Higher order risk attitudes and prevention under different timings of loss: A laboratory experiment and prospect theory reexamination

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Abstract

This paper provides experimental evidence of the role of higher order risk attitudes, especially prudence, in prevention behavior. Prudence is theoretically known to have a negative effect on prevention if the loss could come today and a positive effect on prevention if the loss could come in the future, under expected utility frame work. To test these comparative statics, we employed a novel experimental design where each subject plays one of four variations of prevention game which differ in i) timing of loss - today or one week later, and ii) whether externality of prevention exists or not, preceded by a higher order risk elicitation task. In contrast to the predictions, we find that elicited prudence is negatively correlated with prevention regardless of the timing of the loss. To explain this, we provide a prospect theory counterpart of the comparative statics, in line with our observations of a high level of prudence and low level of prevention. Lastly, we also find that prevention decreases when it acts as a strategic substitute between subjects, which is consistent with our theoretical results.

Keywords: Higher order risk attitudes; Prudence; Prevention; Timings of loss; Prospect theory

JEL classification: C70, C90, C61.

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1. Introduction

Intertemporal choice under risk dates back to Leland's (1968) analysis of precautionary saving. Then, Kimball (1990) identified that willingness to save more under a greater background risk, called prudence, is equivalent to a positive third derivative of the von Neumann–Morgenstern utility function under the expected utility framework. Starting from the seminal work, the concept of higher order risk attitudes, including prudence, has also been widely applied to non-financial contexts. Gollier (2001) showed that the intensity of prudence matters for the optimal investment in new technology, such as genetically-modified food, when potential damage may occur in the future due to scientific advancement. Bramoullé and Treich (2009) studied a pollution emission game with uncertain damage. They find that a prudent player will increase emission more when uncertainty about damage increases. White (2008) studied the role of prudence in a bargaining situation and showed that an increase in prudence plays a similar role as increasing a player's patience and, hence, improves the bargaining outcome.[1]

Experimental investigation of higher order risk attitudes emerged around this decade. Eeckhoudt and Schlesinger (2006) developed a method based on risk appointment tasks to address higher order risk attitudes. Since then, recent experimental economics studies applied risk appointment tasks to elicit subjects' higher order risk attitudes, especially prudence and temperance (Crainich et al. 2013; Deck and Schlesinger 2010, 2014; Ebert and Wiesen 2011, 2014; Noussair et al. 2014). One stylized fact in the literature is that prudence prevails in a wide range of subjects, from undergraduate students (Deck and Schlesinger 2010, 2014; Ebert and Wiesen 2011, 2014) to general subjects (Noussair et al. 2014). Noussair et al. (2014) linked the elicited higher order risk attitudes with the financial choice. They find that higher order risk attitudes determine a wide range of real economic behavior including savings. Nevertheless, the role of higher order risk attitudes in in-game behaviors, especially in the self-protection context, remains empirically unexplored.

This study is, to the best of our knowledge, the first attempt to test comparative statics between higher order risk attitudes and prevention experimentally under different timings of loss in a self-protection context. We introduced a prevention game where a player can make an effort to reduce the probability of a loss. It is known that, in prevention games, prudence increases (decreases) the prevention effort when the loss could occur in the far future (today). (Eeckhoudt and Gollier 2005; Menegatti 2009).

We also explore group prevention, where each of two players benefits from the other player's effort. A good example of the externality of prevention would be efforts to reduce carbon dioxide because global warming could damage all countries, but the cost of effort to reduce carbon dioxide

[1] Courbage et al. (2009) surveyed previous results with intertemporal self-protection and higher order risk attitudes. See also Gollier, Hammitt and Treich (2013).

belongs to each country. The theoretical predictions are in line with standard public good games, the symmetric Nash equilibrium effort in group prevention game is below the socially optimal level regardless of the timing of the loss and risk attitudes. Nevertheless, theoretically, the comparative statics between prudence and effort in a group prevention game no longer exist. Hence, whether such comparative statics hold for a group is a rather empirical question.

In this experiment, the subjects participated in a higher order risk attitude task (an extended version of Noussair et al. 2014), prevention game, and time preference elicitation. We employed a between-subject design. Each subject is assigned to one of four variants of the prevention game, depending on to the timing of the loss (current loss and future loss) and externality of effort (individual and group). In group prevention games, subjects are matched by the elicited prudence to obtain symmetric players.

The data systematically violate the expected utility predictions. We find that most subjects are highly prudent, in line with the previous literature. Under the predictions of Eeckhoudt and Gollier (2005) and Menegatti (2009), we expected the subjects facing a future loss would make more effort than those facing a current loss. Nevertheless, there is no significant difference in the efforts associated with different timings of losses. When we analyze the within-treatment data, more prudent subjects make lower preventive effort, regardless of the timing of the loss, in line with the findings of Eeckhoudt and Gollier (2005), but in contrast with Menegatti (2009).

Prospect theory (Kahneman and Tversky, 1979; Wakker, 2010) provides a rationale for the above observations. We establish prospect theory predictions in a prevention game, and each prediction corresponds to an expected utility counterpart in Eeckhoudt and Gollier (2005) and Menegatti (2009). Especially, we show that regardless of the timing of loss, a prospect theory player makes less effort relative to a risk-neutral scenario if the probability distortion á la Goldstein-Einhorn (1987) is less than the curvature parameter of the power value function. Notably, this condition is widely supported in the main literature on parameter estimation of the prospect theory model (Gonzalez and Wu, 1999; Abdellaoui, 2000; Abdellaoui et al., 2005; Booiji et al., 2010; Choi et al., 2017). Finally, we also show that a prospect theory player chooses prudent alternatives in our elicitation task using the estimates provided in the literature. These results together explain why we observe both a high score of prudence in the elicitation task and less effort than predicted by expected utility model.

Our contributions to the literature are three-fold. First, we provide the first experimental data on the both comparative statics by Eeckhoudt and Gollier (2005) and Menegatti (2009) between higher order risk attitudes and a prevention game by varying the timing of the loss. We find a consistent negative correlation, regardless of the timing of loss, which previous theoretical predictions do not explain. Second, we also contribute to emerging attempts to connect elicited higher order risk attitudes with the prospect theory model (Deck, and Schlesinger, 2010; Ebert and Wiesen, 2014). With the help of the estimates provided in the recent literature on prospect theory model (Gonzalez and Wu, 1999; Abdellaoui, 2000; Abdellaoui et al., 2005; Booiji et al., 2010; Choi et al., 2017), we provide a unified explanation of our data from both the elicitation task and prevention games. In contrast to Deck and Schlesinger (2010) and Ebert and Wiesen (2014), who focused on prospect theory foundation of an elicitation task, our attempt also sheds light on intertemporal decision making through prospect theory. Last, our study is also novel in that we conduct group prevention game treatments, finding a significant decrease in effort when effort is a strategic substitute between players, and a negative impact of prudence on efforts, as in the individual case. To the best of our knowledge, no study has ever explored the connection between higher order risk attitudes and group prevention behavior.

The remainder of this paper is organized as follows. Section 2 presents the prevention game, the experiment, the predictions based on the expected utility framework, and the simulations. Section 3 describes the experimental design and Section 4 discusses the main results. Section 5 discusses how prospect theory fits the data. Section 6 provides our concluding remarks.

2. The Model

2.1. Prudence: downside risk aversion

Consider two compound lotteries, L and R, which have a base lottery (75, 0.5; 30) in common, but differ in whether a zero-mean risk (+10, 0.5; -10) is attached to a richer or a poorer state of the base lottery. The general experimental evidence shows that most subjects prefer R to L. A player is prudent if she prefers a risk (at zero-mean risk) attached to a richer to a poorer state. In other words, a player is downside risk-averse:

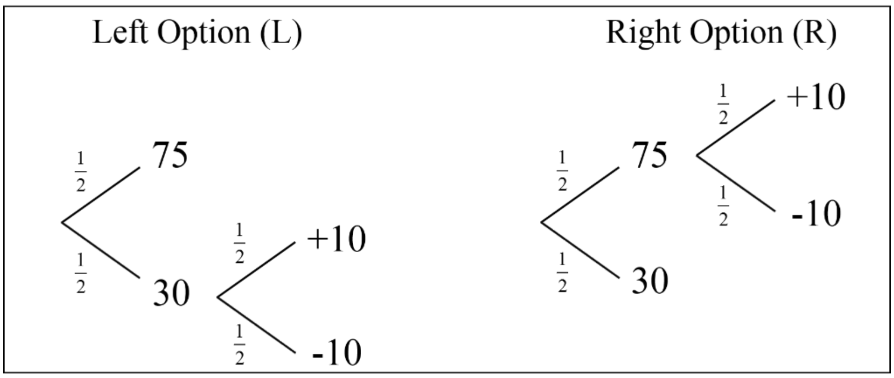

Fig. 1 Upside and downside risk

It is known that, under the expected utility framework, prudence is equivalent to a convex marginal von Neumann–Morgenstern utility function. To see this, let $B = (a, p; b)$ with $a > b$ be a base lottery and $\tilde{\varepsilon}$ be a zero mean risk. Consider two lotteries that combine *B* and $\tilde{\varepsilon}$: L such that $\tilde{\varepsilon}$ is attached to the better outcome *a* of *B*, and *R* such that $\tilde{\varepsilon}$ is attached to the worse outcome *b* of *B*. We want a down side risk-averse as a preference of *R* over *L* whenever $a > b$. This is true if and only if $2\{EU(R) - EU(L)\} = \{E(a+\tilde{\varepsilon}) + E(b)\} - \{E(a) + E(b+\tilde{\varepsilon})\} = \int_b^a [Eu'(w+\tilde{\varepsilon}) - u'(w)]dw > 0$, whenever $a > b$, which is equivalent to a convex u'. In other words, $u'''(w) > 0 \text{ for all } w$.

Definition 1 (Kimball, 1990). The player is *prudent (imprudent)* if u' is convex (concave).

Kimball (1990) showed that the optimal saving when uncertainty regarding future income grows if and only if u' is convex. The logic is as follows. When *u'* is convex, the future marginal expected utility increases under a greater risk. Today's marginal utility also increases, via the first order condition, which, in turn, implies saving more today. In our prevention game with a future loss, which we will explain in the next subsection, prudence plays a similar role.

2.2. Prevention game with a future loss

Consider a player endowed with income equal to 11 today, and its future income is at risk, taking value 13 or 5. The player chooses an effort $e \in [0,3]$ today to reduce the probability of future income taking value 5, which is given by 2/(e+2). The player's effort decreases today, regardless of the realized future income. Figure 2-(a) illustrates the example time line.

(a) Future Loss (b) Current Loss

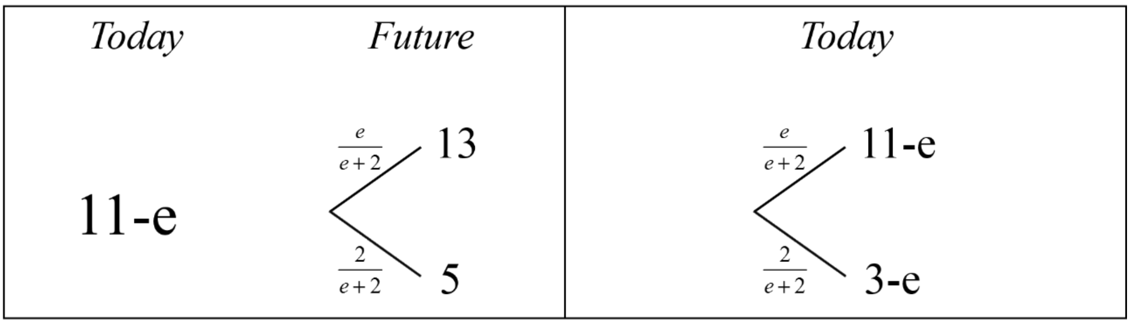

Fig. 2 Prevention game depending on the timing of the loss

First, consider a risk neutral player. His/her expected payoff, (11-e)+[13e+10]/(e+2), is maximized when *e*=2. Note that the risk neutral player faces a fifty-fifty chance lottery of future income at his/her optimal effort level. Next, consider a prudent (convex u') player. We will show that the prudent player has an incentive to increase his/her effort from value 2. Suppose that the prudent player chooses 2+*s*, where *s* is a small marginal effort. Then, the increase in the expected utility for the additional effort is given by:

$EU(2+s)-EU(2)=\left[u(13)-u(5)\right]\left(p(2)-p(2+s)\right)+\left[u(9-s)-u(9)\right]$, which approaches

to $EU'(2)=-p'(2)\int_5^{13}u'(w)dw-u'(9)=\frac{1}{8}\int_5^{13}u'(w)dw-u'(9)$ for a sufficiently small *s*. The convexity of *u*' ensures that $EU(2+s)>EU(2)$.

Menegatti (2009) generalized the above observation.[2] Let *y* and *z* be a player's today and future income, respectively. The player faces endogenous uncertainty regarding the probability of losing d out of *z*. The player chooses an effort $e\in[0,\bar{e}]$ where $\bar{e}<w,$ to reduce the probability of a future loss event, $p(e)\in[0,1]$, where the subscript indicates the individual decision making. Assume $p'<0, p''>0$. At effort *e*, the player faces a lottery (p(e), y-e-d; 1-p(e), y-e). Given the player's vN-M utility function *u*, we can formulate the player's problem as the maximization of his/her expected utility:

$$\max_{e\in[0,\bar{e}]} U_f(e)=u(y-e)+p(e)u(z-d)+(1-p(e))u(z). \tag{0.1}$$

We assume $u''\le 0,$ so that $U_f''=u''+p''\{u(z-d)-u(z)\}<0.$ First, consider the risk-neutral case: $u(x)=x.$ Then, (1.1) reduces to:

$$\max_{e\in[0,\bar{e}]} y-e+p(e)(z-e-d)+(1-p(e))(z-e). \tag{0.2}$$

The first order condition is given by:

$$-p'(e)d=1. \tag{0.3}$$

Denote the solution of (1.3) by e_n. We follow Menegatti's (2009) assumption on endowments *y* and *z*[3]:

$$y=z-p(e_n)d+e_n. \tag{0.4}$$

Proposition 1 (Menegatti 2009). *Consider a prevention game with a future loss. Assume* $p(e_n)=1/2$ and *(1.4). If the player is prudent (imprudent), then, his/her optimal effort is higher (lower) than* e_n.

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[2] In a two-period model where a player can choose both prevention effort and monetary saving, prudence has a negative effect on effort (Peter, 2017).

[3] In our example, we used *y*=11, *z*=13, en=2, and p(pn)=1/2, which satisfy (1.4).

2.3. Prevention game with a current loss

Interestingly, prudence has a negative impact on the optimal effort if the loss event occurs in the same period as the effort. We call this a prevention game with a current loss. Figure 2-(b) illustrates another example, where there is only one period, and today's income, equal to 11, is at risk. Note that changes in the timing of loss do not alter the risk neutral player's effort, and, hence, such player chooses 2 again. Now, suppose that a prudent player slightly decreases his/her effort from 2 by *s* in the game with a current loss. Notice that the richer state outcome is decreasing in *e*. A prudent player prefers to accumulate a good stage wealth and has an incentive to make less effort than the risk-neutral player does. In fact, this player will be better off in this case since, for a sufficiently small *s*, the difference $EU(2)-EU(2-s)$ approaches $EU'(2)=[p'(2)(u(1)-u(9))+.5u'(9)+.5u'(1)]=$

$\frac{-1}{8}\int_1^9 u'(w)dx+.5u'(9)+.5u'(1)\geq 0.$

Eeckhoudt and Gollier (2005) generalized the above observation. In the game with a current loss, we can formulate the player's problem as the maximization of his/her expected utility:

$$\max_{e\in[0,\bar{e}]} U_c(e)=p(e)u(y-e-d)+(1-p(e))u(y-e). \tag{0.5}$$

The negative effect of prudence on effort is summarized as follows.[4]

Proposition 2 (Eeckhoudt and Gollier 2005). *Consider a prevention game with a current loss. Assume* $p(e_n)=1/2$. *If the player is prudent (imprudent), then, his/her optimal effort is smaller (higher) than* e_n.

2.4. Loss function

The above comparative statics (Propositions 1 and 2) do not restrict the functional form of the loss probability *p*(*e*). In the experiment, however, it is essential for experimental subjects to easily interpret how their effort *e* relates to *p*. We propose the following specification of *p*:

$$ke=\frac{1-p}{p}, k>0. \tag{0.6}$$

In one sentence, *p* implies that "the odds against loss is proportional to the player's effort." Although we did not use the word "odds" in the experimental instructions, it seems natural to assume that people can understand the concept, since it is sometimes used in an election or a horse race (Noussair 2011, Koessler, Noussair, and Ziegelmeyer, 2012). Rearranging (1.6) by *p*, we

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[4] Note that the concavity of *Uc* is ensured. By letting $u_- = u(y-e-d)$ and $u=u(y-e)$, we obtain $U_c' = p'(u_- - u) - p(u_-' + u')$, and $U_c'' = p''(u_- - u) - p'(u_-' - u') - \{p'(u_-' + u') - p(u_-'' + u'')\}$
$= p''(u_- - u) - 2p'u' + p(u_-'' + u'') < 0.$

obtain:

$$p = \frac{1}{1+ke} \equiv p(e). \tag{0.7}$$

Note that the above example is the case of k=1/2. In addition to odds interpretation, the formulation (1.7) of p has another advantage, as we obtain a simple solution for the risk-neutral optimal effort e_n. By letting $u(x)$=x in (1.5) and with (1.7), we obtain:

$$e_n = 1/k\,. \tag{0.8}$$

Moreover, by substituting (1.8) into the first order condition (1.3), we obtain:

$$d = 4/k. \tag{0.9}$$

2.5. Numerical simulation

In this subsection, we numerically show how much risk attitudes affect the optimal effort using the parameters $e \in \{0,1,...,300\}$, $e_n = 200$, and $w = 1100$. Together with (1.4), (1.8), and (1.9), the above specification implies k=0.005, d=800, and z=1300. Table 1 summarizes the optimal efforts under some examples of u and the above parameters[5].

Utility function		$\log(1+x)$	Expo-power	x^3	x	$x^{1.5}$
Risk attitude	Prudent	Yes	Yes	Yes	-	No
	Averse	Yes	Yes	No	-	No
Optimal effort with a current loss		96	30	166	200	213
Optimal effort with a future loss		213	240	255	200	198

Table 1 Optimal efforts under different timings of loss and utility functions

2.6. Group case

Consider the case where the prevention effort has a positive externality. In particular, we consider a group of two, in which each simultaneously and privately chooses his/her effort level. Let f be the other player's effort. We assume that the loss probability is given by the average effort of the two players: $p_g((e+f)/2), p_g' < 0, p_g'' > 0$. We compare the per-player efforts between the symmetric socially optimal and symmetric Nash equilibrium level.

[5] See Appendix for the graphs of expected utilities under different values of u.

Proposition 3. *Regardless of the timing of loss, the symmetric Nash equilibrium effort is below the socially optimal level.*

Proof. See Appendix.||

We have not addressed the group version of the comparative statics. Thus, the role of higher order risk attitudes in the externality case remains a rather empirical question.

2.7. Numerical simulation for the group case

Regarding the group treatments, assuming $p = 1/\{1 + k(e + f)/2\}$, yields a symmetric risk-neutral Nash equilibrium (83,83). Thus, given risk-neutrality, per-player effort in group treatments will be smaller than that in individual treatments. The welfare-maximizing per-player effort is equal to 200.

3. Experimental Design and Hypotheses

3.1. Design

We conducted the experiment at Osaka University, Japan, and Seoul National University, South Korea. The procedure was the same in Osaka and Seoul. Most of subjects were recruited through the recruiting system ORSEE (Greiner, 2004).[6] No individual participated in more than one session. The experiment was computerized using the experimental software z-Tree (Fischbacher 2007). Figure 3 summarizes the three parts in one session.

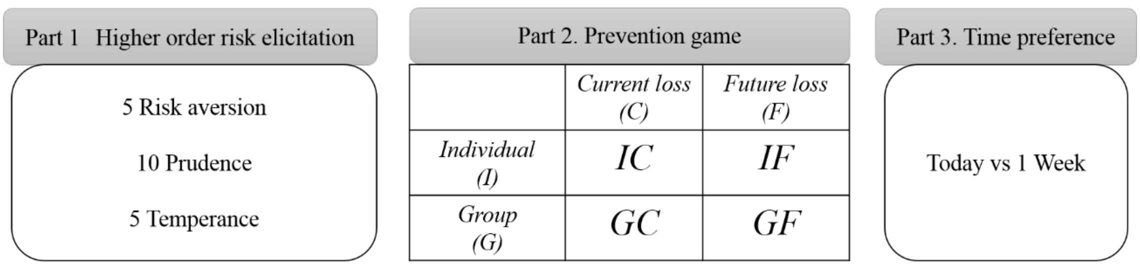


Fig. 3 Compositions in a session

The first part is a lottery, in line with Noussair et al. (2014), to elicit higher order risk attitudes;[7] 20 questions in Part 1 were grouped in three subparts to measure different aspects of

[6] At Seoul National University, we also recruited some subjects using the official website of undergraduate students, which students at Seoul National University can easily access.

[7] We added 5 more prudence tasks to allow more variations in the prudence level.

higher order risk attitudes. The first five questions are to measuring the risk aversion of subjects. On the one hand, there is a lottery with a risky outcome; on the other hand, there is a certain amount. The second subpart aimed at measuring the level of prudence using a compound lottery structure. Figure 4 shows an example of questions which measure the level of prudence. We expect prudent subjects to allocate their mean-zero risk when they have a more substantial endowment (option R).

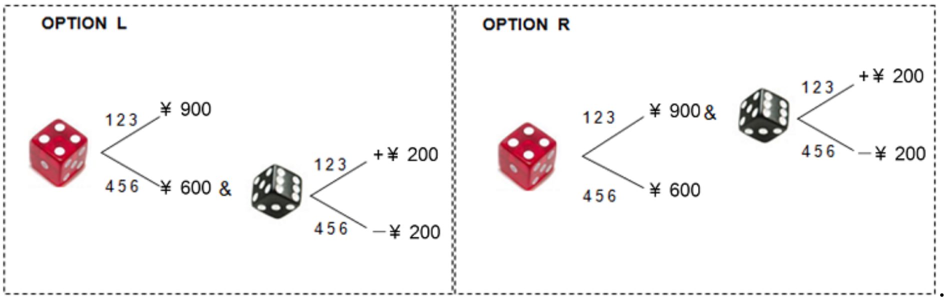


Fig. 4 Example of prudence task based on Noussair et al. (2014)

The third subpart of Part1 is to measure temperance using a 3-dices structure. Table 2 reports the list of lotteries used in Part 1. In Table 2, we use the notation [x_y], which indicates a lottery to receive either x (yen) or y (yen) with probability 0.5, respectively. For example, option L in Figure 4 can be represented as [900_(600+[200_-200])]. For the payment in Part 1, one of the 20 questions is randomly selected, and its payoff is realized after the end of the session.

In the second part of the experiment, respondents simultaneously participated in one of the four variations of the prevention game. In the prevention game, we introduced a 2 by 2 between-subject design. The first dimension relates to the timing of the loss. There are a current loss (C) treatment and a future loss (F) treatment. Current loss means that a loss is determined within the session, while future loss treatments imply a loss one week later. The second dimension relates to the level of decision-making. In the individual treatment (I), subjects decide their effort level regarding prevention, which implies no externalities. In group treatments (G), subjects are matched into pairs by the level of prudence elicited in Part 1 and imply externalities in their effort. The members of a group in G treatment remain the same throughout the experiment, in this part.

As shown in the above numerical simulations, we used $w = 1100$, $d = 800$, $z = 1300$ as represented in Experimental Currency Units (ECUs), with the conversion rate of 1 ECU= 2 JPY.[8] Among the 1100 ECUs, subjects are called to choose an amount of effort between 0 and 300 ECUs for the prevention of a loss. If subjects choose a higher amount of effort (than the average

[8] 1 ECU=20 KRW in Seoul National University experiment.

amount of effort in the group treatment), they face a smaller probability of loss. The relation between the probability of loss and effort follows equation (1.7) with k=1/200. Prevention effort is not refundable. In the experiment, subjects are presented with the graph and table of the probability for loss and prevention for clarification. The subjects can use a slider to choose their effort, which allows them to simultaneously check the possible outcomes with the probability when they change their level of effort. They can also use arrows to marginally change their level of effort. In each session, subjects play 10 payment rounds in Part 2 for real payment, preceded by five rounds.

Risk av1	[650_50]	200
Risk av2	[650_50]	250
Risk av3	[650_50]	300
Risk av4	[650_50]	350
Risk av5	[650_50]	400
Prudence 1	[900_(600+[200_-200])]	[900(+[200_-200])_600]
Prudence 2	[1350_(900+[300_-300])]	[1350(+[200_-200])_900]
Prudence 3	[900_(600+[100_-100])]	[900(+[100_-100])_600]
Prudence 4	[650_(350+[200_-200])]	[650(+[200_-200])_350]
Prudence 5	[900_(600+[400_-400])]	[900(+[400_-400])_600]
Prudence 6	[1100_(600+[400_-400])]	[1100(+[400_-400])_600]
Prudence 7	[750_(300+[100_-100])]	[750(+[100_-100])_300]
Prudence 8	[1000_(400+[300_-300])]	[1000(+[300_-300])_400]
Prudence 9	[600_(350+[200_-200])]	[650(+[200_-200])_350]
Prudence 10	[800_(400+[300_-300])]	[800(+[300_-300])_400]
Temperance 1	[(900+[300_-300])_(900+[300_-300])]	[900_(900+[300_-300] +[300_-300])]
Temperance 2	[(300+[100_-100])_(300+[100_-100])]	[300_(300+[100_-100] +[100_-100])]
Temperance 3	[(900+[300_-300])_(900+[100_-100])]	[900_(900+[300_-300] +[100_-100])]
Temperance 4	[(700+[300_-300])_(700+[300_-300])]	[700_(700+[300_-300] +[300_-300])]
Temperance 5	[(900+[300_-300])_(900+[500_-500])]	[900_(900+[300_-300] +[500_-500])]

Notes Approximately 1 USD = 110 yen in Aug 2017. We translated 1 yen as 10 won in the sessions of Seoul National University. The position between Option R and Option L is reversed in some sessions to balance the order effect.

Table 2 List of choices in the first part

At the end of the session, one of the 10 rounds is randomly selected for payment. Subjects are paid their future reward seven days after the session by bank transfer.[9] Therefore, all subjects

[9] In the future loss treatment, subjects only know the probability loss and possible outcome when the session ends. After one week they realize their exact payoff.

need to visit to the lab only once, and hence there is no substantial difference in the opportunity cost of participating in the experiment between current loss treatment and future loss treatment.

The third part of our experiment is to measure the time preferences of each individual. The purpose of this part is to control for the heterogeneous time preferences of individuals. To this end, we introduced the Random Binary Choice (RBC) mechanism, which is procedurally identical to the Becker-DeGroot-Marschak (BDM) mechanism.[10] There are 1,300 questions (or rows) in which subjects are asked to choose between Option A (today payment) and Option B (one week later payment). While Option A stays as 1000 yen, Option B increases with 1 yen increments between questions. Instead of answering all questions in Part 3, subjects choose the switching point between the fixed amount (Option A) and varying amount (Option B). To introduce an incentivizing structure, we draw a 20% lottery to select subjects who will be paid in Part 3, after the session. If subjects are selected to be paid, one of the 1300 questions is randomly selected at the end of the experiment. Depending on their choice and the randomly selected question, their payment and payment timing in Part 3 are decided.

Throughout the sessions, each subject was seated at a computer terminal assigned by a lottery. All terminals were separated by partitions. No communication was allowed between subjects. Each subject had a set of printed instructions (distributed in each part, as the game proceeded) and a piece of paper to take notes. In each part, the experimenter read aloud the instructions. Then, the experimenter explained how to operate the computer interface, using slides containing screenshots. Then, the subjects were given time to ask questions by raising their hands quietly. After finishing Part 3, the subjects completed a demographic questionnaire asking their age, gender, department, and grade. Table 3 summarizes the information on the subjects and payments. Individual payments ranged from 500 yen to 5760 yen.

Treatment	Risk-neutral effort	Number of Sessions	Subjects per session	Payoff (yen) Avg	Min	Max
IC	200	4 (2)	20,18,18,13	1860	500	3600
IF	200	2 (0)	20,19	4380	2760	5760
GC	83	4 (2)	22,20,20,16	2040	550	3970
GF	83	2 (0)	20,18	4280	2800	5200

Notes: Statistics in parenthesis represent the sessions of Seoul National University.

Table 3 Summary of the sessions

[10] Azrieli et al. (2012) find incentive compatibility of the RBC mechanism. Truth telling is a dominant strategy for this mechanism.

3.2. Hypotheses

We answer the following questions: 1) How prevention efforts vary with the timing of the loss? 2) Does prudence correlate with prevention depending on the timing of the loss? 3) Does group prevention differ from individual prevention? The formal hypotheses based on the theoretical results are as follows.

Noussair et al. (2014) report that more than half of general subjects are prudent and classify around 80% subjects in the lab as prudent subjects. Therefore, given random assignment, we might expect that this high level of prudence leads to a negative effect on current loss treatment (Proposition 1) and a positive effect on future loss treatment (Proposition 2), which leads to the following hypothesis.

[Hypothesis 1: Efforts under different timing of the loss]: The subjects in future loss treatment make more effort those in current loss treatment.

Proposition 1 states that prudent players choose a lower level of prevention than risk-neutral players, while all imprudent players choose a higher level of prevention than risk-neutral players. Therefore, we expect a negative correlation between prudence and prevention in the current loss treatment. For group prevention treatments, it is reasonable to say prudence have a similar effect to individual prevention, given Kocher et al.'s (2015) the observations of precautionary bidding in auction.

[Hypothesis 2-1: Role of prudence in the current loss]: In the current loss treatment, the degree of prudence and effort are negatively correlated in both individual and group treatments.

Proposition 2 states that subjects prefer to accumulate wealth to face the occurrence of a loss. Therefore, hypothesis 1-2 aims to test whether there is a positive correlation between prudence and the degree of prevention.

[Hypothesis 2-2: Role of prudence in the future loss]: In the future loss treatment, the degree of prudence and effort are positively correlated in both individual and group decisions.

Proposition 3 shows that, when strategic interactions are introduced, there is a free-riding incentive to their partner's prevention. These theoretical results lead to Hypothesis 3.

[Hypothesis 3: Role of group decision making]: Group decision-making decreases the amount of effort in both the current loss and future loss treatments.

4. Experimental Results

4.1. High order risk attitudes

We investigate the summary statistics of prudence, risk aversion, and temperance. Prudence has a score between 0 and 10, while risk aversion and temperance score have a value between 0 and 5. Figure 5 reports the histograms of the risk attitude traits of subjects.

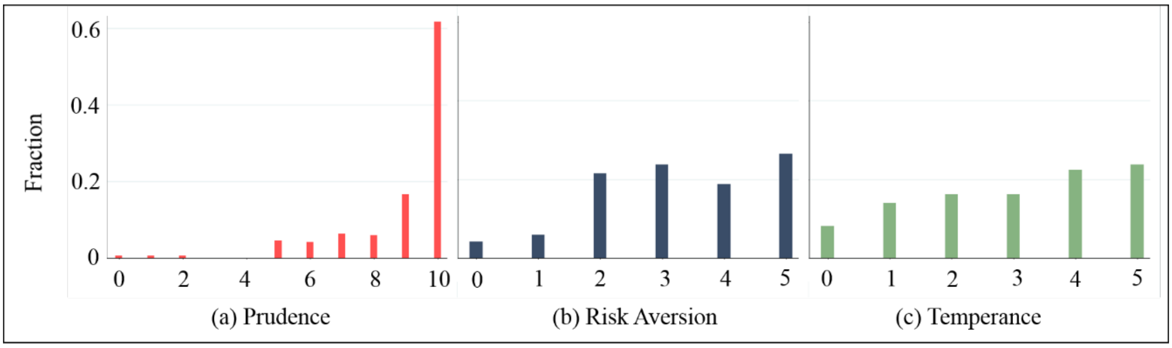


Fig. 5 Distribution of higher order risk attitudes

Regarding prudence, 61.9% of subjects have a score of 10, the maximum value of prudence. Additionally, 90% of subjects have a score of more than or equal to 5. This shows the presence of little variance in prudence compared with risk-aversion and temperance. This pattern is in line with Noussair et al. (2014), which found that about 70% of samples in the lab have their maximum level of prudence. Gender difference is not significant; male subjects have an average level of prudence of 9.06 and female subjects 8.99 (two-sample t-statistics: 0.31 and p-value: 0.75). This result is consistent with Noussair et al. (2014), which find no gender difference in prudence. Female subjects have a risk aversion score of 3.71 on average, while male subjects have 2.82. This difference is significant at the 1% level (t-statistics: 4.98) and consistent with the literature (Eckel and Grossman 2008), which confirms that females are more likely to be risk-averse. Last, we confirm that female subjects are likely to have higher temperance (3.51) than male subjects (2.51) on average. This difference is also significant at the 1% level (t-statistics: 4.66).

Regarding the correlation within higher order risk attitudes, only risk aversion and temperance are significantly correlated. The correlation of risk aversion and temperance is significant at the 1% level in the pairwise correlation test (test statistics: 3.99), while no other relation has a significant correlation.[11] This pattern is also consistent with the results of Noussair et al. (2014) and Crainich (2013), which show positive correlation between risk aversion and

[11] We also tested whether Osaka and Seoul subjects differ in risk attitudes, as reported in appendix B. There is no significant difference in the risk attitudes between Osaka and Seoul subjects.

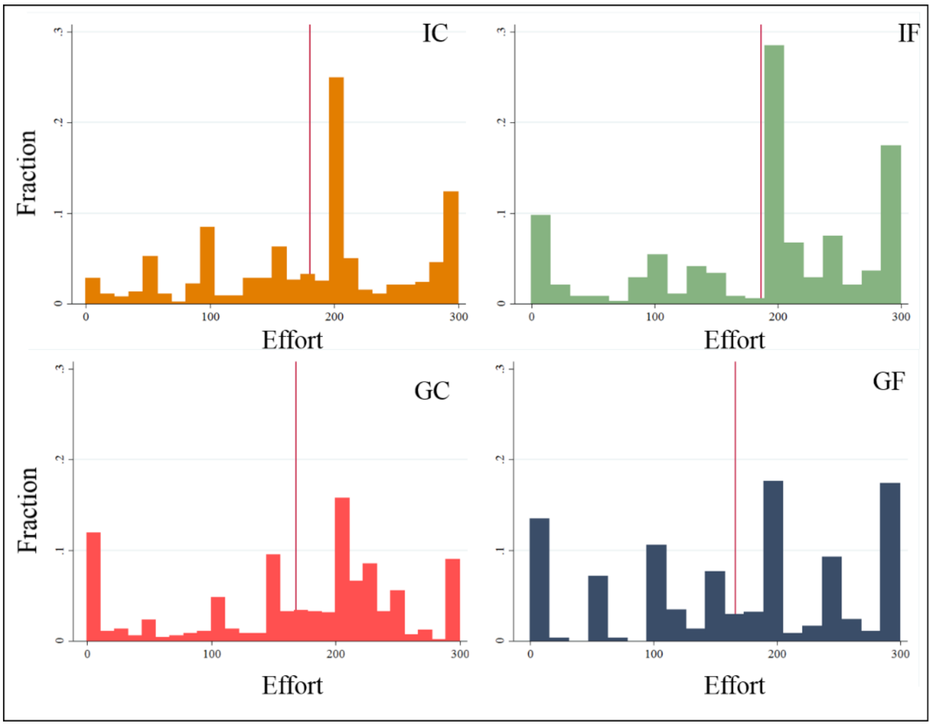
temperance. This result implies that prudence captures different aspects, which are not correlated with risk aversion and temperance.

4.2. Effort in the prevention game

In the prevention game, Figure 6 shows the distribution of prevention across treatments. First, in the individual case, prevention in IC (IF) is, on average, 180.5 (186.3). The difference between IC and IF treatments is not significant at 10% level (t-test statistic: 0.87, p-value: 0.38). Second, in the group case, prevention in GC (GF) is, on average, 168.4 (166.4). This difference is also not significant at the 10% level (t-test statistic: 1.37, p-value: 0.18).

Result 1. *There is no significant difference in effort between the current and future loss, both for individual and group prevention.*

On the other hand, a significant difference exists when we compare I and G treatments. In GC, the effort level decreases by 10 compared with IC. Likewise, in GF, the effort decreases by 20 compared to IF. These decreases are significant at the 1% level (t-test statistic: 3.96 in IC and GC; t-test statistic: 3.99 in IF and GF). The above-mentioned results show that the strategic substitute of effort lowers the average level of effort between players, which confirms the theoretical prediction of Proposition 3. The correlation between period and prevention is negative and significant at the 5% level in the group treatment only (correlation: -0.07 and p-value: 0.03 in GC, correlation: -0.05 and p-value: 0.04 in GF). On the other hand, in the individual treatment, we found no significant relationship between the level of effort and period (correlation: 0.01 and p-value 0.31 in IC, correlation -0.02 and p-value 0.19). This result shows that the significant learning effect exists in G treatment only.



Notes. horizontal line represents the average level of effort.

Fig. 6 Distribution of prevention across treatments

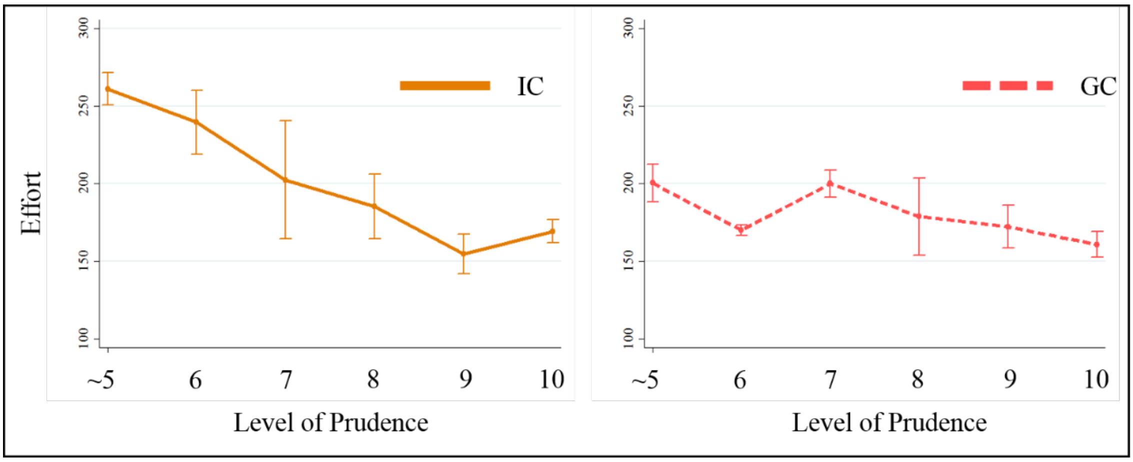
We divide the individual's average prevention into three parts using 200 (risk-neutral player's prevention) as a standard. Table 4 shows the proportions of each criterion. In all treatments, most of players choose a level of prevention lower than 200, on average.

	IC	IF	GC	GF
Avg Effort < 200	57%	49%	59%	66%
Avg Effort = 200	9%	13%	1%	3%
Avg Effort > 200	35%	38%	40%	32%
Total	69	39	78	38

Table 4 Classification of prevention

In Part 1, we showed that more than 60% of subjects have a maximal prudent score and more than 90% of subjects tend to take the prudent choice more than the imprudence choice. In line with the expected utility theory, we might expect that subjects choose prevention above the risk-neutral prevention level (200) in the future loss treatment. However, Table 4 shows that, on average, about 49% (66%) of subjects violated the theoretical results under the expected utility framework. This result implies that players systematically deviate from Menegati's (2009) prediction based on expected utility framework. In the next section, we provide an alternative model using prospect theory to explain this systematic deviation from expected utility theory.

4.2.1. Role of Prudence: Current Loss



Notes. Bar shows 95% confidence interval.

Fig. 7 Prevention across the level of Prudence in current loss treatments

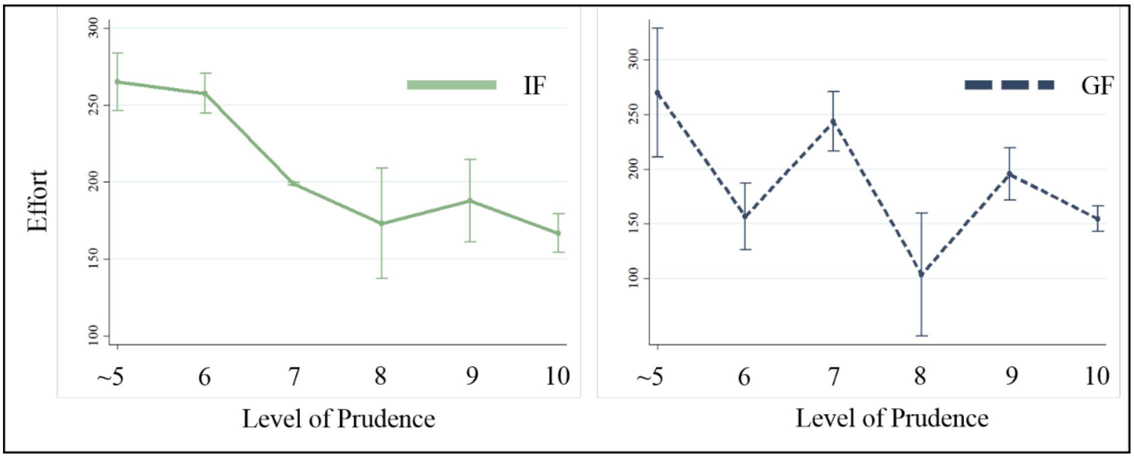
Figure 7 shows the degree of effort by the level of prudence in both the current loss treatments. The figure shows a decreasing trend for prudence and effort to prevention for both the IC and GC case. In the IC case, when the level of prudence is less than 5, the average prevention is around 260; however, when the level of prudence is 10, the average prevention is around 170. The decrease amounts to more than 80 points as the level of prudence increases. In GC, the decrease in prevention is equal to 40; hence, smaller than in the IC case. These results show a negative correlation (-0.29, p-value <0.01) in IC between prudence and effort to prevention, which is consistent with the theory of Eeckhoudt and Gollier (2005).[12] In the GC treatment, the correlation is also negative (-0.11, p-value<0.05) regardless of the decision-making level. These results are consistent with Hypothesis 2-1, which predicts a negative correlation between prudence and efforts. Therefore, our corresponding Result 2 is as follows.

Result 2-1. *In the current loss treatment, there is a negative correlation between prudence and effort in both individual and group decision-making.*

4.2.2. Role of Prudence: Future Loss

[12] In the appendix, figure X uses the first 5 rounds and the last 5 rounds of the results which show a pattern consistent with Figure 8.

In this subsection, we address the role of prudence when the timing of the loss is not concurrent with the prevention. Figure 8 shows the correlation of prudence and prevention in the future loss treatment.



Notes. Bar shows the 95% confidence interval.

Fig. 8 Prevention across the level of Prudence in FL treatments

Figure 8 shows the average effort across the levels of prudence in the future loss treatments. IF shows a negative correlation, consistent with the IC case. In IF, subjects who have a prudence level lower than 5 have a tendency to contribute more than 250. However, those with a prudence level equal to 10 chose an effort to prevention around 170. The negative correlation (-0.35, p-value<0.01) contradicts the theoretical results of Menegatti (2009). In the GF treatment, there is a negative correlation (-0.19 p-value <0.01) as well. These results show that, in the future loss treatment, a negative correlation exists between prudence and effort which contradicts Hypothesis 2-2.

Result 2-2. *In the future loss treatment, there is a negative correlation between prudence and effort in both individual and group decision-making.*

4.2.3. Regression

In this subsection, we check the role of prudence using regression analysis. We use linear regression to check the correlation between the level of prudence and prevention. The regression specification is as follows. In the specification, i denotes individuals and t denotes a period in the prevention game. We also include individual characteristics including age, sex, and the degree of time preference:

$$Effort_{it} = \beta_0 + \beta_1 Prudence_i + \beta_2 Aversion_i + \beta_3 Temperance_i + \beta_4 Timepreference_i + \beta_5 Female_i + \beta_6 Age_i + \epsilon_{it}$$

.

Table 4 shows the regression results using sub-samples corresponding to each treatment. Column (1) shows the regression results using the IC sample only. The coefficient on prudence (-10.67) is negative and significant at the 1% level, which confirms the results of Eeckhoudt and Gollier (2005). Column (2) reports the regression results of the IF treatment, which also show a significant negative correlation between prudence and prevention (-14.69). These results violate the theoretical result of Mengatti (2009), which predicts a positive correlation between prudence and prevention in the IF treatment. In the group case, we also found a negative correlation between prudence and prevention. In the GC (GF) treatment, there is a negative correlation, the coefficient is -8.25 (-14.59) and significant at the 10% level in column 3 (4).

Treatment	IC	IF	GC	GF
	(1)	(2)	(3)	(4)
	Dependent variable: effort to prevention			
Prudence (0-10)	-10.67***	-14.69**	-8.25*	-14.59*
	(3.640)	(6.400)	(4.699)	(8.019)
Aversion (0-5)	-0.582	-3.880	-5.313	-0.501
	(6.314)	(8.622)	(7.100)	(13.36)
Temperance (0-5)	2.830	-1.872	4.719	6.313
	(4.494)	(6.549)	(5.545)	(10.54)
Female	-3.924	-62.64***	-28.94*	-39.47
	(18.73)	(22.55)	(16.60)	(35.00)
Age	6.378**	0.558	-10.46**	-4.124
	(2.549)	(1.779)	(4.740)	(5.779)
Time_preference	0.135**	-0.170	0.0474	0.0806
	(0.0594)	(0.128)	(0.0637)	(0.187)
Constant	-7.276	525.9***	468.1***	330.7*
	(91.89)	(123.0)	(138.3)	(173.8)
Observations	690	390	780	380
R-squared	0.155	0.277	0.083	0.071

Notes. Individually clustered standard errors in parentheses. Significance levels */**/*** : 10/5/1%. In all specifications, we controlled periods fixed effect.

Table 5 Regression analysis

In sum, we find a significant and consistent negative correlation between prudence and prevention regardless of treatments. The degree of risk aversion and temperance are not significantly correlated, in any treatments.

In the previous section, we found a significant decrease in the average effort in the group treatment using a two-sample t-test. We performed a regression analysis after controlling for higher order risk attitudes, individual characteristics, and fixed effects, and investigated the impact of the group treatment indicator variable.[13] We find a decrease in effort equal to 20 in the last round in the GC compared with the IC. The coefficient is significant at the 1% level (p-value: 0.007). We also find a decrease equal to 18.3 in the last round in the GF compared with the IF treatment. The coefficient is not significant at the 10% level (p-value: 0.14).[14]

Result 3. *In the GC (GF) treatment, the level of effort decreases compared with the IC (IF) treatment.*

5. Reexamination of the data from prospect theory

5.1. Prospect theory explains low effort in the prevention game with future loss

Our data has consistent negative correlation between prudence and prevention effort, in both the current and future loss treatment. To explain this trend, we introduce prospect theory, motivated by Ebert and Wiesen's (2014) observation that the measured risk premiums to avoid downside risk are beyond the predicted ones under several expected utility models, in favor of prospect theory. Prospect theory composed of two main features as loss aversion and probability weighting (Kanheman and Tversky 1979; Tversky and Kanehman 1992). Loss aversion suggests that a player cares about whether each monetary outcome is in the gain or loss domain with respect to some reference point, and is more sensitive to losses than gains. Probability weighting describes individual's inability to discriminate the changes in probability sufficiently. The main findings in this section are that i) a prospect theory player will choose an optimal effort lower than that of a risk-neutral player, regardless of the timing of the loss (Sections 5.2); ii) Prospect theory explains why a large portion of subjects chose prudent options in our elicitation task (Section 5.3). Together, these two results explain the observed high prudence and prevention effort below the risk neutral level well.

To get an intuition of the lower level of effort obtained using prospect theory, consider the prevention game again with future loss. In Figure 2, where a player chooses an effort of 1, 2, or 3. In Figure 9, the first row shows the three lotteries (A, B, and C) that an expected utility

[13] Appendix X provides the full specification results.

14 Using data for all periods, we find negative coefficients (-5 in GC and -6 in GF) that are not significant at the 10% level.

maximizer faces. As we discussed, a risk-neutral player prefers B. We will show a prospect player prefers A' to B' and C'.

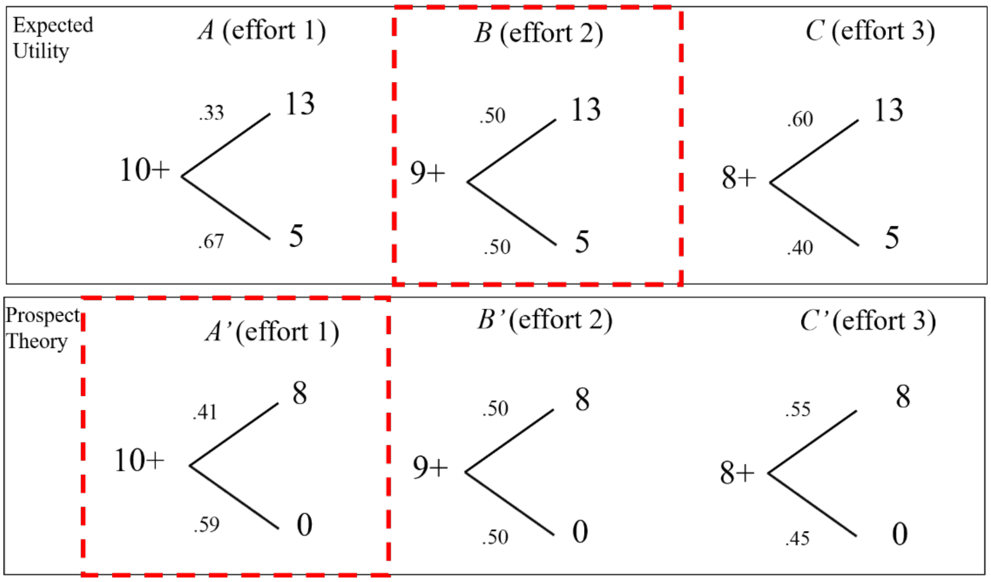


Fig. 9 Role of prospect theory in a prevention game

How does a prospect theory player perceive these lotteries? She converts lotteries A, B, and C into A', B', and C' based on a reference point and a probability weighting. First, the PT player cares about whether each monetary outcome is in the gain or loss domain with respect to some reference point, and is more sensitive to losses than gains. Moreover, the prospect theory player subtracts 5, the bad outcome, from each monetary outcome. The conversion of lottery C to C' is likewise. Second, each probability q=1-p of getting a higher outcome, is over-weighted if it is small, while q is under-weighted if it is large. For instance, consider conversion from lottery A to A' in Figure 9. The probability of a good (bad) outcome in A is .33 (.67), for the expected utility player, while it is perceived as .45 (.55) for the prospect theory player. Note that the probabilities do not change between lottery B and B'[15]

Such distortion of probability of the prospect player especially overweighting the probability of the good outcome in lottery A, discourages her from exerting effort. if we assume that the prospect theory player evaluates each monetary outcome x as it is (a linear value function). Then, the value of A'=(11-1)+0.414*8=13.312; value of B'=(11-2)+ 0.50*8=13; value of C=(11-3)+0.550*8=12.400. In sum, introducing a reference point and a probability weighting together could lead to the PT player's preference of A' over B' and C'. In the following, we show that the above observations hold for a typical prospect theory model.

[15] We used a weighting function $w(q) = q^{.5} \Big/ \left(q^{.5} + (1-q)^{.5} \right)$ to convert the lotteries in Figure 9.

5.2. Prospect theory model

For a clear argument, we focus on common functional forms. Consider a binary lottery, $L=(a,q;b)$, where *a* and *b* with *a*>*b* occurs with probability *q* and 1-*q*, respectively. We use *a symmetric Goldstein and Einhorn (GE)'s* (1987) *weighting function* $w(\bullet;\gamma)$ with parameter $0<\gamma\leq 1$ to represent these biases:

$$w(q;\gamma)=q^{\gamma}\Big/\left(q^{\gamma}+(1-q)^{\gamma}\right) \qquad (1)$$

for any probability $0\leq q\leq 1$. Note that a probability of a bad outcome (*b*) is distorted as $1-w(q)$. See Figure 10 illustrating the GE probability weighting functions $w(q;\delta,\gamma)=\delta q^{\gamma}\Big/\left(\delta q^{\gamma}+(1-q)^{\gamma}\right)$ with $\delta=1$, varying γ between 0.2 and 1. An advantage of the GE probability weighting functions is each of the parameters has a different role: The parameter γ determines the slope of probability weighting. The case of γ =0 reduces the equal weight by 1/2 regardless of the probability, while the case of γ =1 reduces to the 45-degree line and hence means no distortion. Thus, $1-\gamma$. is useful to measure the degree of probability distortion.[16] The parameter $\delta=1$, determines the crossing point between the probability weighting function and the 45-degree line. The crossing point is $(\delta/(1+\delta),\delta/(1+\delta))$. Assuming $\delta=1$ leads to the weighting function intersects with the 45 degree line at (1/2, 1/2).

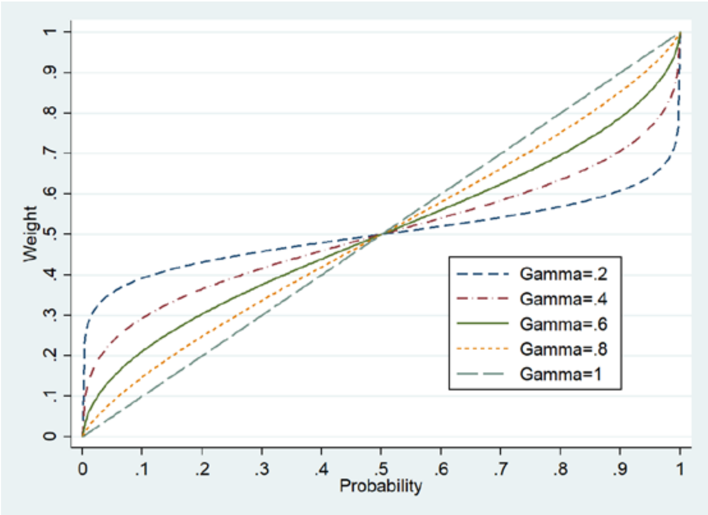


Fig. 10 GE probability weighting functions with $\delta=1$.

The second feature of a prospect theory player is that she/he cares whether each monetary

[16] See Stott (2006) for the existing variations of the value functions and probability weighting functions.

outcome is in the gain or loss domain with respect to some reference point, $r \geq 0$. Moreover, the player is more sensitive to a loss than to a gain, which we represent with $\lambda > 1$. We incorporate these preferences assuming *a power valuation function v* such that:

$$v(x;\alpha,\lambda,r) = \begin{cases} (x-r)^{\alpha} & \text{if } x \geq r \\ -\lambda(r-x)^{\alpha} & \text{if } x < r \end{cases} \tag{2}$$

for all *x*, where $0 < \alpha \leq 1$. We consider *a GE prospect theory player* who evaluates, in period *t*, a lottery L_t resolved in period *t* as:

$$\rho(L_t,\alpha,\gamma,\lambda,r) = w(q;\gamma)v(h;\alpha,\lambda,r) + (1-w(q;\gamma))v(l;\alpha,\lambda,r)$$

where $w(\bullet;\gamma)$ and $v(\bullet;\alpha,\lambda)$ are given by (1) and (2).

5.2.1 The prevention game with current loss

Consider first the prevention game with current loss. Each effort *e* determines the lottery that the player faces $L_1(e) = (y-e, q(e); y-e-d)$, where *q*(e) is the no loss probability (=1-p(e)=ke/(1+ke)). The literature including Hota, Garg, Sundaram (2016) reports that, when a player can earn a certain wealth level for sure by taking some action, this wealth is a plausible reference point. Applying this argument to our case, it is natural to assume $r = y-d$ in the prevention game with the current loss. We evaluate each monetary outcome using (2). When the loss does not happen, $x - r = y - e - (y-d) = d - e > 0$ whenever *e*<*d*, which is satisfied in our experiment. On the other hand, when the loss happens $x - r = y - e - d - (y-d) = -e \leq 0$ for all *e*. By letting $\pi(e;\gamma) = w(q(e);\gamma)$, a prospect theory player's problem becomes:

$$\max_e P^c(e,\alpha,\gamma,\lambda) \equiv \rho(L(e);\alpha,\gamma,\lambda,y-d) = \pi(e;\gamma)(d-e)^{\alpha} + (1-\pi(e;\gamma))(-\lambda)e^{\alpha}.$$

We index a GE-prospect theory player by (α,γ,λ). Let $P^c(e,\alpha,\gamma,\lambda)$ be the corresponding objective function and $e^c(\alpha,\gamma,\lambda) = \arg\max_e P^c(e,\alpha,\gamma,\lambda)$.

Lemma 1. Assume $p(e_n) = 1/2$. Then, $P_e^c(e_n,\alpha,\gamma,\lambda) < (>) 0$ *if and only if* $\gamma < (>) 2\alpha(\lambda + 3^{\alpha-1})/(\lambda + 3^{\alpha})$.

Proof. See Appendix. ||

We introduce two comments on Lemmas 1 and 2. First, if the GE-prospect theory player with

(α,γ,λ) chooses $0 < e^c(\alpha,\gamma,\lambda) < \overline{e}$, we obtain $P^c(e^c(\alpha,\gamma,\lambda),\alpha,\gamma,\lambda) = 0$. Thus, under the concavity of the objective function in *e* (Lemma 2), it suffices to check the condition in Lemma 1 to determine which of $e(\alpha,\gamma,\lambda)$ or *en* is large. Second, for a derivation and interpretation of the Lemma 1 condition, it is useful to rewrite the condition as (probability distortion)= $1-\gamma > (<) 1 - 2\alpha(\lambda + 3^{\alpha-1})/(\lambda + 3^{\alpha})$. For example, consider the case of linear *v* $(\alpha = 1)$, close to Abdellaoui et al.'s (2005) estimates. Then, the right hand side becomes $\gamma(1,\lambda) = 1 - 2(\lambda+1)/(\lambda+3) = (1-\lambda)/(\lambda+3) < 0$, regardless of λ. Hence, for any $0 < \gamma \le 1$ and $\lambda \ge 1$, $e^c(1,\gamma,\lambda) < e_n$, which says that any probability distortion and no-effort reference point together lead to an effort less than the risk-neutral level. Motivated by this observation, we compare various GE-prospect theory players with the risk neutral player to obtain counterpart comparative statics with EG and M, by varying (α,γ,λ).

Proposition 4. *Consider the prevention game with current loss with loss probability given by (#). If* $p(e_n) = 1/2$, $\gamma < \alpha$ and $P^c(e,\alpha,\gamma,\lambda)$ *is concave in e, then a GE-prospect theory player exerts a less effort than a risk neutral player does.*

Proof. Consider the right hand side of the condition obtained in Lemma 1. Since

$$(\lambda + 3^{\alpha-1})/(\lambda + 3^{\alpha}) = 1 - 2\cdot 3^{\alpha-1}/(\lambda + 3^{\alpha}) \ge 1 - 2\cdot 3^{\alpha-1}/(1+3^{\alpha}) \ge 1 - 2\cdot 3^{1-1}/(1+3^{1}) = 1/2,$$

$2\alpha(\lambda + 3^{\alpha-1})/(\lambda + 3^{\alpha}) \ge \alpha$. Hence, if $\gamma < \alpha$, $P^c_e(e_n,\alpha,\gamma,\lambda) < (>) 0$ by Lemma 1. Assuming that $P^c(e,\alpha,\gamma,\lambda)$ is concave in *e* implies $e(\alpha,\gamma,\lambda) < e_n$.||

Proposition 4 provides a simple sufficient condition that the optimal effort of a GE-prospect theory player's optimal effort is lower than in the risk-neutral case. Notably, the main literature supports $\gamma < \alpha$ empirically in estimates of prospect theory model parameters (Gonzalez and Wu, 1999; Abdellaoui, 2000; Abdellaoui et al., 2005; Booiji et al., 2010; Choi et al., 2017, see Table 6 in Appendix). Figure 11 shows examples of PT player value functions.[17] To state the novelty of this result, let us remind Proposition 1, in which Eeckhoudt and Gollier (2005) characterized the

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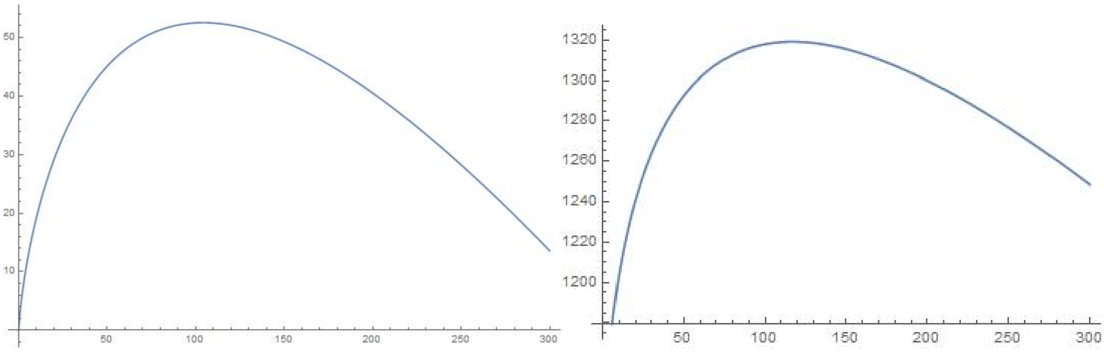
[17] As we show later, we do not use λ since every outcome is in gain domain in the future loss case.

prevention behavior by prudence u’’’>0 within the expected utility framework. Here, we characterized the prevention behavior by a straightforward condition between the weighting function and a value function, within the prospect theory framework. It is noteworthy that we do not need to determine the sign v’’’ in Proposition 4.



(a) Current loss, $(\alpha, \gamma, \lambda) = (0.9, 0.8, 2.0)$. (b) Future loss, $(\alpha, \gamma) = (1, 0.6)$.

Fig 11 Objective functions for GE-prospect theory players

5.2.2 The prevention game with the future loss

In contrast to the current loss, each effort e determines which lottery the player faces, $L_2(e) = (z, q(e); z-d)$. To make a reference point parallel to the current loss case, assume $r = z - d$. Note that $x - r \geq 0$ whether the loss happens or not. A prospect theory player’s problem becomes:

$$\max_e P^f(e, \alpha, \gamma, \lambda) \equiv (y-e)^\alpha + \rho(L_2(e), \alpha, \gamma, \lambda, z-d) = (y-e)^\alpha + \pi(e;\gamma) d^\alpha .$$

Let $e^f(\alpha, \gamma, \lambda) = \arg\max_e P^f(e, \alpha, \gamma, \lambda)$. We establish that a GE-prospect theory player again chooses an effort lower than that of the risk-neutral case, under the same conditions of parameters and concavity of the objective function, as follows.

Proposition 5. *Consider the prevention game with current loss with loss probability given by (#). If* $p(e_n) = 1/2$, $\gamma < \alpha$ *and* $P^f(e, \alpha, \gamma, \lambda)$ *is concave in e, then a GE-prospect theory player exerts less effort than the risk neutral player does.*

Proof. See Appendix. ||

5.3. PT theory support for prudent choices in Part 1 elicitation task

We will show that a prospect theory player chooses the upside risk (option R) in the Part 1 prudence questions. We slightly generalize the weighting functions. A *symmetric weighting function w:* [0,1]->[0,1] distorts each probability q for the good outcome a to $w(q)$ (and assigns 1-$w(q)$ for the bad outcome b). Assume w satisfies $w(1/2)=1/2$, $w'(q)$>0 and $w'''(q)$ >0 for all q, $w''(q)$<0 for q<1/2, and $w(q)''$>0 for q>1/2.[18] *A prospect theory player* is a player with a power value function v given in (#) and a symmetric weighting function, who evaluates lottery $L=(h,q_h;m,q_m;l)$ with h>m>l as:

$$P(L)=w(q_h)v_p(h,r,\lambda)+(w(q_h+q_m)-w(q_h))v_p(m,r,\lambda)+(1-w(q_h+q_m))v_p(l,r,\lambda)\,,$$

To evaluate the compounded lotteries in the prudence questions, we reduce them to simpler cases. Given a pair of red dice (h, 0.5; l) and black dice (e, 0.5; -e) with h-e>l, with slight abuse of notations, we can write the two options in Part 1 as $R=(h+e,0.25;h-e,0.25;l)$, $L=(h,0.5;l+e,0.25;l-e)$, respectively. Note that h-e>l is satisfied in 9 out of 10 of our prudence questions (see Table 1; the only exception is question 5). Note also that for these 9 questions, the rank of three outcomes R is h+e>h-e>l, while that of L is h>l+e>l-e. As in footnote 32 in Deck and Schlesinger (2010), we borrow the estimated parameters in the literature and assume a GE-prospect theory player with the reference point $r=(h+l)/2$, which is a common expected payoff of R and L. Note that a pair $(\alpha,\delta)=(1,1)$ is close enough to Abdellaoui et al.'s (2005) estimates. Then, a prospect theory player, without restricting to a GE-prospect theory player, prefers prudent choices $(P(R)>P(L))$.

Observation. *Let* $(\alpha,\delta)=(1,1)$ *. For any* $w(\bullet),\lambda>1$*, a prospect theory player chooses lottery R in all ten prudence elicitation questions in our experiment.*

The derivation of this result is available upon request.

6. Conclusions

This paper provides original data to connect higher order risk attitudes and decisions in prevention games with a rich action space, varying the timing of the loss and the externality of the effort.

In both timings of the loss, we observed a negative correlation between prudence and effort, supporting the comparative statics of Eeckhoudt and Gollier (2005), but rejecting Menegatti (2009), while we confirmed a high prevalence of prudence in line with the recent literature (Crainich et al. 2013; Deck and Schlesinger 2010, 2014; Ebert and Wiesen 2011, 2014; Noussair et al. 2014),

[18] A symmetric GE weighting function satisfies these assumptions.

These results suggest a systematic violation of the expected utility theory. To explain these observations in a unifying way, we introduced prospect theory by establishing the prospect theory comparative statics of Eeckhoudt and Gollier (2005) and Menegatti (2009). Our predictions using prospect theory are consistent with our data under the estimates in experimental studies of prospect theory (Gonzalez and Wu, 1999; Abdellaoui, 2000; Abdellaoui et al., 2005; Booiji et al., 2010; Choi et al., 2017). Hence, we also contribute to the emerging literature reexamining decision making related to higher order risk from the prospect theory view (Deck and Schlesinger 2010; Ebert and Wiesen 2014). Though we did not establish comparative statics of group prevention, we again observed a negative correlation between prudence and effort, and efforts were well above a symmetric Nash equilibrium prediction.

Areas deserving future research include: (i) Connecting higher order risk attitudes with other games in line with Eso and White (2004), White (2008), and Kocher et al. (2015); (ii) equilibrium analysis in typical games where prospect theory players face risky outcomes associated with uncontrollable environmental factors in line with Hota, Garg and Sundaram (2016) and Iturbe-Ormaetxe, Ponti, Tomás, and Ubeda (2011); (iii) connecting higher order ambiguity attitudes (Baillon, Schlesinger, and van de Kuilen, 2016) and behavior in game under uncertainty.

Appendix A. Proofs

Proof of Proposition 3.

To analyze the socially optimal level for the current loss case, let us define per-player payoff at effort pair (*e*,*e*) as:

$$CW(e) = p_g(e)u(w-e-d_g) + (1-p_g(e))u(w-e),$$

where *dg* is the loss of each group member. Since CW’’<0, let $e_s = \arg\max CW(e)$ be the socially optimal per-player effort. To analyze the equilibrium level, let us consider:

$$U_{c,g}(e,f) = p_g((e+f)/2)u(w-e-d) + (1-p_g((e+f)/2))u(w-e).$$

Consider, first, the risk-neutral case. The first-order condition is:

$$-d_g \cdot p_g'(e) = 1.$$

On the other hand, at risk-neutral Nash equilibrium, the first-order condition is:

$$-d_g \cdot p_g'((e+f)/2)/2 = 1. \tag{1.3}$$

We focus on a unique symmetric Nash equilibrium. By 1.11 and p’<0, the equilibrium effort is below the socially optimal level.[19]

To analyze future treatments, we define $FW(e) = u(w-e) + p_g(e)u(z-d_g) + (1-p_g(e))u(z)$, and

$FV(e,f) = u(w-e) + p_g((e+f)/2)u(z-d_g) + (1-p_g((e+f)/2))u(z)$. Assuming that CV_G CW_G, FV_G, and FW_G are concave, we obtain the following results for a general *u*.

Take any *u* such that *CV_G CW_G, FV_G, and FW_G* are concave. First, consider a prevention game with a current loss:

$$CV_1(e,f) = p_g'((e+f)/2)/2 \cdot \left\{u(w-e-d_g) - u(w-e)\right\} \\ -\left\{p_g((e+f)/2)/2 \cdot u'(w-e-d_g) + (1-p_g((e+f)/2))u'(w-e)\right\}.$$

By definition of *CW*:

$$CW(e) = CV_1(e,e) + p_g'(e)/2 \cdot \left\{u(w-e-d_g) - u(w-e)\right\}.$$

Let (e_g, e_g) be a symmetric Nash equilibrium under *u*. Then, $CV_1(e_g, e_g) = 0$.

Moreover, we also know that $p_g'(e) < 0, \text{and}\, u(w_g - d_g) < u(w_g).$ Therefore, $CW_g(e_g) > 0.$

Let *es* be per-player socially optimal effort. Then, we obtain $CW_g(e_s) = 0 < CW_g(e_g).$

Together with the concavity of C*W*, it implies that $e_g < e_s$.

Next, consider a prevention game with a future loss:

$$FV_1(e,f) = -u'(w-e) + p_g'((e+f)/2)/2 \cdot \{u(z-d_g) - u(z)\}.$$

By definition of *FW*:

$$FW_1(e) = FV_1(e,e) + p_g'(e)/2 \cdot \{u(z-d_g) - u(z)\}.$$

Let (e_g^f, e_g^f) be a symmetric Nash equilibrium under *u*. Then, $FV_1(e_g^f, e_g^f) = 0$.

---

[19] Our current setting assumes dg=di and kg=ki. Then, $e_g \approx 0.414/k_i < e_i/2$ (it is 83 in our discrete setting) and $p_g(e_g) > 1/2$.

Moreover, we also know that $p'_G(e) < 0$, and $u(z - d_G) < u(z)$. Therefore, $FW_1(e_g^f) > 0$. Let *esF* be per-player socially optimal effort. Then, we have $FW_g(e_s^f) = 0 < FW_g(e_g^f)$. Together with the concavity of *FW*, it implies that $e_g^f < e_s^f$. ||

Proof of Lemma 1.

Consider any GE-prospect theory player with $(\alpha, \gamma, \lambda)$. Remember $P^c(e, \alpha, \gamma, \lambda) = \pi(e;\gamma)(d - e)^\alpha + (1 - \pi(e;\gamma))(-\lambda)e^\alpha$. By differentiating $P^c(e, \alpha, \gamma, \lambda)$ by *e*, we have $P_e^c(e;\alpha, \gamma, \lambda) = w'q'\{(d - e)^\alpha + \lambda e^\alpha\} - \alpha\{\pi(d - e)^{\alpha-1} + (1 - \pi)\lambda e^{\alpha-1}\}$. At the risk neutral choice $e_n = d/4$, By presumption of lemma 1 and FOC (#), we have $q(e_n) = 1 - p(e_n) = 1/2$, and $q'(e_n) = -p'(e_n) = 1/d$. By symmetry of *w*, $\pi(q(e_n);\gamma) = w(1/2;\gamma) = 1/2$. Moreover, by $w'(q;\gamma) = \gamma\left((1-q)q\right)^{-1+\gamma} \Big/ \left((1-q)^\gamma + q^\gamma\right)^2$, we have $w'(1/2;\gamma) = \gamma$. By substituting these results into $P_e^c(e, \alpha, \gamma, \lambda)$, we have

$$\begin{aligned} P_e^c(e_n, \alpha, \gamma, \lambda) &= w'(q(e_n);\gamma)q'(e_n)((3d/4)^\alpha + \lambda(d/4)^\alpha) - (\alpha/2)\{(3d/4)^{\alpha-1} + \lambda(d/4)^{\alpha-1}\} \\ &= \gamma(1/d)(\lambda + 3^\alpha)(d/4)^\alpha - (\alpha/2)(\lambda + 3^{\alpha-1})(d/4)^{\alpha-1} \\ &= (d/4)^{\alpha-1}\{\gamma(\lambda + 3^\alpha)/4 - (\alpha/2)(\lambda + 3^{\alpha-1})\} \\ &= (d^{\alpha-1}/4^\alpha)\{\gamma(\lambda + 3^\alpha) - 2\alpha(\lambda + 3^{\alpha-1})\} \end{aligned}$$

Therefore, $P_e^c(e, \alpha, \gamma, \lambda) < (>) 0$ if and only if $\gamma < (>) 2\alpha(\lambda + 3^{\alpha-1})/(\lambda + 3^\alpha)$. ||

Proof of Proposition 5.

Consider any prospect theory player with $\gamma < \alpha$. By the assumption of concavity of P^f, it suffices to show $P_e^f(e_n, \alpha, \gamma, \lambda) < 0$. Note that

$$P_e^f(e, \alpha, \gamma, \lambda) = -\alpha(y - e)^{\alpha-1} + d^\alpha \pi'(e;\gamma).$$

By substituting the risk neutral optimal effort e_n, we have

$$
\begin{aligned}
P_e^f(e_n,\alpha,\gamma,\lambda) &= -\alpha(y-e_n)^{\alpha-1}+d^{\alpha}\pi'(e_n;\gamma) \\
&\le -\alpha d^{\alpha-1}+d^{\alpha}\pi'(e_n;\gamma) \\
&= d^{\alpha-1}(-\alpha+d\gamma/d) \\
&= d^{\alpha-1}(-\alpha+\gamma)
\end{aligned}
$$

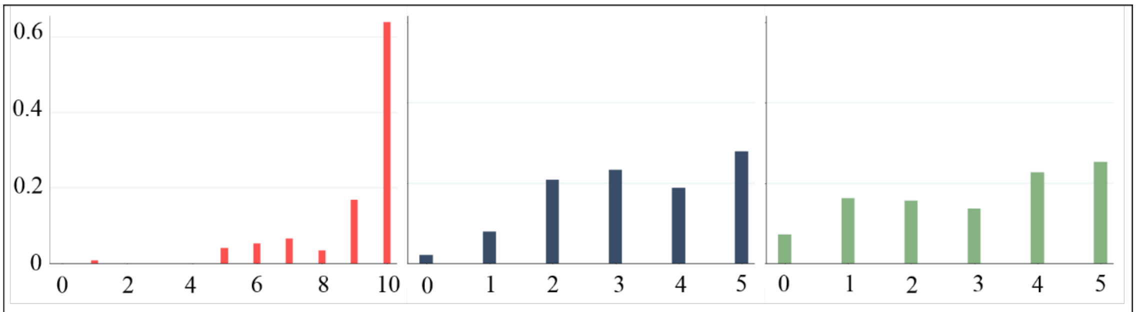
where the inequality holds by $y-e_n > y-\bar{e} \ge d$. By $\gamma<\alpha$, $P_e^f(e_n,\alpha,\gamma,\lambda)<0.$ By the assumption that $P^c(e,\alpha,\gamma,\lambda)$ is concave in *e*, it implies $e(\alpha,\gamma,\lambda)<e_n.$ ||

γ	α	δ	Subjects	Paper
0.44	0.49	0.77	400	Gonzalez and Wu(1999)
0.42	0.89	0.65	40	Abdellaoui (2000)
0.83	0.98	0.98	41	Abdellaoui et al.(2005)
0.61	0.85	0.77	1500	Booiji et al. (2010)
0.28-0.52	0.91-1.03	0.9-1.03	600	Choi et al. (2017)

Table 6 Estimates in the literature for power value functions and GE weighting functions

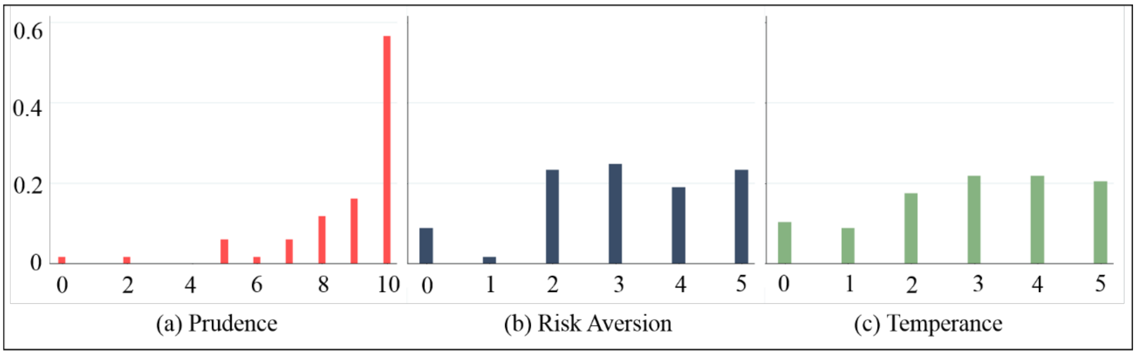
Appendix B. Details about the summary statistics

Figure 12 shows the results on high order risk attitude using Osaka and Seoul samples, respectively. They show a similar pattern regarding prudence.



(a) Prudence (b) Risk Aversion (c) Temperance

(i) Osaka



(ii) Seoul

Fig. 12 Summary of Higher order risk attitude by place

About 62% of Osaka samples scored around the maximum value of prudence, while 57% of Seoul National University sample scored around the maximum value. None of the three risk attitude measures has a significant difference (two-sample Kolmogorov-Smirnov test, test statistic=0.0676, p=0.981 for risk aversion; test statistic=0.0818, p= 0.907 for prudence; test statistic= 0.0571, p=0.998 for temperance).

B.2 Regression using Osaka and Seoul samples respectively.

	Osaka		Seoul	
	IC	GC	IC	GC
Prudence	-7.935*	-19.69***	-13.62**	-2.414
	(3.939)	(6.569)	(6.260)	(5.508)
Aversion	-3.515	-9.334	0.911	-4.012
	(9.007)	(7.897)	(8.522)	(11.91)
Temperance	1.932	-0.334	5.588	14.30
	(5.335)	(4.893)	(9.209)	(9.405)
Female	-4.176	-48.63*	4.335	-2.798
	(26.10)	(24.19)	(28.54)	(26.62)
Age	6.549	-5.759	10.13*	-9.629
	(3.979)	(7.032)	(5.672)	(7.508)
TimePref	0.162**	0.0355	0.105	0.0604
	(0.0631)	(0.0672)	(0.0988)	(0.104)
Period	-0.223	-3.300***	-2.483	-1.135
	(1.020)	(0.872)	(1.499)	(1.439)

Constant	-59.96	543.5**	-48.10	314.0
	(101.9)	(203.5)	(158.9)	(201.0)
Observations	380	400	310	380
R-squared	0.128	0.146	0.192	0.117

Table 7 Regression specification using Osaka and Seoul sample

Appendix C. Robustness check

C.1. Learning effect

In this subsection, we show the same results using the last 5 periods of the samples. We find the robust pattern as we have shown in Figures 7 and 8.

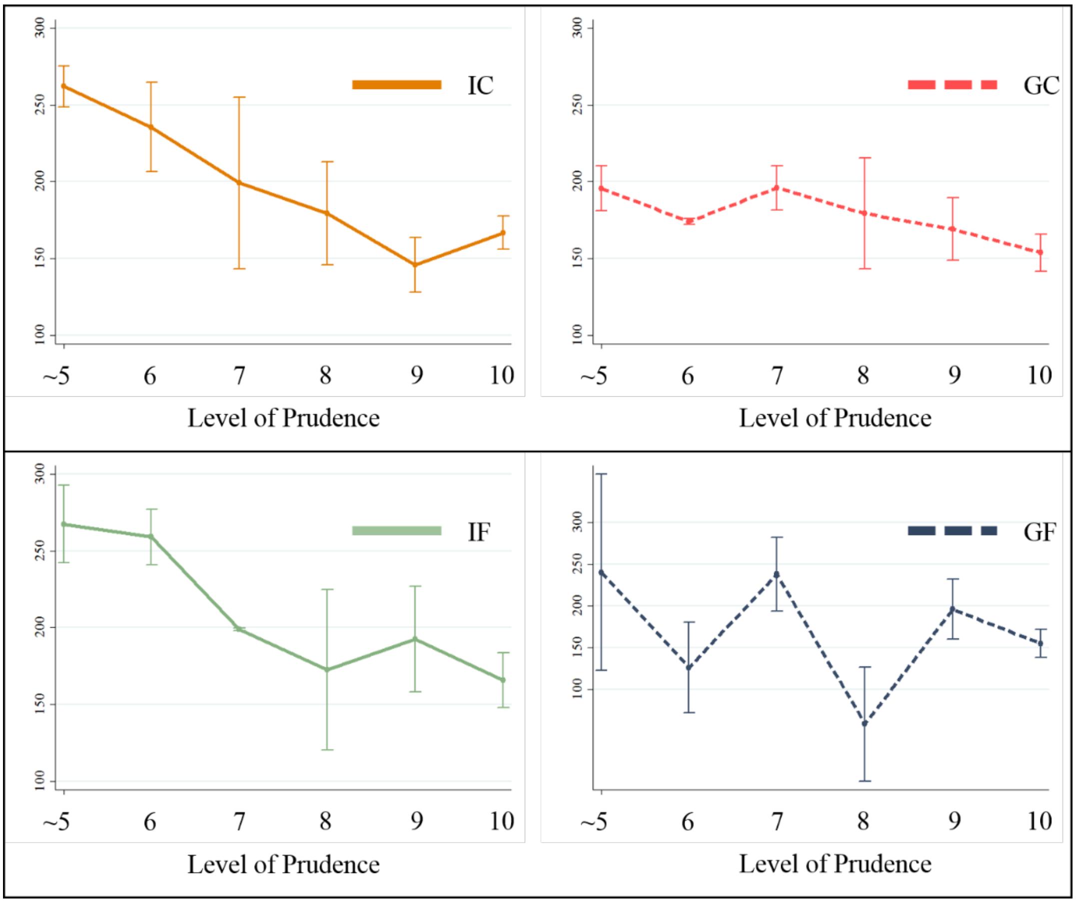


Fig. 13 Robustness check

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