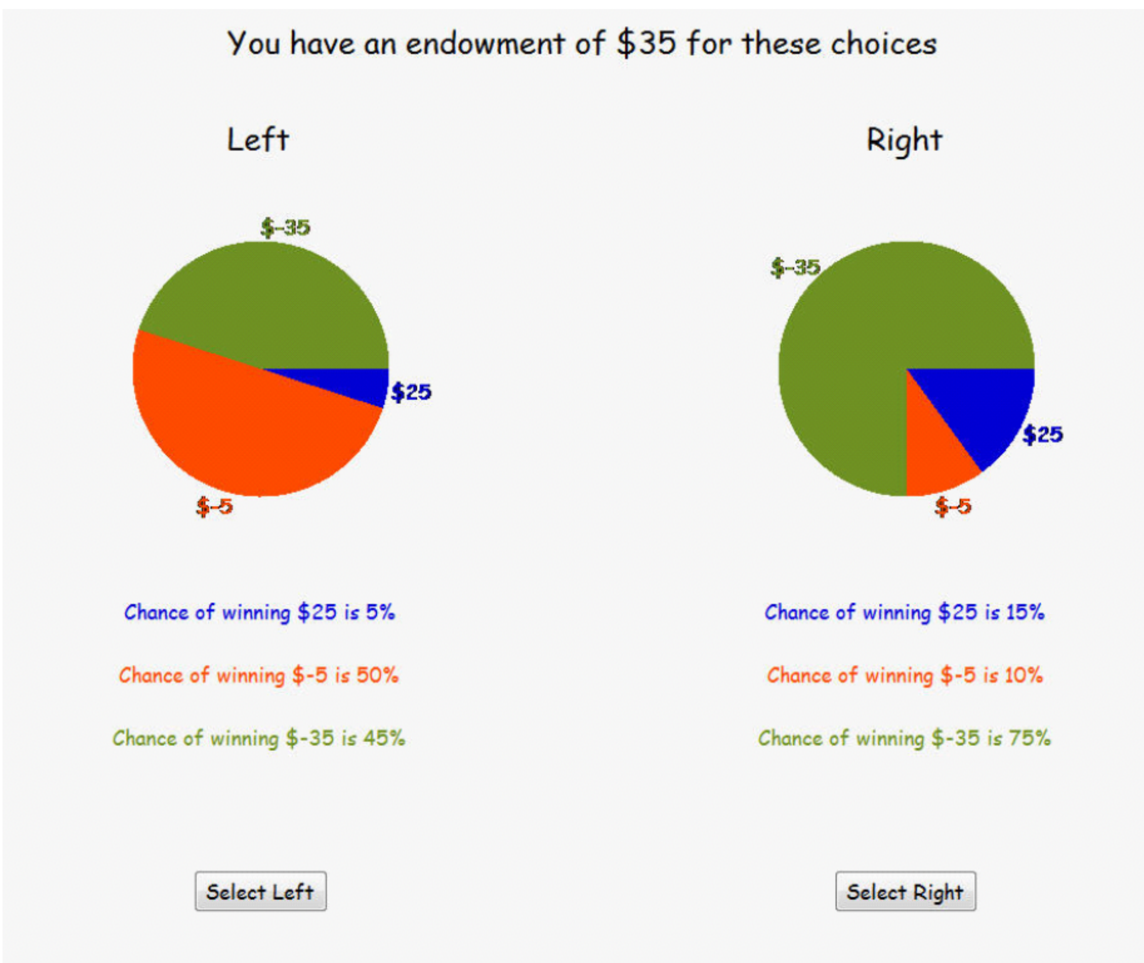
C.3 Risk Preferences Elicitation

Choices Over Risky Prospects

This is a task where you will choose between prospects with varying prizes and chances of winning each prize. You will be presented with a series of pairs of prospects where you will choose one of them. For each pair of prospects, you should choose the prospect you prefer. You will actually get the chance to play one of these prospects for earnings, and you will be paid according to the outcome of that prospect, so you should think carefully about which prospect you prefer on each decision screen.

Here is an example of what the computer display of such a pair of prospects will look like.

Figure C.4



The outcome of the prospects will be determined by the draw of a random number between 1 and 100. Each number between, and including, 1 and 100 is equally likely to occur. In fact, you will be able to draw the number yourself using two 10-sided dice.

You might be told your cash endowment for each decision at the top of the screen. In this example it is $35, so any earnings would be added to or subtracted from this endowment. The endowment may change from choice to choice, so be sure to pay attention to it. The endowment you are shown only applies for that choice.

In this example the left prospect pays twenty-five dollars ($25) if the number drawn is between 1 and 5, pays negative five dollars ($-5) if the number is between 6 and 55, and pays negative thirty-five dollars ($-35) if the number is between 56 and 100. The blue color in the pie chart corresponds to 5% of the area and illustrates the chances that the number drawn will be between 1 and 5 and your prize will be $25. The orange area in the pie chart corresponds to 50% of the area and illustrates the chances that the number drawn will be between 6 and 55 and your prize will be $-5. The green area in the pie chart corresponds to 45% of the area and illustrates the chances that the number drawn will be between 56 and 100. When you select the decision screen to be played out the computer will confirm the die rolls that correspond to the different prizes.

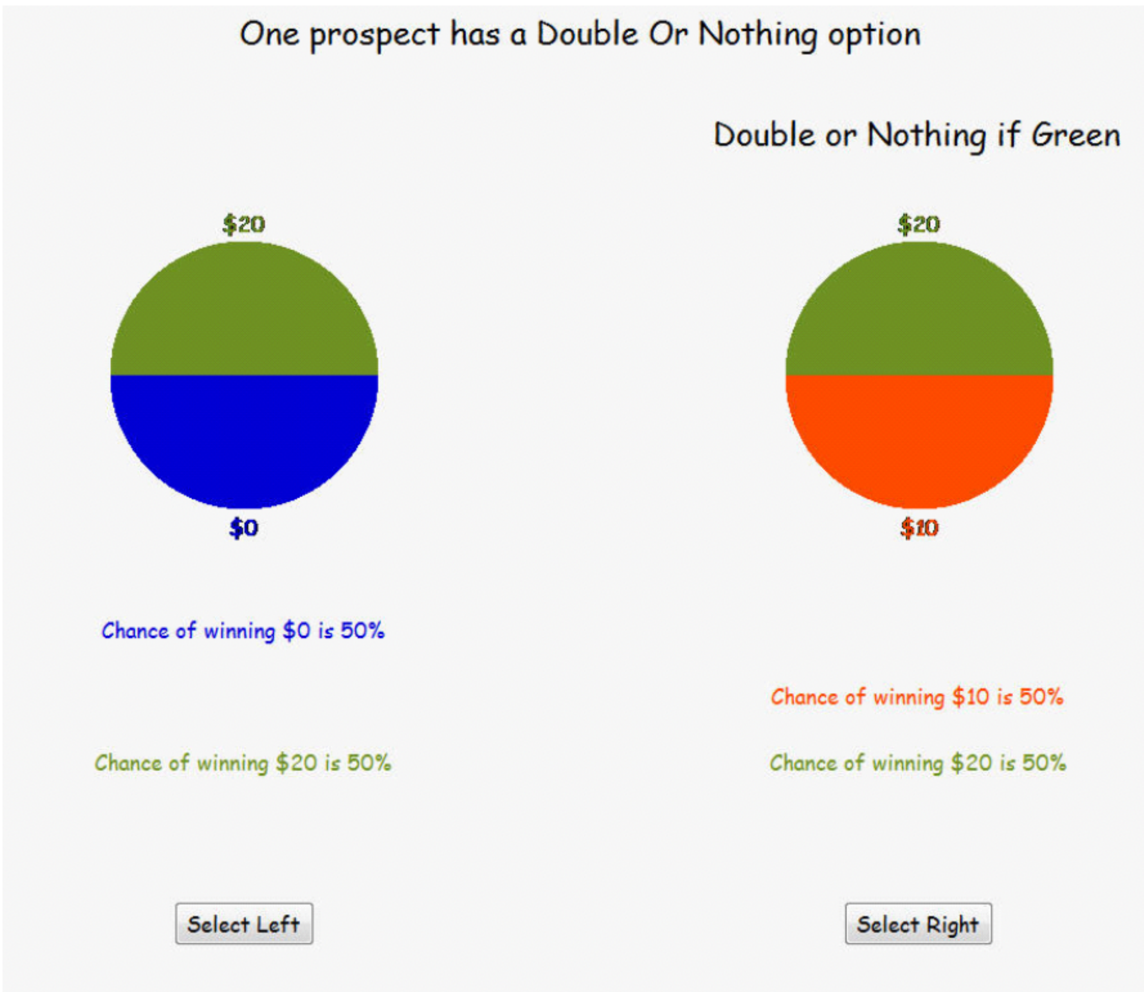
Now look at the pie on the right. It pays twenty-five dollars ($25) if the number drawn is between 1 and 15, negative five dollars ($-5) if the number is between 16 and 25, and negative thirty-five dollars ($-35) if the number is between 26 and 100. As with the prospect on the left, the pie slices represent the fraction of the possible numbers which yield each payoff. For example, the size of the $25 pie slice is 15% of the total pie.

Even though the screen says that you might win a negative amount, this is actually a loss to be deducted from your endowment. So if you win $-5, your earnings would be $30 = $35 - $5.

Each pair of prospects is shown on a separate screen on the computer. On each screen, you should indicate which prospect you prefer to play by clicking on one of the buttons beneath the prospects.

Some decision screens could also have a pair of prospects in which one of the prospects will give you the chance for "Double or Nothing." For instance, the right prospect in this screen image pays "Double or Nothing" if the Green area is selected, which happens if the number drawn is between 51 and 100. The right pie chart indicates that if the number is between 1 and 50 you get $10. However, if the number is between 51 and 100 we will flip a coin with you to determine if you get either double the amount or $0. In this example, if it comes up Heads you get $40, otherwise you get nothing. The prizes listed underneath each pie refer to the amounts before any "Double or Nothing" coin toss.

Figure C.5



After you have worked through all of the pairs of prospects, please wait quietly until further instructions. When it is time to play this task out for earnings, you will then roll two 10-sided dice until a number comes up to determine which pair of prospects will be played out. If there are 40 pairs we will roll the dice until a number between 1 and 40 comes up, if there are 80 pairs we will roll until a number between 1 and 80 comes up, and so on.

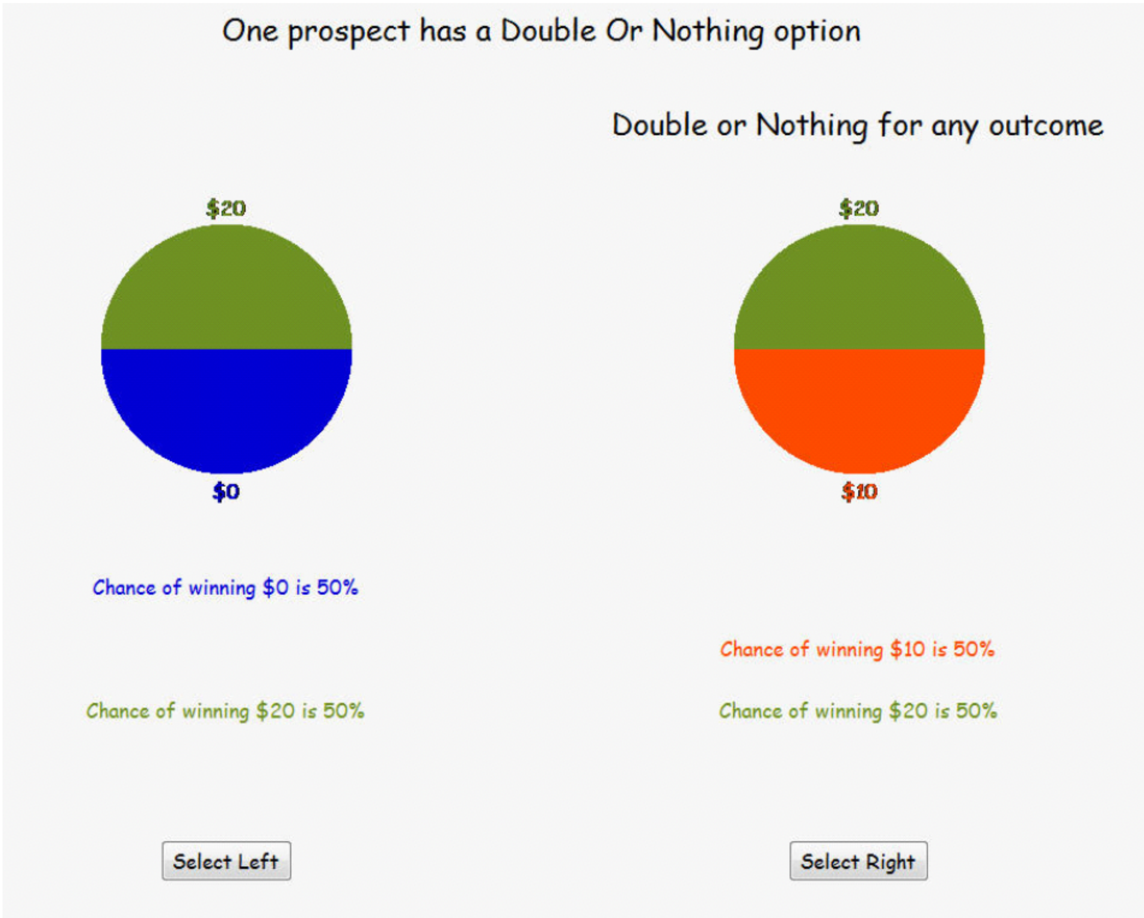
Since there is a chance that any of your choices could be played out for real, you should approach each pair of prospects as if it is the one that you will play out. Finally, you will roll the two ten-sided dice to determine the outcome of the prospect you chose, and if necessary we will then toss a coin to determine if you get “Double or Nothing.”

Here is an example: suppose your first roll was 81. We would then pull up the 81st decision that you made and look at which prospect you chose – either the left one or the right one. Let’s say that the 81st lottery was the same as the last example, and you chose the left prospect. If the random number from your second roll was 37, you would win $0; if it was 93, you would get $20.

If you picked the prospect on the right and drew the number 37, you would get $10; if it was 93, we would have to toss a coin to determine if you get “Double or Nothing.” If the coin comes up Heads then you would get $40. However, if it comes up Tails you would get nothing from your chosen prospect.

It is also possible that you will be given a prospect in which there is a “Double or Nothing” option no matter what the outcome of the random number. This screen image illustrates this possibility.

Figure C.6



In summary, your payoff is determined by five things:

1. by your endowment, if there is one, shown at the top of the screen;
2. by which prospect you selected, the left or the right, for each of these pairs;
3. by which prospect pair is chosen to be played out in the series of pairs using the two 10-sided dice;
4. by the outcome of that prospect when you roll the two 10-sided dice; and
5. by the outcome of a coin toss if the chosen prospect outcome is of the “Double or Nothing” type.

Which prospects you prefer is a matter of personal choice. The people next to you may be presented with different prospects, and may have different preferences, so their responses should not matter to you or influence your decisions. Please work silently, and make your choices by thinking carefully about each prospect.

All payoffs are in cash, and are in addition to the $5 show-up fee that you receive just for being here, as well as any other earnings in other tasks from the session today.

D Welfare Calculations for Index Insurance (NOT FOR PUBLICATION)

To understand the mechanics of evaluating lotteries using RDU it is useful to see worked numerical examples. Although this is purely a pedagogic exercise, in our experience many users of RDU are not familiar with these mechanics, and they are critical to the correct application of these models. Even the best pedagogic source available, Wakker (2010), leaves many worked examples as exercises, and many of the examples are correctly contrived to make a special pedagogic point.

We first review the general case, and then explain the application to index insurance.

General Rank-Dependent Decision Weights

Assume a simple power probability weighting function $\omega(p) = p\gamma$ and let $\gamma = 1.25$. To see the pure effect of probability weighting, assume $U(x) = x$ for $x \geq 0$. Start with a two-prize lottery, then consider three-prizes and four-prizes to see the general logic. The lotteries in our risk aversion task contain up to 4 prizes and probabilities.

In the two-prize case, let y be the smaller prize and Y be the larger prize, so $Y > y \geq 0$. Again, to see the pure effect of probability weighting, assume objective probabilities $p(y) = p(Y) = \frac{1}{2}$. The first step is to get the decision weight of the largest prize. This uses the answer to the question, "what is the probability of getting at least Y?" This is obviously $\frac{1}{2}$, so we then calculate the decision weight using the probability weighting function as $\omega(\frac{1}{2}) = (\frac{1}{2})\gamma = 0.42$. To keep notation for probability weights and decision weights similar but distinct, denote the decision weight for Y as $w(Y)$. Then we have $w(Y) = 0.42$.

The second step for the two-prize case is to give the other, smaller prize y the residual weight. This uses the answer to the question, "what is the probability of getting at least y?" Since one always gets at least y, the answer is obviously 1. Since $\omega(1) = 1$ for any of the popular probability weighting functions, 2 we can attribute the decision weight $\omega(1) - \omega(\frac{1}{2}) = 1 - 0.42 = 0.58$ to the prize y. Another way to see the same thing is to directly calculate the decision weight for the smallest prize to ensure that the decision weights sum to 1, so that the decision weight $w(y)$ is calculated as $1 - w(Y) = 1 - 0.42 = 0.58$. The two-prize case actually makes it harder to see the rank-dependent logic than when we examine the three-prize or four-prize case, but can be seen in retrospect as a special case.

With these two decision weights in place, the RDU evaluation of the lottery is $0.42 \times U(Y) + 0.58 \times U(y)$, or $0.42Y + 0.58y$ given our simplifying assumption of a linear utility function. Inspection of this RDU evaluation, and viewing the decision weights as if they were probabilities, shows why the RDU evaluation has to be less than the Expected Value (EV) of the lottery using the true probabilities, since that is $0.5Y + 0.5y$. The RDU evaluation puts more weight on the worst prize, and greater weight on the better prize, so it has to have a CE that is less than the EV (this last step is helped by the fact that $U(x) = x$, of course). Hence probability weighting in this case generates a CE that is less than the EV, and hence a risk premium.

However, the two-prize case collapses the essential logic of the RDU model. Consider a three-prize case in which we use the same probability weighting functions and utility functions, but have three prizes, y, Y and $\mathbf{Y}$, where $\mathbf{Y} > Y > y$, and $p(y) = p(Y) = p(\mathbf{Y}) = \frac{1}{3}$.

The decision weight for $\mathbf{Y}$ is evaluated first, and uses the answer to the question, "what is the probability of getting at least Y?" The answer is $\frac{1}{3}$, so the decision weight for Y is then directly evaluated as $w(Y) = \omega(\frac{1}{3}) = (\frac{1}{3})\gamma = 0.25$.

The decision weight for Y is evaluated next, and uses the answer to the more interesting question, "what is the probability of getting at least Y?" This is $p(Y) + p(\mathbf{Y}) = \frac{1}{3} + \frac{1}{3} = \frac{2}{3}$, so the probability weight is $\omega(\frac{2}{3} = (\frac{2}{3})\gamma = 0.60$. But the only part of this probability weight that is to be attributed solely to Y is the part that is not already attributed to $\mathbf{Y}$, hence the decision weight for Y is $\omega(\frac{2}{3}) - \omega 13 = \omega(Y) - \omega(\mathbf{Y}) = 0.60 - 0.25 = 0.35$. This intermediate step shows the rank-dependent logic in the clearest fashion. One could equally talk about cumulative probability weights, rather than just probability weights, but the logic is simple enough when one thinks of the question being asked "psychologically" and the partial attribution to Y that flows from it. In the two-prize case this partial attribution is skipped over.

The decision weight for y is again evaluated residually, as in the two-prize case. We can either see this by evaluating $\omega(1) - \omega(\frac{2}{3}) = 1 - 0.60 = 0.40$, or by evaluating $1 - w(Y) - w(\mathbf{Y}) = 1 - 0.35 - 0.25 = 0.40$.

The general logic may now be stated in words as follows:

- Rank the prizes from best to worst.
- Use the probability weighting function to calculate the probability of getting at least the prize in question.
- Then assign the decision weight for the best prize directly as the weighted probability of that prize.
- For each of the intermediate prizes in declining order, assign the decision weight using the weighted cumulative probability for that prize less the decision weights for better prizes (or, equivalently, the weighted cumulative probability for the immediately better prize).
- For the worst prize the decision weight is the residual decision weight to ensure that the decision weights sum to 1.

The key is to view the decision weights as the **incremental** decision weight attributable to that prize.

Figure D.1 collects these steps for each of the examples, and adds a four prize example. From a programming perspective, these calculations are tedious but not difficult as long as one can assume that prizes are rank-ordered as they are evaluated. Our computer code in Stata allows for up to four prizes, which spans most applications in laboratory or field settings, and is of course applicable for lotteries with any number of prizes up to four. The logic can be easily extended to more prizes.

Figure D.3 illustrates these calculations using the power probability weighting function. The dashed line in the left panel displays the probability weighting function $\omega(p) = p\gamma = p1.25$, with the vertical axis showing underweighting of the objective probabilities displayed on the bottom axis. The implications for decision weights are then shown in the right panel, for the two-prize, three-prize and four-prize cases. In the right panel the bottom axis shows prizes ranked from worst to best, so one immediately identifies the “probability pessimism” at work with this probability weighting function. Values of $\gamma < 1$ generate overweighting of the objective probabilities and “probability optimism,” as one might expect.

Figure D.4 shows the effects of using the "inverse-S" probability weighting function $\omega(p) = p\gamma/(p\gamma + (1-p)\gamma)1/\gamma$ for $\gamma = 0.65$. This function exhibits inverse-S probability weighting (optimism for small p, and pessimism for large p) for $\gamma < 1$, and S-shaped probability weighting (pessimism for small p, and optimism for large p) for $\gamma > 1$.

Rank-Dependent Decision Weights for Index Insurance Choices

Notation necessarily becomes more complex with index insurance. There are 8 possible states, depending on the permutations of binary outcomes if the individual chooses to purchase insurance $\{I_1, I_0\}$, if the index reflects a loss $\{L_1, L_0\}$, and if the individual's outcome matches the outcome of the index $\{P_1, P_0\}$. For instance, if the individual chooses not to purchase insurance (I_0), the index reflects a loss outcome (L_1), and the individual's outcome matches the index (P_1), the individual would also experience a personal loss ($I_0L_1P_1$) and be left with \$25. If the individual's outcome does not match the index (P_0), she does not experience a loss ($I_0L_1P_0$) and would keep her \$60. By the same logic, $I_0L_0P_1$=\$60 and $I_0L_0P_0$=\$25.[36]

If the individual chooses to purchase insurance (I_1) the outcomes are slightly more complex. If the index reflects a loss (L_1), and if the individual's outcome matches the outcomes of the index (P_1), the individual experiences a personal loss and receives a payout ($I_1L_1P_1$), hence she will keep her initial endowment less the premium (\$60 - \$9 = \$51). However, if the individual's outcome does not match the index, and the index shows a loss ($I_1L_1P_0$), the individual does not experience a personal loss but still receives a payout of \$35 on top of her initial endowment less premium (\$60 - \$9 +\$35 = \$86). This is the upside basis risk. Conversely if the individual's outcome does not match the index when the index does not show a loss ($I_1L_0P_0$), then the individual experiences a loss but receives no payout from insurance (\$60 - \$9 - \$35 = \$16). This is the downside basis risk. There are 8 possible states, depending on the permutations of binary outcomes of if the individual chooses to purchase insurance $\{I_1, I_0\}$, if the index reflects a loss $\{L_1, L_0\}$, and if the individual's outcome matches the outcome of the index $\{P_1, P_0\}$.

For instance, if the individual chooses not to purchase insurance (I_0), the index

[36]Some states may have the same final monetary outcome, but we consider them as separate states here to avoid making assumptions to combine probabilities.

reflects a loss outcome (L_1), and the individual's outcome matches the index (P_1), the individual would also experience a loss ($I_0L_1P_1$) and be left with \$5. If the individual's outcome does not match the index ($P0$), she does not experience a loss ($I_0L_1P_0$) and would keep her \$20. By the same logic, $I_0L_0P_0 = \$20$ and $I_0L_0P_0 = \$5$.

The logic for the case in which the individual does purchase insurance (I_1) is the same, other than the fact that a premium is deducted for each outcome.

The essential point to take into account with this index insurance contract is that the top two prizes should be associated with the sum of the probabilities of each outcome, and then the bottom two prizes should be associated with the sum of the probabilities of each outcome. Then the analyses proceeds as if there were only two prizes. Figure D.2 illustrates. Panel A repeats the 4-prize example from Figure D.1, where all 4 prizes are distinct in value. Panel B changes the calculations in panel B assuming instead that the top 2 prizes are the same value, and the bottom 2 prizes are the same value. Panel C then shows an example from the text and Figure B.1, assuming that $\sigma = 0.7$.

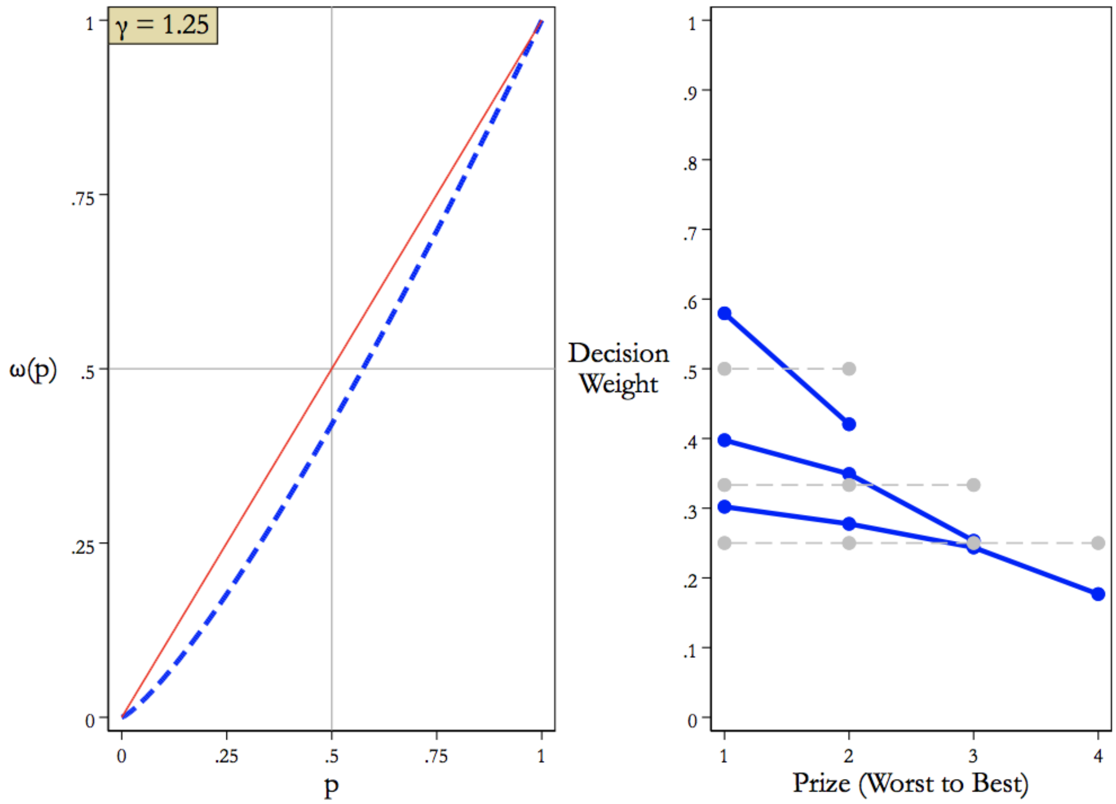
Figure D.1: Tabulations of RDU Examples

Prize	Probability	Cumulative Probability	Weighted Cumulative Probability	Decision Weight
		A. Two Prizes		
Y	0.5	0.5	$0.42 = 0.5^{1.25}$	0.42
y < Y	0.5	1	$1 = 1^{1.25}$	0.58 = 1 - 0.42
		B. Three Prizes		
Y	0.33	0.33	$0.25 = 0.33^{1.25}$	0.25
Y < **Y**	0.33	0.67	$0.60 = 0.67^{1.25}$	0.35 = 0.60 - 0.25
y < Y < **Y**	0.33	1	$1 = 1^{1.25}$	0.40 = 1 - 0.60 = 1 - 0.35 - 0.25
		C. Four Prizes		
Best	0.25	0.25	$0.18 = 0.25^{1.25}$	0.18
2nd Best	0.25	0.5	$0.42 = 0.50^{1.25}$	0.24 = 0.42 - 0.18
3rd Best	0.25	0.75	$0.70 = 0.75^{1.25}$	0.28 = 0.70 - 0.42 = 1 - 0.24 - 0.18
Worst	0.25	1	$1^{1.25}$	0.30 = 1 - 0.70 = 1 - 0.28 - 0.24 - 0.18

Figure D.2: Tabulations of RDU Examples Applied to Index Insurance

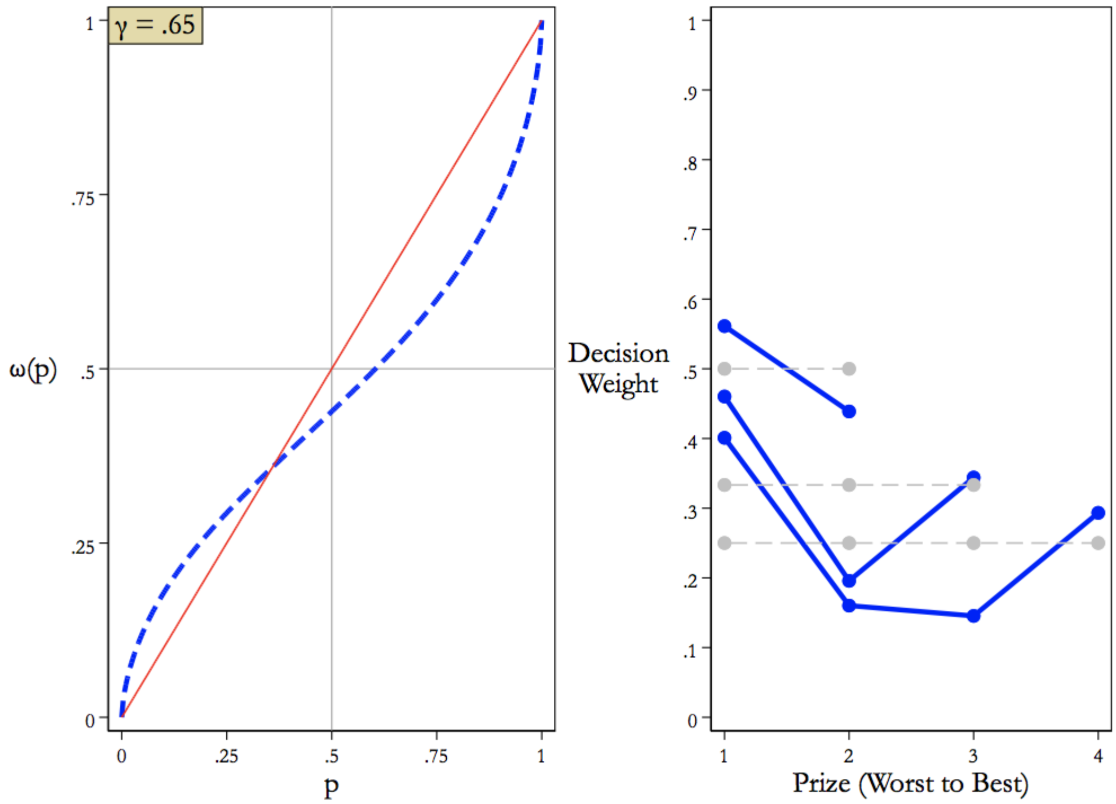
Prize	Probability	Cumulative Probability	Weighted Cumulative Probability	Decision Weight
		A. Four Distinct Prizes		
Best	0.25	0.25	$0.18 = 0.25^{1.25}$	0.18
2^{nd} Best	0.25	0.5	$0.42 = 0.50^{1.25}$	0.24 = 0.42 - 0.18
3^{rd} Best	0.25	0.75	$0.70 = 0.75^{1.25}$	0.28 = 0.70 - 0.42 = 1 - 0.24 - 0.18
Worst	0.25	1	$1^{1.25}$	0.30 = 1 - 0.70 = 1 - 0.28 - 0.24 - 0.18
		B. Four Prizes But Only Two Distinct Prize Levels		
Best 2^{nd} Best	0.25 + 0.25	0.5	$0.42 = 0.50^{1.25}$	0.42
3^{rd} Best Worst	0.25 + 0.25	1	$1^{1.25}$	0.58 = 1 - 0.42
		C. Index Insurance Not Purchased and $\varrho = 0.7$		
$I_0L_1P_0 = \$20$ $I_0L_0P_1 = \$20$	$0.1\,(1-\varrho) + 0.9\,\varrho$ $= 0.025 + 0.675$	0.7	$0.640 = 0.7^{1.25}$	0.64
$I_0L_1P_1 = \$5$ $I_0L_0P_0 = \$5$	$0.1\,\varrho + 0.9\,(1-\varrho)$ $= 0.075 + 0.225$	1	$1^{1.25}$	0.36 = 1 - 0.64

Figure D.3: RDU Risk Preferences with Power Probability Weighting: Implied Decision Weights



Note: Decision weights based on equi-probable reference lotteries, with probabilities 0.5 for 2-outcomes, 0.33 for 3-outcomes, and 0.25 for 4-outcomes, in light grey

Figure D.4: RDU Risk Preferences with Inverse-S Probability Weighting: Implied Decision Weights



Note: Decision weights based on equi-probable reference lotteries, with probabilities 0.5 for 2 outcomes, 0.33 for 3-outcomes, and 0.25 for 4-outcomes, in light grey

E Experimental Parameters (NOT FOR PUBLICATION)

Table E.1: Index Insurance Contracts and Parameters in the Experiment

Choice	Endowment ($)	Personal Loss Probability	Loss Amount ($)	Premium	Correlation	Implied Index Probability
1	60	0.1	20	7	0	0.5
2	60	0.1	20	10	0	0.5
3	60	0.1	20	13	0	0.5
4	60	0.1	20	6	0.2	0.42
5	60	0.1	20	8.5	0.2	0.42
6	60	0.1	20	11	0.2	0.42
7	60	0.1	20	4.75	0.4	0.34
8	60	0.1	20	6.75	0.4	0.34
9	60	0.1	20	8.75	0.4	0.34
10	60	0.1	20	3.75	0.6	0.26
11	60	0.1	20	5.25	0.6	0.26
12	60	0.1	20	6.75	0.6	0.26
13	60	0.1	20	2.5	0.8	0.18
14	60	0.1	20	3.5	0.8	0.18
15	60	0.1	20	4.75	0.8	0.18
16	60	0.1	20	1.5	1	0.1
17	60	0.1	20	2	1	0.1
18	60	0.1	20	2.5	1	0.1
19	60	0.1	35	12.25	0	0.5
20	60	0.1	35	17.5	0	0.5
21	60	0.1	35	22.75	0	0.5
22	60	0.1	35	10.25	0.2	0.42
23	60	0.1	35	14.75	0.2	0.42
24	60	0.1	35	19	0.2	0.42
25	60	0.1	35	8.25	0.4	0.34
26	60	0.1	35	12	0.4	0.34
27	60	0.1	35	15.5	0.4	0.34
28	60	0.1	35	6.25	0.6	0.26
29	60	0.1	35	9	0.6	0.26
30	60	0.1	35	11.75	0.6	0.26
31	60	0.1	35	4.5	0.8	0.18
32	60	0.1	35	6.25	0.8	0.18
33	60	0.1	35	8.25	0.8	0.18
34	60	0.1	35	2.5	1	0.1
35	60	0.1	35	3.5	1	0.1
36	60	0.1	35	4.5	1	0.1
37	60	0.2	35	12.25	0	0.5
38	60	0.2	35	17.5	0	0.5
39	60	0.2	35	22.75	0	0.5
40	60	0.2	35	10.75	0.2	0.44
41	60	0.2	35	15.5	0.2	0.44
42	60	0.2	35	20	0.2	0.44
43	60	0.2	35	9.25	0.4	0.38
44	60	0.2	35	13.25	0.4	0.38
45	60	0.2	35	17.25	0.4	0.38
46	60	0.2	35	7.75	0.6	0.32
47	60	0.2	35	11.25	0.6	0.32
48	60	0.2	35	14.5	0.6	0.32
49	60	0.2	35	6.25	0.8	0.26
50	60	0.2	35	9	0.8	0.26
51	60	0.2	35	11.75	0.8	0.26
52	60	0.2	35	5	1	0.2
53	60	0.2	35	7	1	0.2
54	60	0.2	35	9	1	0.2

Table E.2: Parameters for Double or Nothing Lotteries

	Left Lottery						Right Lottery					
Lottery ID	Prize 1	Prob 1	Prize 2	Prob 2	Prize 3	Prob 3	Prize 1	Prob 1	Prize 2	Prob 2	Prize 3	Prob 3
rdon1	$0	0.5	$10	0.5	$20	0	$0	0.5	$10	0.5	$20	0
rdon3	$0	0	$10	1	$35	0	$0	0	$5	0.5	$18	0.5
rdon5	$0	0	$10	1	$70	0	$0	0	$35	1	$70	0
rdon6	$0	0	$20	1	$35	0	$0	0	$10	0.5	$35	0.5
rdon7	$0	0	$20	0.5	$70	0.5	$0	0	$35	0.5	$70	0.5
rdon8	$0	0	$35	1	$70	0	$0	0	$35	0.5	$70	0.5
rdon9	$0	0	$20	0.5	$35	0.5	$0	0.5	$20	0	$70	0.5
rdon11	$0	0	$20	1	$70	0	$0	0	$20	0.5	$35	0.5
rdon12	$0	0	$35	0.75	$70	0.25	$0	0	$35	0.5	$70	0.5
rdon15	$0	0	$20	0.75	$70	0.25	$0	0	$35	0.5	$70	0.5

Note: Table contains the parameters used to define the compound lotteries used to test violation of the ROCL axiom. Also see the text for the Right Lottery in Table E.3.

Table E.3: Text for Double or Nothing Lotteries

Lottery ID	**Double or Nothing Text**
rdon1	Double or Nothing if outcome 2 in right lottery
rdon3	Double or Nothing for any outcome in right lottery
rdon5	Double or Nothing for any outcome in right lottery
rdon6	Double or Nothing if outcome 2 in right lottery
rdon7	Double or Nothing if outcome 2 in right lottery
rdon8	Double or Nothing if outcome 2 in right lottery
rdon9	Double or Nothing if outcome 3 in left lottery
rdon11	Double or Nothing if outcome 3 in right lottery
rdon12	Double or Nothing if outcome 2 in right lottery
rdon15	Double or Nothing if outcome 2 in right lottery

Note: Table contains the text used to define the compound lotteries and simple lotteries used to test violation of the ROCL axiom. Also see the parameters for the Right Lottery in Table E.2

Table E.4: Parameters for the Actuarially-Equivalent Lotteries

	Left Lottery						**Right Lottery**					
Lottery ID	Prize 1	Prob 1	Prize 2	Prob 2	Prize 3	Prob 3	Prize 1	Prob 1	Prize 2	Prob 2	Prize 3	Prob 3
rae1	$0	0.5	$10	0.5	$20	0	$0	0.75	$10	0	$20	0.25
rae3	$0	0	$10	1	$35	0	$0	0.5	$10	0.25	$35	0.25
rae5	$0	0	$10	1	$70	0	$0	0.5	$10	0	$70	0.5
rae6	$0	0	$20	1	$35	0	$0	0.25	$20	0.25	$35	0.5
rae7	$0	0	$20	0.5	$70	0.5	$0	0.25	$20	0	$70	0.75
rae8	$0	0	$35	1	$70	0	$0	0.25	$35	0	$70	0.75
rae9	$0	0.25	$20	0.5	$70	0.25	$0	0.5	$20	0	$70	0.5
rae11	$0	0	$20	1	$70	0	$0	0.25	$20	0.5	$70	0.25
rae12	$0	0	$35	0.75	$70	0.25	$0	0.25	$35	0	$70	0.75
rae15	$0	0	$20	0.75	$70	0.25	$0	0.25	$20	0	$70	0.75

Note: Table contains the parameters used to define the actuarially equivalent lotteries used to test violation of the ROCL axiom.

Table E.5 contains the parameters used to define the lotteries primarily designed to estimate EUT and RDU models. The key insight of the Loomes and Sugden (1998) design is to vary the "gradient" of the EUT-consistent indifference curves within a Marschak-Machina (MM) triangle.[37] The reason for this is to generate some choice patterns that are more powerful tests of EUT for any given risk attitude. Under EUT the slope of the indifference curve within a MM triangle is a measure of risk aversion. So there always exists some risk attitude such that the subject is indifferent, and evidence of Common Ratio (CR) violations in that case has virtually zero power.[38] The beauty of this design is that even if the risk attitude of the subject makes the tests of a CR violation from some sets of lottery pairs have low power, then the tests based on other sets of lottery pairs have to have higher power for this subject. By presenting subjects with several such sets, varying the slope of the EUT-consistent indifference curve, one can be sure of having some tests for CR violations that have decent power for each subject, without having to know *a priori* what their risk attitude is. Harrison et al (2007) refer to this as a "complementary slack experimental design," since low-power tests of EUT in one set mean that there must be higher-power tests of EUT in another set. Our battery includes 70 lottery pairs based on the Loomes and Sugden (1998) logic. Table E.5 documents these 70 lottery pairs.

[37] In the MM triangle there are always one, two or three prizes in each lottery that have positive probability of occurring. The vertical axis in each panel shows the probability attached to the high prize of that triple, and the horizontal axis shows the probability attached to the low prize of that triple. So when the probability of the highest and lowest prize is zero, 100% weight falls on the middle prize. Any lotteries strictly in the interior of the MM triangle have positive weight on all three prizes, and any lottery on the boundary of the MM triangle has zero weight on one or two prizes.

[38] EUT does not, then, predict 50:50 choices, as some casually claim. It does say that the expected utility differences will not explain behavior, and that then allows all sorts of psychological factors to explain behavior. In effect, EUT has no prediction in this instance, and that is not the same as predicting an even split.

Table E.5: Battery of Lottery Tasks from Harrison and Swarthout (2022)

Task	EV left	EV right	EV ratio	Left $ 1	Left p 1	Left $ 2	Left p 2	Left $ 3	Left p 3	Right $ 1	Right p 1	Right $ 2	Right p 2	Right $ 3	Right p 3	Notes
5	$59.50	$61.25	-3%	$0	0.15	$35	0	$70	0.85	$0	0	$35	0.25	$70	0.75	LS1
6	$49.00	$50.75	-3%	$0	0.3	$35	0	$70	0.7	$0	0.15	$35	0.25	$70	0.6	LS2
7	$49.00	$52.50	-7%	$0	0.3	$35	0	$70	0.7	$0	0	$35	0.5	$70	0.5	LS3
8	$50.75	$52.50	-3%	$0	0.15	$35	0.25	$70	0.6	$0	0	$35	0.5	$70	0.5	LS4
9	$33.25	$35.00	-5%	$0	0.15	$35	0.75	$70	0.1	$0	0	$35	1	$70	0	LS5
10	$28.00	$35.00	-20%	$0	0.6	$35	0	$70	0.4	$0	0	$35	1	$70	0	LS6
12	$7.00	$8.75	-20%	$0	0.9	$35	0	$70	0.1	$0	0.75	$35	0.25	$70	0	LS8
13	$63.00	$63.00	0%	$0	0.1	$35	0	$70	0.9	$0	0	$35	0.2	$70	0.8	LS9
15	$35.00	$35.00	0%	$0	0.5	$35	0	$70	0.5	$0	0	$35	1	$70	0	LS11
16	$35.00	$35.00	0%	$0	0.1	$35	0.8	$70	0.1	$0	0	$35	1	$70	0	LS12
17	$21.00	$21.00	0%	$0	0.7	$35	0	$70	0.3	$0	0.5	$35	0.4	$70	0.1	LS13
18	$21.00	$21.00	0%	$0	0.7	$35	0	$70	0.3	$0	0.4	$35	0.6	$70	0	LS14
19	$21.00	$21.00	0%	$0	0.5	$35	0.4	$70	0.1	$0	0.4	$35	0.6	$70	0	LS15
20	$7.00	$7.00	0%	$0	0.9	$35	0	$70	0.1	$0	0.8	$35	0.2	$70	0	LS16
21	$63.00	$61.25	3%	$0	0.1	$35	0	$70	0.9	$0	0	$35	0.25	$70	0.75	LS17
22	$42.00	$36.75	14%	$0	0.4	$35	0	$70	0.6	$0	0.1	$35	0.75	$70	0.15	LS18
23	$42.00	$35.00	20%	$0	0.4	$35	0	$70	0.6	$0	0	$35	1	$70	0	LS19
24	$36.75	$35.00	5%	$0	0.1	$35	0.75	$70	0.15	$0	0	$35	1	$70	0	LS20
25	$21.00	$19.25	9%	$0	0.7	$35	0	$70	0.3	$0	0.6	$35	0.25	$70	0.15	LS21
26	$21.00	$17.50	20%	$0	0.7	$35	0	$70	0.3	$0	0.5	$35	0.5	$70	0	LS22
27	$19.25	$17.50	10%	$0	0.6	$35	0.25	$70	0.15	$0	0.5	$35	0.5	$70	0	LS23
28	$10.50	$8.75	20%	$0	0.85	$35	0	$70	0.15	$0	0.75	$35	0.25	$70	0	LS24
29	$63.00	$59.50	6%	$0	0.1	$35	0	$70	0.9	$0	0	$35	0.3	$70	0.7	LS25
30	$42.00	$35.00	20%	$0	0.4	$35	0	$70	0.6	$0	0.2	$35	0.6	$70	0.2	LS26
31	$42.00	$31.50	33%	$0	0.4	$35	0	$70	0.6	$0	0.1	$35	0.9	$70	0	LS27
32	$35.00	$31.50	11%	$0	0.2	$35	0.6	$70	0.2	$0	0.1	$35	0.9	$70	0	LS28
33	$28.00	$24.50	14%	$0	0.6	$35	0	$70	0.4	$0	0.5	$35	0.3	$70	0.2	LS29
34	$28.00	$21.00	33%	$0	0.6	$35	0	$70	0.4	$0	0.4	$35	0.6	$70	0	LS30
35	$24.50	$21.00	17%	$0	0.5	$35	0.3	$70	0.2	$0	0.4	$35	0.6	$70	0	LS31
36	$14.00	$10.50	33%	$0	0.8	$35	0	$70	0.2	$0	0.7	$35	0.3	$70	0	LS32

Task	EV left	EV right	EV ratio	Left $ 1	Left p 1	Left $ 2	Left p 2	Left $ 3	Left p 3	Right $ 1	Right p 1	Right $ 2	Right p 2	Right $ 3	Right p 3	Notes
37	$63.00	$56.00	13%	$0	0.1	$35	0	$70	0.9	$0	0	$35	0.4	$70	0.6	LS33
38	$52.50	$42.00	25%	$0	0.25	$35	0	$70	0.75	$0	0.1	$35	0.6	$70	0.3	LS34
39	$52.50	$35.00	50%	$0	0.25	$35	0	$70	0.75	$0	0	$35	1	$70	0	LS35
40	$42.00	$35.00	20%	$0	0.1	$35	0.6	$70	0.3	$0	0	$35	1	$70	0	LS36
41	$28.00	$21.00	33%	$0	0.5	$35	0.2	$70	0.3	$0	0.4	$35	0.6	$70	0	LS37
42	$31.50	$21.00	50%	$0	0.55	$35	0	$70	0.45	$0	0.4	$35	0.6	$70	0	LS38
43	$31.50	$28.00	13%	$0	0.55	$35	0	$70	0.45	$0	0.5	$35	0.2	$70	0.3	LS39
44	$21.00	$14.00	50%	$0	0.7	$35	0	$70	0.3	$0	0.6	$35	0.4	$70	0	LS40
45	$63.00	$63.00	0%	$0	0.1	$35	0	$70	0.9	$0	0	$35	0.2	$70	0.8	LS9
46	$35.00	$35.00	0%	$0	0.5	$35	0	$70	0.5	$0	0.1	$35	0.8	$70	0.1	LS10
47	$35.00	$35.00	0%	$0	0.5	$35	0	$70	0.5	$0	0	$35	1	$70	0	LS11
48	$35.00	$35.00	0%	$0	0.1	$35	0.8	$70	0.1	$0	0	$35	1	$70	0	LS12
49	$21.00	$21.00	0%	$0	0.7	$35	0	$70	0.3	$0	0.5	$35	0.4	$70	0.1	LS13
50	$21.00	$21.00	0%	$0	0.7	$35	0	$70	0.3	$0	0.4	$35	0.6	$70	0	LS14
51	$21.00	$21.00	0%	$0	0.5	$35	0.4	$70	0.1	$0	0.4	$35	0.6	$70	0	LS15
52	$7.00	$7.00	0%	$0	0.9	$35	0	$70	0.1	$0	0.8	$35	0.2	$70	0	LS16
53	$63.00	$56.00	13%	$0	0.1	$35	0	$70	0.9	$0	0	$35	0.4	$70	0.6	LS33
54	$52.50	$42.00	25%	$0	0.25	$35	0	$70	0.75	$0	0.1	$35	0.6	$70	0.3	LS34
55	$52.50	$35.00	50%	$0	0.25	$35	0	$70	0.75	$0	0	$35	1	$70	0	LS35
56	$42.00	$35.00	20%	$0	0.1	$35	0.6	$70	0.3	$0	0	$35	1	$70	0	LS36
57	$28.00	$21.00	33%	$0	0.5	$35	0.2	$70	0.3	$0	0.4	$35	0.6	$70	0	LS37
58	$31.50	$21.00	50%	$0	0.55	$35	0	$70	0.45	$0	0.4	$35	0.6	$70	0	LS38
59	$31.50	$28.00	13%	$0	0.55	$35	0	$70	0.45	$0	0.5	$35	0.2	$70	0.3	LS39
60	$21.00	$14.00	50%	$0	0.7	$35	0	$70	0.3	$0	0.6	$35	0.4	$70	0	LS40
61	$59.50	$51.80	15%	$35	0.1	$21	0	$70	0.9	$35	0	$21	0.2	$70	0.8	LS9
62	$17.50	$13.30	-232%	$35	0.5	$21	0	$70	0.5	$35	0.1	$21	0.8	$70	0.1	LS10
63	$17.50	$21.00	-183%	$35	0.5	$21	0	$70	0.5	$35	0	$21	1	$70	0	LS11
64	$13.30	$21.00	-37%	$35	0.1	$21	0.8	$70	0.1	$35	0	$21	1	$70	0	LS12
65	$3.50	$18.90	-81%	$35	0.7	$21	0	$70	0.3	$35	0.5	$21	0.4	$70	0.1	LS13
66	$3.50	$26.60	-87%	$35	0.7	$21	0	$70	0.3	$35	0.4	$21	0.6	$70	0	LS14
67	$18.90	$26.60	-29%	$35	0.5	$21	0.4	$70	0.1	$35	0.4	$21	0.6	$70	0	LS15
68	$24.50	$32.20	-24%	$35	0.9	$21	0	$70	0.1	$35	0.8	$21	0.2	$70	0	LS16
69	$59.50	$33.60	77%	$35	0.1	$21	0	$70	0.9	$35	0	$21	0.4	$70	0.6	LS33
70	$43.75	$4.90	793%	$35	0.25	$21	0	$70	0.75	$35	0.1	$21	0.6	$70	0.3	LS34
71	$43.75	$21.00	-308%	$35	0.25	$21	0	$70	0.75	$35	0	$21	1	$70	0	LS35
72	$4.90	$21.00	-123%	$35	0.1	$21	0.6	$70	0.3	$35	0	$21	1	$70	0	LS36
73	$0.70	$26.60	-97%	$35	0.5	$21	0.2	$70	0.3	$35	0.4	$21	0.6	$70	0	LS37
74	$12.25	$26.60	-146%	$35	0.55	$21	0	$70	0.45	$35	0.4	$21	0.6	$70	0	LS38
75	$12.25	$0.70	-1850%	$35	0.55	$21	0	$70	0.45	$35	0.5	$21	0.2	$70	0.3	LS39
76	$3.50	$29.40	-88%	$35	0.7	$21	0	$70	0.3	$35	0.6	$21	0.4	$70	0	LS40

Note: Table contains the parameters used to define the lotteries primarily designed to estimate EUT and RDU models. LS refers to Loomes and Sugden (1998). The number in the first column refers to the lottery number in Harrison and Swarthout (2022), and the lottery ID in the final column connects back to Loomes and Sugden (1998).

Table E.6: Parameters for the Actuarially-Equivalent Index Insurance Lotteries

	Left Lottery								**Right Lottery**							
ID	Prize 1	Prob 1	Prize 2	Prob 2	Prize 3	Prob 3	Prize 4	Prob 4	Prize 1	Prob 1	Prize 2	Prob 2	Prize 3	Prob 3	Prize 4	Prob 4
iiae2	$0	0	$0	0	$25	0.1	$60	0.9	$18.75	0.01	$53.75	0.09	$53.75	0.81	$88.75	0.09
iiae3	$0	0	$0	0	$25	0.1	$60	0.9	$16	0.02	$51	0.08	$51	0.72	$86	0.18
iiae4	$0	0	$0	0	$25	0.1	$60	0.9	$13	0.03	$48	0.07	$48	0.63	$83	0.27
iiae5	$0	0	$0	0	$53.75	0.1	$88.75	0.9	$10.25	0.04	$45.25	0.06	$45.25	0.54	$80.25	0.36
iiae6	$0	0	$0	0	$25	0.1	$60	0.9	$7.50	0.05	$42.50	0.05	$42.50	0.45	$77.50	0.45
iiae8	$0	0	$0	0	$25	0.2	$60	0.8	$16	0.02	$51	0.18	$51	0.72	$86	0.08
iiae9	$25	0.2	$60	0.8	$0	0	$0	0	$13.75	0.04	$48.75	0.16	$48.75	0.64	$83.75	0.16
iiae10	$0	0	$0	0	$25	0.2	$60	0.8	$11.75	0.06	$46.75	0.14	$46.75	0.56	$81.75	0.24
iiae11	$0	0	$0	0	$25	0.2	$60	0.8	$9.5	0.08	$44.50	0.12	$44.50	0.48	$79.5	0.32
iiae12	$0	0	$0	0	$25	0.2	$60	0.8	$7.5	0.1	$42.50	0.1	$42.50	0.4	$77.50	0.4

Additional References

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