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

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Abstract

This paper provides experimental evidence of the role of higher order risk attitudes, especially prudence, in prevention behavior. We address the timings of loss and whether prevention presents externalities. Prudence is theoretically known to have a negative effect on prevention in the current loss and a positive impact on prevention in the future loss. Nevertheless, we find that prudence is negatively correlated with prevention regardless of the timing of the loss. This observation questions the expected utility framework in favor of prospect theory. We provide a prospect theory version of the comparative statics of prevention, in line with our observations of a high level of prudence and low level of prevention. 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 the seminal work by Kimball (1990), who established that downside risk aversion, called prudence, is equivalent to the third derivative of von Neumann–Morgenstern utility function under the expected utility framework. 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 a potential damage in the future may occur due to scientific advancement. Bramoullé and Treich (2014) studied a pollution emission game with uncertain damage. Treich (2009) considered the purchase of insurance. White (2008) showed that an increase in the discount factor and prudence play a similar role increasing a player’s patience and, hence, improve the bargaining outcome.

Experimental investigation of higher order risk attitudes emerged in this decade. Eeckhoudt and Schlesinger (2006) developed a method based on risk appointment tasks to address any *n*-th order risk attitudes. Since then, experimentalists have been applying risk appointment tasks to elicit subjects’ higher order risk attitudes, especially prudence and temperance (Crainich et al. 2013; Deck and Schlesinger 2010 & 2011; 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 undergraduates (Deck and Schlesinger 2010 & 2011; Ebert and Wiesen 2011 & 2014) to large internet panels (Noussair et al. 2014). Noussair et al. (2014) also linked the elicited attitudes with the financial portfolio in the panel. Nevertheless, the comparative statics between higher order risk attitudes and the behaviors in a game remain empirically unexplored.

This study is, to the best of our knowledge, the first attempt to experimentally test comparative statics between higher order risk attitudes and prevention under different timings of the loss. We introduced a prevention game where a player can make an effort to reduce the probability of a loss event. It is known that, in prevention games, prudence increases (decreases) the prevention effort when the loss is in the far (or near) future (Eeckhoudt and Gollier 2005; Menegatti 2009). Hence, the timing of loss events is our first treatment variable.

We also explored group prevention, where each of two players benefits from the other player’s effort. A good example of the externality of effort would be the anti-pollution effort. 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 experienced a higher order risk elicitation (an extended version of Nousseir 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 and externality of effort. In group prevention games, subjects are matched by the elicited prudence to obtain symmetric players.

The data systematically violate the expected utility predictions. Under high prevalence of prudent subjects and the expected utility predictions introduced by Eeckhoudt and Gollier (2005) and Menegatti (2009), 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 the different timing of the loss. 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 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 i) in the current loss game, the direction of prevention relative to a risk-neutral scenario is determined by a simple comparison of the probability distortion á la Goldstein-Einhorn (1987) and the curvature parameter of the power value function, and ii) in the future loss game, a prospect theory player exerts less effort than the risk-neutral optimum level, for any parameter sets. These predictions do not include the third order derivatives. Finally, we also show that a prospect theory player chooses prudent alternatives in our elicitation task, using the estimates provided in the literature.

Our contributions to the literature are three-fold. First, we provide the first experimental data on the comparative statics between higher order risk attitudes and a prevention game with rich action space and a simple loss probability function with odds interpretation.[5] Second, since the observations seem against the predictions based on the expected utility framework, we introduce counterpart comparative statics from the prospect theory viewpoint, which act as an alternative explanation mechanism. Third, our study also contributes to the literature on higher order risk elicitation by providing international data, which confirm the high prevalence of prudence compared to risk aversion and temperance.

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.

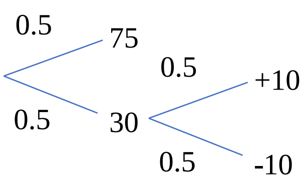
[5] One exception is Krieger and Mayrhofer (2017), who conducted an experiment on single player's prevention with binary choices, which follows after the EW (2011). We measure prudence by an 11-point scale based on Noussair e al., while Krieger and Mayrhofer's (2017) classification is binary.

2. The Model

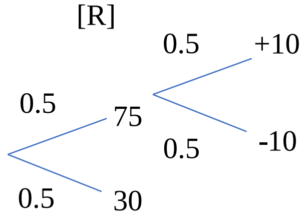
2.1. Prudence: downside risk aversion

Consider two compound lotteries, L and R, which have a base lottery (0.5, 75; 0.5, 30) in common, but differ in whether a zero-mean risk (0,5, +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:

[L]



[R]



It is known that, under the expected utility framework, prudence is equivalent to a convex marginal vN-M utility function. To see this, let $L = \left(p, a; 1-p, b\right)$ with $a > b$ be a lottery and $\tilde{\varepsilon}$ be a zero mean risk. Consider two lotteries that combine *L* and $\tilde{\varepsilon}$: L_a such that $\tilde{\varepsilon}$ is attached to the better outcome *a* of *L*, and L_b such that $\tilde{\varepsilon}$ is attached to the worse outcome *b* of *L*. We want a down side risk-averse player to prefer L_a to L_b whenever $a > b$. This is true if and only if $2\{EU(L_b) - EU(L_a)\} =$

$$\{E(a+\tilde{\varepsilon}) + E(b)\} - \{E(a) + E(b+\tilde{\varepsilon})\} = \int_b^a [Eu'(w+\tilde{\varepsilon}) - u'(w)]dw > 0,$$

whenever $a > b$, which is equivalent to a convex u'. In other words, $u'''(w) > 0$ for all *w*.

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

Kimball (1990) discussed the optimal saving when the uncertainty regarding the future income grows and 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 1 shows the timeline of this game.

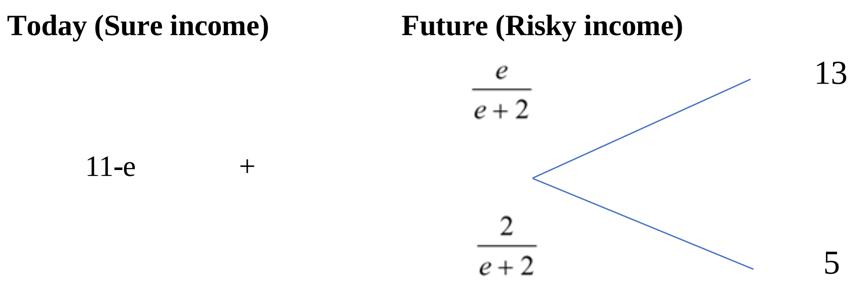


Figure 1. Prevention game with a future loss

Consider, first, 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. 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 $e\in[0,\overline{e}]$ where $\overline{e}<w,$ 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, the player's problem can be formulated as the maximization of his/her expected utility:

$$\max_{e\in[0,\overline{e}]} U_f(e)=u(y-e)+p(e)u(z-d)+(1-p(e))u(z). \tag{1.1}$$

We assume $u''\leq 0,$ so that $U_f''=u''+p''\{u(z-d)-u(z)\}<0.$ Consider, first, the risk-neutral case: $u(x)=x.$ Then, (1.1) is reduced to:

$$\max_{e\in[0,\overline{e}]} y-e+p(e)(z-e-d)+(1-p(e))(z-e). \tag{1.2}$$

The first order condition is given by:

$$-p'(e)d = 1. \tag{1.3}$$

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

$$y = z - p(e_n)d + e_n. \tag{1.4}$$

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.

Remember that, in the above example, *y*=11, *z*=13, and (1.4) are satisfied.

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 when the effort is made. We call this a prevention game with a current loss. Figure 2 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.

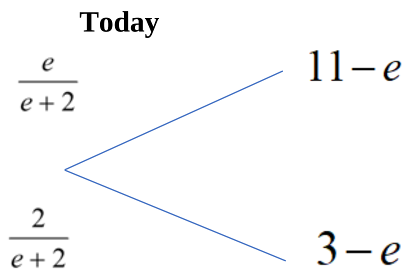


Figure 2. Prevention game with a current loss

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. 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, the player's problem can be formulated as the maximization of his/her expected utility:

$$\max_{e \in [0,\bar{e}]} U_c(e) = p(e)u(y-e-d) + (1-p(e))u(y-e). \tag{1.5}$$

The negative effect of prudence on effort is summarized as follows.[6]

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. Our specification of the loss probability function for the experiment

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:

$$ke = \frac{1-p}{p}, k > 0. \tag{1.6}$$

In one sentence, p implies that "the odds against loss is proportional to the player's effort." Note that odds are commonly used in the pari-mutuel betting market literature (Noussair 2011). Rearranging (1.6) by p, we obtain:

$$p = \frac{1}{1+ke} = p(e), \tag{1.7}$$

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 (1.5) and (1.7), we obtain:

$$e_n = 1/k. \tag{1.8}$$

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

$$d = 4/k. \tag{1.9}$$

2.5. Numerical simulation

In this subsection, we numerically show how much risk attitudes affect the optimal effort using the parameters $e \in \{0,1,...,300\}, e_i = 200$ 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 a typical u and the above parameters, and Figure 3 illustrates the corresponding expected utility curves.

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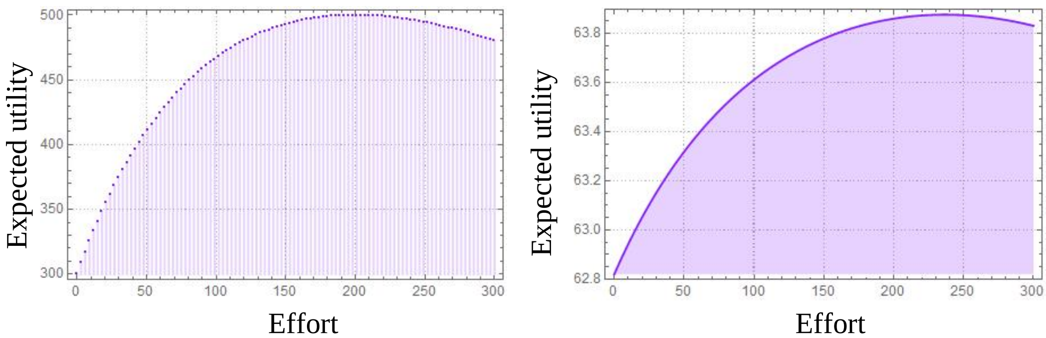
[6] Note that the concavity of Uc is ensured. By letting $u_- = u(y-e-d)$ and $u = u(y-e)$, we obtain $U_c' = p'(u_- - u) - p(u_-' + u')$, and $U_c'' = p''(u_- - u) - p'(u_-' - u') - \{p'(u_-' + u') - p(u_-'' + u'')\}$
$= p''(u_- - u) - 2p'u' + p(u_-'' + u'') < 0.$

Utility function		$\log(1+x)$	x	$x^{1.5}$	x^3	Expo-power[a)]
Risk attitude	Aversion	Yes	-	No	No	Yes
	Prudence	Yes	-	No	Yes	Yes
Optimal effort in current loss		96	200	213	166	30
Optimal effort in future loss		213	200	198	225	240

Note: a) We used the parameters estimated in Holt and Laury (2002).

Table 1. Optimal efforts under different timing of loss and utility functions



(a) Current loss, risk neutral (optimal=200) (b) Future loss, expo-power (optimal=236)

Figure 3. Expected utilities

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.

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, discrete maximization using Mathematica, 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. The subjects were recruited through the recruiting system ORSEE (Greiner, 2004). No individual participated in more than one session. The experiment was computerized using the experimental software z-Tree (Fischbacher 2007). Figure 4 summarizes the three parts in one session.

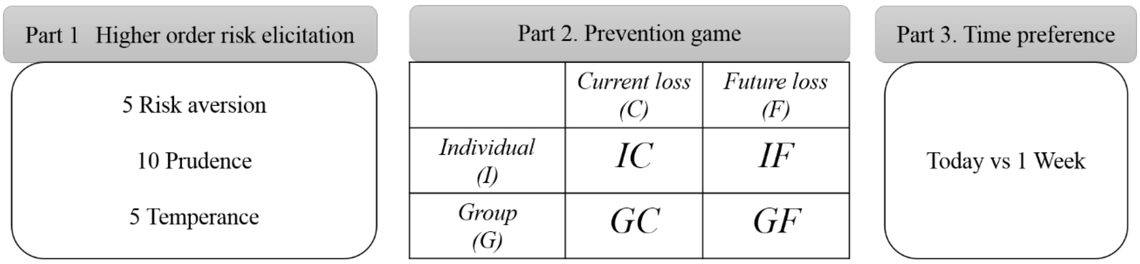


Figure 4. Compositions in a session

The experiment consists of three parts. The first part is a lottery, in line with Nousseiar 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 higher order risk attitudes. The first five questions aimed at 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 5 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).

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

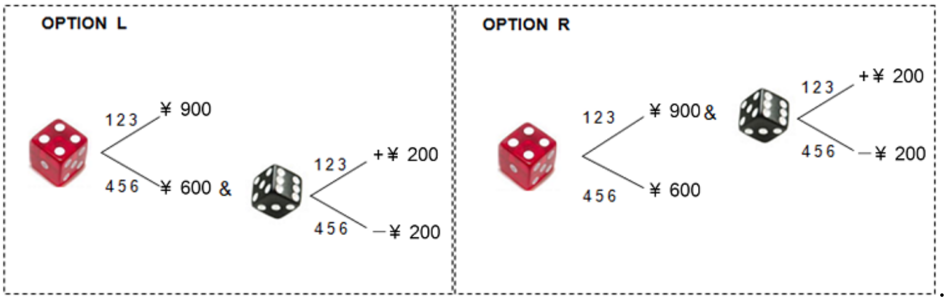


Figure 5. Example of prudence task based on Noussair et al. (2014)

The third subpart of Part1 aimed 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.

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 made in the first part

For example, option L in Figure 5 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 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 amount of effort in the group treatment), they face a smaller probability of loss. The relation between the probability of loss and effort follows the equation XX. The effort aimed at prevention is not refundable. In the experiment, graph and table report the probability of loss. The subjects can use a slider to choose their efforts, which allows them to simultaneously check the possible outcomes and attached a probability when they change their level of effort. They can also use arrows to marginally change their level of effort. In each session, subjects played 10 payment rounds, in Part 2, for real payment, preceded by five rounds. At the end of the session, one of the 10 rounds is randomly selected to be paid. Subjects were paid their future reward seven days after the session by bank transfer.[9] Therefore, all subjects need to go to the lab only once, and, hence, there is no substantial difference in the opportunity cost of participating in the experiment between subjects incurring the current and future loss.

The third part of our experiment aimed at measuring 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

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

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

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

rows) in which subjects are asked to choose between Option A (today payment) and Option B (one week later payment). While Option A is 1000 yen, Option B increases with 1 yen increments between questions. Instead of answering all questions in Part 3, respondents choose to switch 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 participants 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.[11] 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. 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 relative 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 he sessions of Seoul National University.

Table 3. Summary of the sessions

3.2. Hypotheses

We attempted to 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.

Let us begin with a comparison across individual treatments. Given a random assignment

[11] See the online Appendix.

from a large subject pool, there is no reason to expect that the elicited higher order risk attitudes vary with sessions. Hence, the high prevalence of prudence reported in the literature and Propositions 1 and 2 altogether lead to the following hypothesis.

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

Proposition 1 states that prudent agents choose a lower level of prevention than risk-neutral agents, while all imprudent agents choose a higher level of prevention than risk-neutral agents. Therefore, there is a negative correlation between prudence and prevention in the current loss treatment.

[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, the above hypothesis 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: Individual vs Group]: Group decision-making decreases the amount of effort in both the current loss and future loss scenarios.

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 show a value between 0 and 5. Figure 5 reports the histograms of the risk attitude traits of subjects.

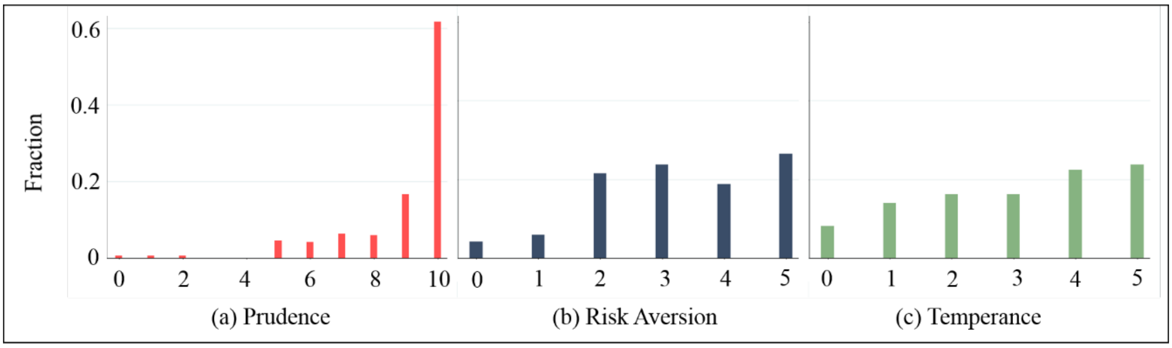


Figure 5. Prevalence of higher order risk attitudes

Regarding prudence, 61.9% of subjects have a score of 10, the maximum value of prudence. 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 participants reported their maximum value. 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 found no gender impact on 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.[13] This pattern is also consistent with the results of Noussair et al. (2014) and Crainich (2013), which showed a positive correlation between risk aversion and 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

[13] 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.

IC and IF treatments is not significant when we ran a two-sample t-test on each observation level (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 (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-statistic: 3.96 in IC and GC; t static: 3.99 in IF and GF). The above-mentioned results show that the strategic substitute of effort lowers the average level of effort between agents, 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 prudence (correlation: 0.01 and p-value 0.31 in IC, correlation -0.02 and p-value 0.19).

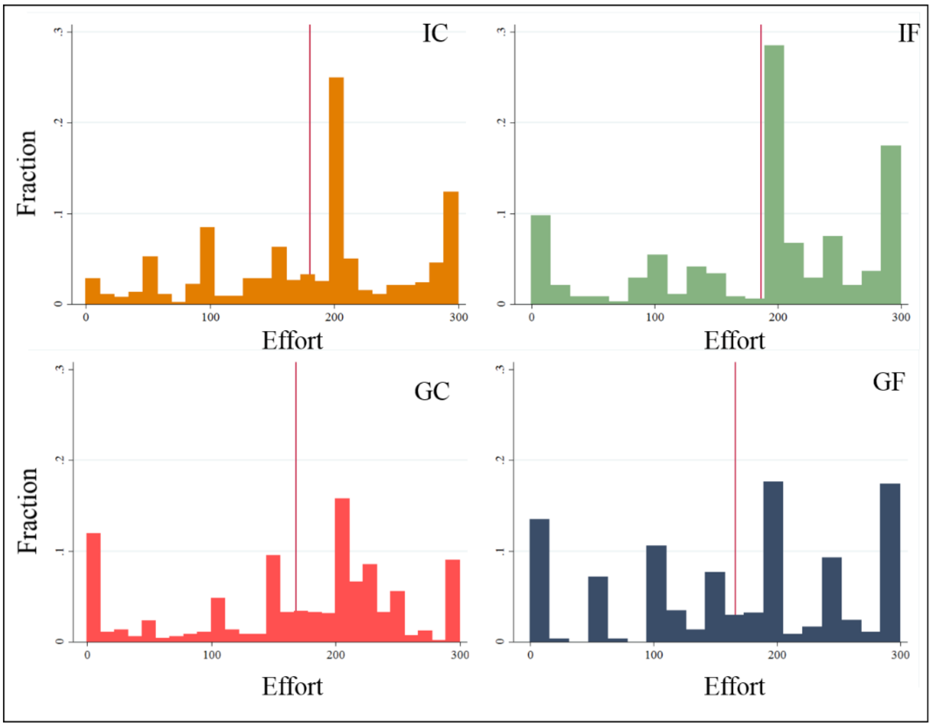


Figure 6. Distribution of prevention across treatments

We divide the individual's average prevention into three parts using 200 (risk-neutral agent's prevention) as a standard. Table 4 shows the proportions of each criterion. In all treatments, most people 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. Distribution of prevention levels

In Part 1, we showed that most subjects are prudent. In line with the expected utility theory, they should choose more prevention than the risk-neutral prevention level (200) in the future treatment. However, Table 4 shows that, on average, about 49% (66%) of subjects violated the theoretical results under the expected utility framework. Moreover, a prevention lower than the risk-neutral level is found in half of the cases, regardless of the timing of the loss and externality.

4.2.1. Role of Prudence: Current Loss

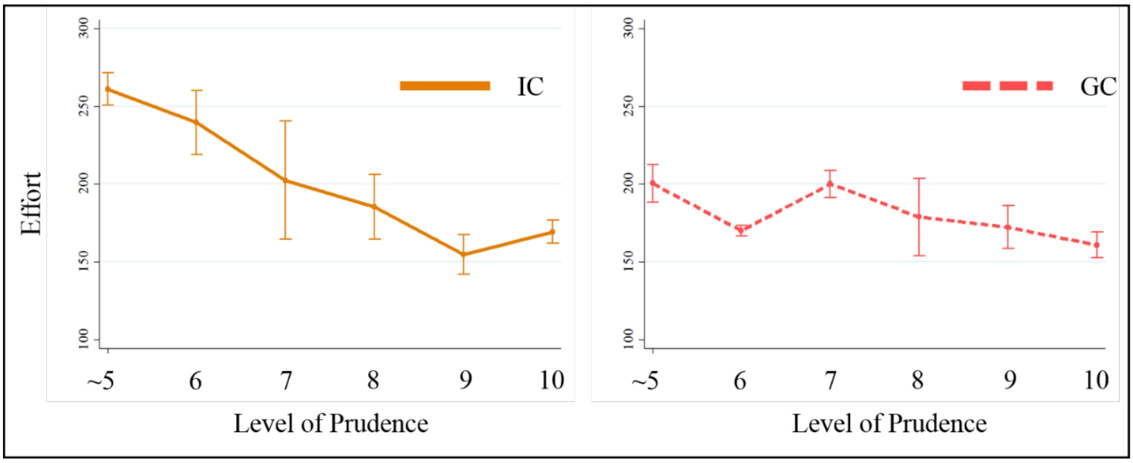


Figure 7. Prevention across the level of Prudence in CL treatments

Figure 7 shows the degree of effort by the level of prudence in both the current loss treatments. The figure shows a clear decreasing trend for prudence and 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 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 prevention, which is consistent with the theory of EG (2005).[14] 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 1-1, which predicts a negative correlation between prudence and efforts. Therefore, our corresponding Result 2 is as follows.

Result 2. In IC and GC treatments, there is a negative correlation between prudence and effort.

4.2.2. Role of Prudence: Future Loss

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 FL treatment.

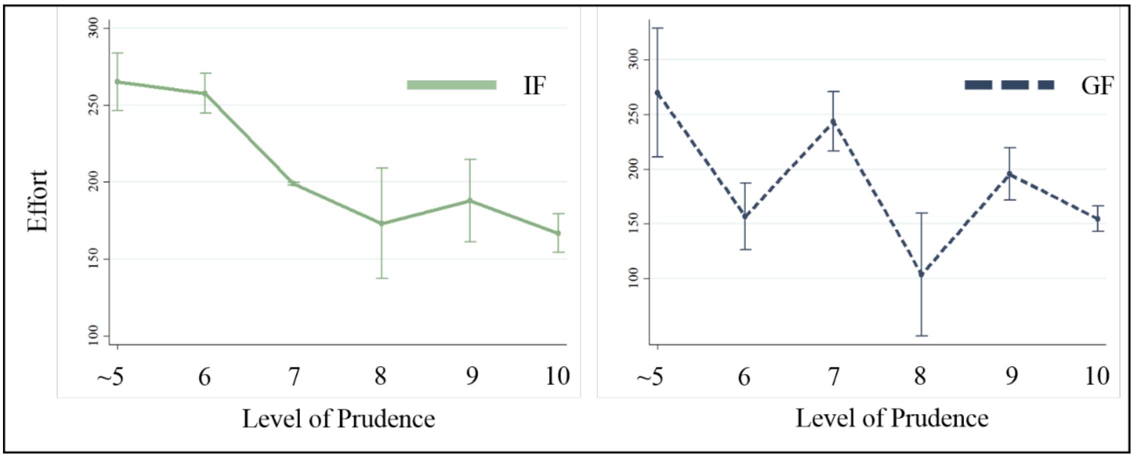


Figure 8. Prevention across the level of Prudence in FL treatments

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 a prevention level around 170. The negative correlation (-0.35, p-value<0.01) contradicts the theoretical results of Mengatti (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

[14] 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.

1-2.

Result 3. In the IF and GF treatments, there is a negative correlation between prudence and effort.

4.2.3. Regression

In this subsection, we assess 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. X_i is a vector that includes individual characteristics including age, sex, and time preference:

$$effort_{it} = \beta_0 + \beta_1 prud_i + \beta_2 aversion_i + \beta_3 temp_i + \beta_4 timepref_i + X'_i \beta_5 + \epsilon_{it} . \quad (1)$$

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) 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 negative correlation between prudence and prevention 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 (-14) and significant at the 10% level. In sum, we find a significant and consistent negative correlation between prudence and prevention. On the other hand, the degree of risk aversion and temperance are not significantly correlated, in any treatments. This also confirms that the degree of risk aversion does not correlate with prevention.

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 regression analysis after controlling for higher order risk attitudes, individual characteristics, and fixed effect, and we investigate the impact of the group treatment indicator variable.[15] We find a decrease in effort equal to 20 in the last round in GC compared with 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 GF compared with the IF treatment. The

[15] Full specification results can be found in Appendix X.

coefficient is not significant at the 10% level (p-value: 0.14).[16]

Table 4. Determinants of prevention

	(1) IC	(2) IF	(3) GC	(4) GF
Prudence (0-10)	-10.67***	-14.69**	-8.254*	-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)
Period	-1.239	0.182	-2.245***	-1.810
	(0.876)	(0.692)	(0.831)	(1.290)
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

Individually clustered standard errors in parentheses.

Result 4. In GC (GF) treatment, there is a decrease in the level of effort compared with the IC (IF) treatment.

5. Prospect Theory

5.1. Lottery example

Our data show a consistent negative correlation between prudence and prevention effort, not only in the current loss treatment but also in future loss treatment. To explain this trend, we introduce

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

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. 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 (Section 5.2); ii) PT explains why a large portion of subjects are prudent in our elicitation task (Section 5.3). These two facts lead to the negative correlation between prudence and prevention effort in our regression.

To get an intuition of the lower level of effort obtained using prospect theory, consider a simplified prevention game. Suppose now that the feasible efforts are limited to 100, 200, or 300. Then, a player faces three lotteries, each corresponding to an effort level. In Figure 9, the first row shows the three lotteries (A, B, and C) which an expected utility maximizer faces. As we have discussed, a risk-neutral player prefers B.

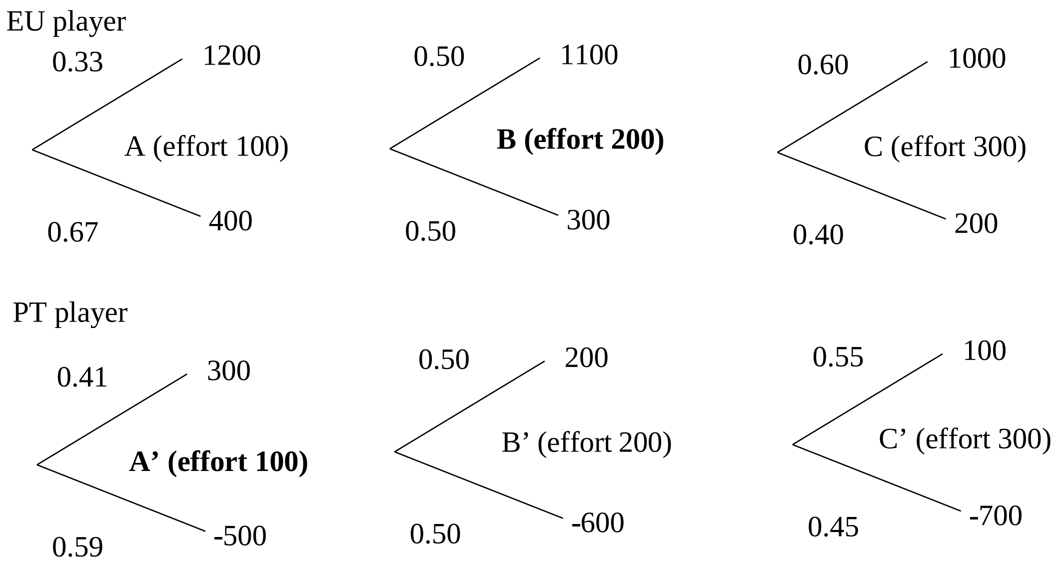


Figure 9. How a prevention game is perceived differently between an EU player and a PT player

How does a PT player perceive these lotteries? Lotteries A, B, and C are converted into A', B', and C' based on two rules. First, the PT player cares about whether each monetary outcome is in the gain or loss domain with respect to the reference point and is more sensitive to losses than gains. Second, each probability of no loss q=1-p is overweighted via an inverted-S shape function with a unit range. We assume that the reference point is equal to the expected wealth per period that would be obtained if the player faces the lottery with a fifty-fifty chance, which is given by (y+z-en-d/2)/2=(1300+1100-200-800/2)/2=900 under our experimental parameters.[19]

[19] A fifty-fifty chance is achieved by the risk neutral player's optimal choice, 200.

Then, the smallest loss with respect to the reference point is 500 attached to A'.[20] Furthermore, overweighting the probability of the good outcome discourages the player's effort. These two factors together could lead to the PT player's preference of A' over B' and C'.[21] We show that the above observations hold for a typical prospect theory model.

5.2. One-period prospect theory model

Consider a binary lottery, $L = (q, a; 1-q, b), a > b$. *A probability 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.[22] Each monetary outcome is evaluated through a function v_p of the form:

$$v_p(x, r, \lambda) = \begin{cases} v(x-r) & \text{if } x \geq r \\ -\lambda v(r-x) & \text{if } x < r \end{cases},$$

where *v* is *a valuation function* such that v'(*m*)>0 and v''(*m*)<0 for all *m*. *A prospect theory player* (*with current risk)* is a player who evaluates a lottery L as:

$$P(L) = w(q)v_p(h, r, \lambda) + (1 - w(q))v_p(l, r, \lambda).$$

Consider a prospect theory participant playing a prevention game with a current loss. Each effort *e* determines a lottery that the player faces, $L(e) = (q(e), y-e, 1-q(e), y-e-d)$, where *y* is an endowment and *q*=*q*(e)=1-p(e)=ke/(1+ke) is the no loss probability. Assume that the reference point is:

$r_c = y - e^* - d/2,\ p(e^*) = 1/2$. Then, without loss (x=y-e), $x - r_c = e^* + d/2 - e,$ hence, it is in the loss domain if and only if $e \geq e_+ \equiv e^* + d/2$. Likewise, with loss (x=y-e-d), the monetary outcome is in the loss domain if and only if $e \geq e_- \equiv e - d/2$.

In line with EG and M propositions, we assume that a risk-neutral player chooses an effort

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[20] EG's weighting function *w* is such that $w(q) = q^{0.6} / ((1-q)^{0.6} + q^{0.6})$ for all *Qs*.
For comparison, each monetary outcome x (after gain/loss calculation) is evaluated using v = {u=x^0.8 for gain, -2u=-2*(-x)^0.8 for loss}, which yields a value of A'= 0.41*300^0.8 + 0.59*(-2)*500^0.8=-130.931; Value of B': In[29]:= 0.50*200^0.8 + 0.50*(-2)*600^0.8= -132.268; Value of C'= 0.55*100^0.8 + 0.45*(-2)*700^0.8= -148.054.

[21] Specifically, consider an EU player with u=x^0.8. Then, the value of A= 0.33*1200^0.8 + 0.67*400^0.8=176.767; value of B=0.50*1100^0.8 + 0.50*300^0.8=183.482; value of C=0.60*1000^0.8 + 0.40*200^0.8=178.439. Hence, the EU player prefers B to A and C.

[22] Satisfied by G-E weighting functions with delta=1. These symmetry leads to clear results.

en=*e**. Also, we assume that the maximum feasible effort is not very large, $\overline{e} < 3e^*$. By q(e)=ke/(1+ke), we know that *d*=4 e_n , and, together with $\overline{e} < 3e_n$, this implies that

$e_- < 0 \le e \le \overline{e} < e_+$. Thus, any monetary outcome with (without) loss is in the loss (gain) domain.

By letting $v_- = v(e - e_-)$ and $v_+ = v(e_+ - e)$, $\pi(e) = w(q(e))$, PT player's problem becomes:

$$\max_e PV(e) \equiv P(L(e)) = \pi(e)v_+ + (1 - \pi(e))(-\lambda)v_- .$$

For a clear argument, we focus on commonly used functional forms. We use a power function for valuation and Goldstein and Einhorn's (1987, hereafter GE) for the probability weighting.[23] A *GE-prospect theory* player is a player who has a power valuation function $v(x) = x^a$ for some $0 < a < 1$, a pessimism-neutral probability weighting function $w(q) = q^\gamma \Big/ \left(q^\gamma + (1-q)^\gamma\right)$ for some $0 < \gamma < 1$, and a loss aversion sensitivity lambda>1. In what follows, we index a *GE-prospect theory* player by a triplet (a, γ, λ). See Figure 10 illustrating the GE probability weighting functions $w(q) = \delta q^\gamma \Big/ \left(\delta q^\gamma + (1-q)^\gamma\right)$ with delta=1, varying gamma between 0.2 and 1.

Each of the two parameters of the GE probability weighting functions is discussed in Abdellaoui et al. (2005).

Delta=1 ensures that $w(q) = 1 - w(1-q)$ for all q, which simplifies our analysis and has an implication of pessimism-optimism neutral behavior. The case of Gamma=0 reduces the equal weight of 1/2 regardless of the probability, while the case of Gamma=1 reduces to the 45 degrees line and, hence, means no distortion.

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

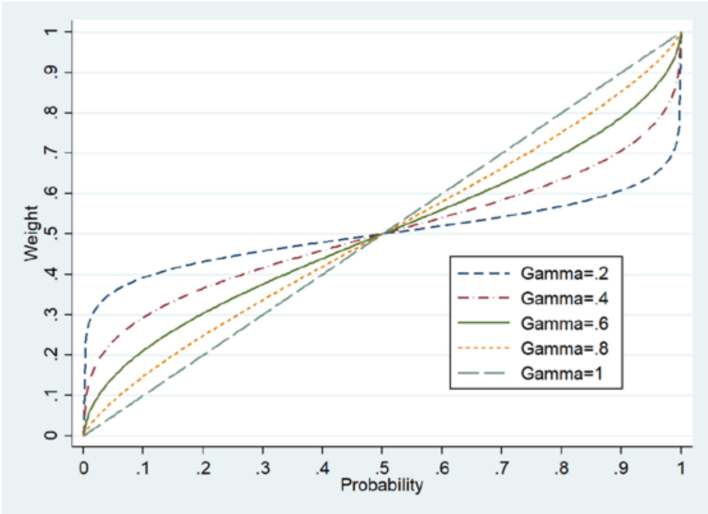

Figure 10. GE probability weighting functions with delta=1.

Hence, measuring the probability of distortion by $1-\gamma$. is useful to characterize the deviation prevention behavior of a GE-prospect theory player from a risk-neutral one. For a GE-prospect theory player (a,γ,λ), let $PV(e,a,\gamma,\lambda)$ be the corresponding value function and $e(a,\gamma,\lambda)=\arg\max_{e} PV(e,a,\gamma,\lambda)$.

Lemma 1. $PV_e(e_n,a,\gamma,\lambda)<(>)0$ *if and only if* $a>(<)\gamma$.

Proof. See Appendix. ||

We introduce two comments on Lemma 1. First, if the GE-prospect theory player with (a,r) chooses $0<e(a,\gamma,\lambda)<\overline{e}$, we obtain $PV_e(e(a,\gamma,\lambda),a,\gamma,\lambda)=0$. Thus, under the concavity of *PV* in *e*, Lemma 1 determines which of $e(a,\gamma,\lambda)$ or *en* is large. Second, we can more easily interpret the Lemma 1 condition by rewriting it as $1-a<(>)1-\gamma$. Consider an extreme case, *a*=1. Then, we obtain $0<(>)1-\gamma$. The condition says that, for a linear *v*, any overweighting (underweighting) to no loss probability alone leads to less (more) effort relative to the risk-neutral case. If *a*=0.5, the condition of Lemma 1 is $0.5<(>)1-\gamma$, indicating that a relatively large probability of distortion is necessary for the optimal effort lower than the risk-neutral case to occur. These cases indicate that this condition is general. Lemma 2 ensures the second order condition.

Lemma 2. *For any triplet* (a,γ,λ), $PV(e,a,\gamma,\lambda)$ *is concave in e.*

Proof. See Appendix. ||

The above-mentioned Lemmas characterize how GE-prospect theory player's behavior differs from that of a risk-neutral player.

Proposition 4. $e(a,\gamma,\lambda) < e_n$ *if and only if* $a > (<)\gamma$.

Proof. It immediately follows from Lemma 1 and 2.||

Figure 11 shows a PT player's value of each effort level, by high and low probability distortion.

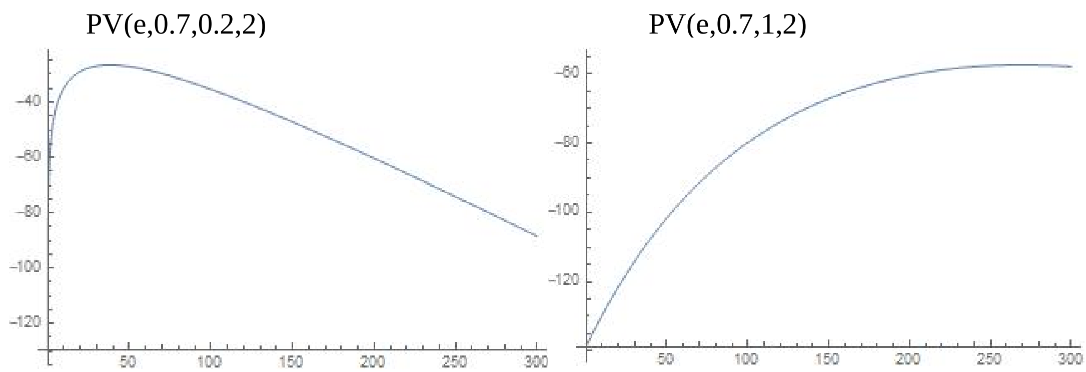

Figure 11. High probability distortion (low gamma) decreases effort.

To state the novelty of this result, let us remind Proposition 1, in which Eeckhoudt and Gollier characterized the 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.

Moreover, we can establish comparative statics among GE-prospect theory players with a different probability of distortion, loss aversion parameter, or curvature of *v*, who exert a lower optimal effort. More precisely:

Proposition 5. i) *Assume* $\overline{e} \le 3e_n / 2$ and $q(\overline{e})/(1-q(\overline{e})) < 2.71828...$ *Then, for every* a,λ *and every* γ,γ' *with* $\gamma > \gamma'$, $e(a,\gamma,\lambda) > e(a,\gamma'\lambda)$.

ii) A higher lambda decreases effort *(to be proven).*

iii) A higher a decreases effort. *(to be proven).*

Proof. See Appendix. ||

5.3. Two-period prospect theory model

Assume that an EG-prospect theory player evaluates monetary outcomes with a reference point in both periods 1 and 2, using:

$$FPV(e) = v_p(y-e, r_f, \lambda) + \pi(e) v_p(z, r_f, \lambda) + (1-\pi(e))(-\lambda) v_p(z-d, r_f, \lambda),$$

where the reference point is:

$$r_f = (r_c + z)/2 = (w + z - e^* - d/2)/2,\ p(e^*) = 1/2.$$

Now, the risk-neutral choice e^* separates the monetary outcomes into the gain or loss domain.[24] FPV reduces to a simple form:

$$FPV(e) = \begin{cases} v(e^*-e) \ if \ e \le e^* \\ -\lambda v(e-e^*) \ if \ e > e^* \end{cases} + (\lambda v(d/8) + v(5d/8))\pi(e) - \lambda v(d/8), \text{ for all } e.$$

Let $e_f(a,\gamma,\lambda) = \arg\max_e FPV(e,a,\gamma,\lambda)$. We establish that any GE-prospect theory player chooses an effort lower than that of the risk-neutral case.

Proposition 6. *For any triplet* (a,γ,λ), $e_f(a,\gamma,\lambda) < e_n$.

Proof. See Appendix. ||

5.4. PT theoretic support for prudent choices in Part 1 elicitation task

We will show that a PT player chooses the upside risk (option R) in the Part 1 prudence questions. A PT player evaluates a lottery L with three outcomes h, m, l with h>m>l as:

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[24]
$$y - e - r_f = y - e - (y + z - e^* - d/2)/2 = (y-z)/2 - (e - e^*) + d/4 > 0 \Leftrightarrow e < e^*$$
$$z - d - r_f = z - d - (y + z - e^* - d/2)/2 = (z-y)/2 + e^* - d/4 > 0 \Leftrightarrow d/8 > 0$$
$$z - r_f = z - (y + z - e^* - d/2)/2 = (z-y)/2 + e^* + d/4 > 0 \Leftrightarrow 5d/8 > 0$$
$$z - y = p(e^*)d - e^* = (1/2)d - d/4 = d/4.$$

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

where $q_{\cdot}$ is the probability of the corresponding outcome. For evaluating the compounded lotteries in prudence questions, we reduce them to simpler cases. Given a pair of red dice (0.5, *a*; 0.5, *b*) and a black dice (0.5, *e*; 0.5, -*e*) with *a*-*e*>*b*, we can write options L and R as $L_+ = (0.25, a+e; 0.25, a-e; 0.5, b)$, $L_- = (0.5, a; 0.25, b+e; 0.25, b-e)$, respectively. Note that *a*-*e*>*b* 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 is L+ is *a*+*e*>*a*-*e*>*b*, while that of L- is *a*>*b*+*e*>*b*-*e*. As in footnote 32 in Deck and Schlesinger (2010), we borrow the estimated parameters in the literature, and we assume (#,#) and GE weighting function, but without assuming symmetry (delta=1). We also assume the reference point r=(a+b)/2, which is a common expected payoff of L+ and L-. Let (a,delta)=(0.8, 1, 1), which are close enough to the estimates of Abdellaoui et al. (2005). The PT player makes prudent choices, as formalized in the following observation.

Observation. *For any* (γ, λ), *a PT player chooses L+ in 9 questions satisfying a-e>b out of 10 prudence elicitation questions in our experiment.*

See Appendix B for detail.

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 Eeckhoudt and Gollier (2005), but rejecting Menegatti (2009) comparative statics. Such negative correlation empirically relies on group prevention treatments, and we also observe prevention efforts well above a symmetric Nash equilibrium prediction. These results suggest a systematic violation of the expected utility theory. We introduced prospect theory to provide a consistent explanation of the observed negative correlation between prudence and effort and the elicited high prudence, introducing the prospect theory comparative statics of Eeckhoudt and Gollier (2005) and Menegatti (2009). Our experiment not only confirms the universality of the elicited higher order risk attitudes in the recent literature but also shed lights on higher order risk attitudes from the viewpoint of prospect theory.

References

Abdellaoui, M., Vossmann, F., & Weber, M. (2005). Choice-based elicitation and decomposition of decision weights for gains and losses under uncertainty. *Management Science*, 51(9), 1384–1399.

Booij, A. S., Van Praag, B. M., & Van De Kuilen, G. (2010). A parametric analysis of prospect theory's functionals for the general population. *Theory and Decision*, 68(1-2), 115–148.

Courbage, C., Rey, B., & Treich, N. (2013). Prevention and precaution. In, *Handbook of insurance* (pp. 185–204). New York: Springer.

Eeckhoudt, L., & Gollier, C. (2013). The effects of changes in risk on risk taking: A survey. In, *Handbook of insurance* (pp. 123–134). New York: Springer.

Gollier, C. (2004). *The economics of risk and time*. Cambridge, Massachusetts: MIT press.

Gollier, C., Hammitt, J. K., & Treich, N. (2013). Risk and choice: A research saga. *Journal of Risk and Uncertainty*, 47(2), 129–145. doi:10.1007/s11166-013-9175-7

Goldstein, W. M. & Einhorn., H. J. (1987). Expression theory and the preference reversal phenomena. *Psychological Review*, 94, 236–254.

Crainich, D., Eeckhoudt, L., & Trannoy, A. (2013). Even (mixed) risk lovers are prudent. *American Economic Review*, 103(4): 1529–35.

Bramoullé, Y., & Treich, N. (2009). Can uncertainty alleviate the commons problem? *Journal of the European Economic Association*, 7(5), 1042–1067.

Deck, C., & Schlesinger, H. (2010). Exploring higher order risk effects. *The Review of Economic Studies*, 77(4), 1403–1420.

Eeckhoudt, L., Etner, J., & Schroyen, F. (2009). The values of relative risk aversion and prudence: A context-free interpretation. *Mathematical Social Sciences*, 58(1), 1–7. doi:10.1016/j.mathsocsci.2008.09.007

Eeckhoudt, L., & Schlesinger, H. (2006). Putting risk in its proper place. *The American Economic Review*, 96(1), 280–289.

Heinrich, T., & Mayrhofer, T. (2017). Higher-order risk preferences in social settings. *Experimental Economics*,

Kimball M.S. (1990). Precautionary savings in the small and in the large *Econometrica*, 58(1), 53-73.

Krieger, M., & Mayrhofer, T. (2017). Prudence and prevention: an economic laboratory experiment. *Applied Economics Letters*, 24(1), 19–24.

Noussair, C. (2011). 13 Experimental prediction and pari-mutuel betting markets. *Prediction Markets: Theory and Applications*, *66*, 174.

Noussair, C. N., Trautmann, S. T., & van de Kuilen, G. (2014). Higher order risk attitudes, demographics, and financial decisions. *The Review of Economic Studies*, 81(1), 325–355. doi:10.1093/restud/rdt032.

White, L. (2008). Prudence in bargaining: The effect of uncertainty on bargaining outcomes. *Games and Economic Behavior*, 62(1), 211–231.

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:

$$-d_g \cdot p_g'((e+f)/2)/2 = 1. \tag{1.10}$$

We focus on a unique symmetric Nash equilibrium. By 1.11 and p'<0, the equilibrium effort is below the socially optimal level.[25]

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:

[25] 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 $p_g(e_g) > 1/2$.

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

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, $FV_1(e_g^f, e_g^f) = 0$.

Moreover, we also know that $p_G'(e) < 0, \text{ and } u(z-d_G) < u(z)$. 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.

Take any (a, γ, λ).

$$PV_e(e,a,\gamma,\lambda) = \pi' v_+ + \pi(-v_+') + (-\lambda)\{(-\pi')v_- + (1-\pi)v_-'\} = \pi'(v_+ + \lambda v_-) - \{\pi v_+' + \lambda(1-\pi)v_-'\}$$

Let $\pi_n = \pi(e_n)$. If e=en, $v_+ = v(e_n + d/2 - e_n) = v(d/2) = v(e_n - (e_n - d/2)) = v_-$.

Since $w'(q) = \gamma\delta\left((1-q)q\right)^{-1+\gamma} \Big/ \left((1-q)^\gamma + q^\gamma\right)^2$, at the risk neutral choice with

$q(e_n) = 1/2,$

$w'_n = w'(1/2) = \gamma\left((1-1/2)1/2\right)^{-1+\gamma} \Big/ \left((1-1/2)^{\gamma} + 1/2^{\gamma}\right)^2 = \gamma$. Thus,

$$\begin{aligned} PV'_{(a,\gamma)}(e_n) &= \pi'_n(\lambda+1)v(2e_n) - \{\pi_n v'(2e_n) + \lambda(1-\pi_n)v'(2e_n)\} \\ &= (\lambda+1)\{w'_n(1/4e_n)v(2e_n) - v'(2e_n)/2\} \ \ if\ \pi(1/2) = 1/2 \\ &= (\lambda+1)\{(\gamma/4e_n)(2e_n)^a - a(2e_n)^{a-1}/2\} \\ &= (\lambda+1){e_n}^{a-1}(\gamma - a)/2 \end{aligned}$$

Therefore, $PV'(e_n) < (>) 0$ if and only if $a > (<) \gamma$. ||

Proof of Lemma 2.
Pick any (a,γ) and consider the GE-prospect theoretic player with (a,γ).

$$\begin{aligned} PV''(e) &= \{\pi''(v_+ + \lambda v_-) + \pi'(-v'_+ + \lambda v'_-)\} - [\{\pi' v'_+ + \lambda(-\pi')v'_-\} + \{\pi(-v'')_+ + \lambda(-\pi)v''_-\}] \\ &= \pi''(v_+ + \lambda v_-) - 2\pi'(v'_+ + \lambda v'_-) + \pi(v''_+ + \lambda v''_-) \end{aligned}$$

Note that for all $e > 0, v', q, q'w, w', \pi > 0, v'' < 0, \pi' = w' \cdot q + w \cdot q' > 0$. Hence,

$$-2\pi'(v'_+ + \lambda v'_-), \pi(v''_+ + \lambda v''_-) < 0 .$$

Moreover, since the player is GE-prospect theoretic with (a,γ),

$$\pi'' = w'' \cdot (q')^2 + w' \cdot q'' = -\frac{\left(\frac{ek}{(1+ek)^2}\right)^{\gamma} \gamma}{e\left(\left(\frac{1}{1+ek}\right)^{\gamma} + \left(\frac{ek}{1+ek}\right)^{\gamma}\right)^2} < 0 \quad \text{for any e.}$$

Therefore, $PV''(e) < 0$ for any e.||

Proof of Proposition 5. Take any (a,γ,λ) We want to know how $\arg\max_{0 \le e \le \bar{e}} PV(e;a,\gamma,\lambda)$ changes. Since the total differential for $f = PV_e(e,a,\gamma,\lambda)$ is $\frac{\partial f}{\partial e}de + \frac{\partial f}{\partial a}da + \frac{\partial f}{\partial \gamma}d\gamma + \frac{\partial f}{\partial e}d\lambda = df$. Note that, for all *e*, $\frac{\partial f}{\partial e} < 0,$ by Lemma 2.

i) By letting da=dl=df=0, we obtain $\frac{de}{d\gamma} = -\frac{\partial f}{\partial \gamma} \Big/ \frac{\partial f}{\partial e}$. It is enough to show that $\frac{\partial f}{\partial \gamma} > 0.$ By PV' in Lemma 1, we have:

$$\frac{\partial f}{\partial \gamma} = \pi_{\gamma e}(v_+ + \lambda v_-) - \pi_\gamma(v'_+ + \lambda v'_-) = (e_+ - e)^{a-1}\{\pi_{\gamma e}(e_+ - e) - \pi_{\gamma +}a\} + \lambda(e - e_-)^{a-1}\{\pi_{\gamma e}(e - e_-) - \pi_\gamma a\}.$$

Note that:

$$\pi_{\gamma e} = \frac{\left(\frac{ek}{(1+ek)^2}\right)^\gamma \left(\left(\frac{1}{1+ek}\right)^\gamma + \left(\frac{ek}{1+ek}\right)^\gamma - \left(\left(\frac{1}{1+ek}\right)^\gamma - \left(\frac{ek}{1+ek}\right)^\gamma\right)\gamma \log\left[\frac{1}{1+ek}\right] + \left(\left(\frac{1}{1+ek}\right)^\gamma - \left(\frac{ek}{1+ek}\right)^\gamma\right)\cdots}{e\left(\left(\frac{1}{1+ek}\right)^\gamma + \left(\frac{ek}{1+ek}\right)^\gamma\right)^3}$$

$$= \left(\frac{ek}{(1+ek)^2}\right)^\gamma \frac{\left((1-q)^\gamma + q^\gamma + \gamma\left((1-q)^\gamma - q^\gamma\right)(\log q - \log(1-q))\right)}{e\left((1-q)^\gamma + q^\gamma\right)^3}$$

$$== \left(\frac{ek}{(1+ek)^2}\right)^\gamma \frac{1 + \gamma f(q)(\log q - \log(1-q))}{e\left((1-q)^\gamma + q^\gamma\right)^2}, \text{where } f(q) = \left((1-q)^\gamma - q^\gamma\right) / \left((1-q)^\gamma + q^\gamma\right).$$

By f(q)<=1, f(q)>(<)0⇔q<(>)1/2, $\gamma f(q)(\log q - \log(1-q)) > 0$ for all q. Hence, $\pi_{\gamma e} \geq 0$ for all e. Note also that:

$$\pi_\gamma = \frac{\left(\frac{ek}{(1+ek)^2}\right)^\gamma \left(-\log\left[\frac{1}{1+ek}\right] + \log\left[\frac{ek}{1+ek}\right]\right)}{\left(\left(\frac{1}{1+ek}\right)^\gamma + \left(\frac{ek}{1+ek}\right)^\gamma\right)^2} = \left(\frac{ek}{(1+ek)^2}\right)^\gamma \frac{\log q - \log(1-q)}{\left((1-q)^\gamma + (q)^\gamma\right)^2} < (>)0 \Leftrightarrow q < (>)1/2$$

.

Hence,

$$\pi_\gamma / \pi_{\gamma e} = e((1-q)^\gamma + q^\gamma)(\log q - \log(1-q)) \Big/ \left((1-q)^\gamma + q^\gamma + \gamma\left((1-q)^\gamma - q^\gamma\right)(\log q - \log(1-q))\right)$$

$$= e(\log q - \log(1-q)) \big/ \left(1 + \gamma f(q)(\log q - \log(1-q))\right)$$

$$< 0 \,\text{for}\, e < e_n, < e\log(\bar{q}/(1-\bar{q}))\,\text{for}\, e > e_n,$$

Case 1. e>en,

$$\pi_{\gamma e}(e_{+}-e)-\pi_{\gamma}a=\pi_{\gamma e}\{(e_{+}-e)-a(\pi_{\gamma}/\pi_{\gamma e})\}$$
$$=\pi_{\gamma e}\{(e_{+}-e)-ae\log(q(\overline{e})/(1-q(\overline{e}))\}$$
$$=\pi_{\gamma e}\{e_n+d/2-(a+1)e\}\, if q(\overline{e})/(1-(\overline{e}))<2.71...$$
$$\geq \pi_{\gamma e}\{3e_n-(a+1)\overline{e}\}$$
$$\geq 0, by\, a\leq 1, \text{if } \overline{e}\leq 3e_n/2$$

Case 2. e<en, $by\, \pi_{\gamma e}>0, \pi_{\gamma}<0, a>0, e_{\_}<0$. Therefore, $\dfrac{\partial f}{\partial \gamma}>0$.

$$\pi_{\gamma e}(e-e_{\_})-\pi_{\gamma}a=\pi_{\gamma e}\{(e-e_{\_})-a(\pi_{\gamma}/\pi_{\gamma e})\}>0 \ .$$

ii) By letting da=dgamma=df=0, we obtain $\dfrac{de}{d\lambda}=-\dfrac{\partial f}{\partial \lambda}\Big/\dfrac{\partial f}{\partial e}$. By PV' in Lemma 1, we have $\dfrac{\partial f}{\partial \lambda}=\pi' v_{\_}-(1-\pi)v'_{\_}=(e-e_{\_})^{a-1}\{\pi'(e-e_{\_})-(1-\pi)a\}$.

iii) By letting dlambda=dgamma=df=0, we obtain $\dfrac{de}{da}=-\dfrac{\partial f}{\partial a}\Big/\dfrac{\partial f}{\partial e}$.||

Proof of Proposition 6.

We want to show that PT optimal effort is less than the risk-neutral case. First,

$$FPV'(e)=\begin{cases}-v'(e_n-e)\ if\ e<e_n\\ -\lambda v'(e-e_n)\ if\ e>e_n\end{cases}+(\lambda v(d/8)+v(5d/8))\pi' .$$

Second, $FPV'(0)>0$. Third, note that $\lim\limits_{e\to e_i+0}FPV'(e)=\lim\limits_{e\to e_i-0}FPV'(e)=-\infty$. Fourth, since we already showed that for any e, $\pi''=w''\cdot(q')^2+w'\cdot q''<0$ in Lemma 2, for any e,

$$FPV''(e)=\begin{cases}v''(e_n-e)\ if\ e<e_n\\ \lambda v''(e-e_n)\ if\ e>e_n\end{cases}+(\lambda v(d/8)+v(5d/8)\pi''<0.$$

Therefore, there exists a unique maximizer of FPV less than en.||

Background of observation.

We establish the nine questions. Suppose for simplicity (0.8, 1, 1), which are close enough to the estimates of Abdellaoui et al. (2005).

Then, by letting $\Delta=(a-b)/2$, we obtain:

$$P(L_+) = w(.25)(e+\Delta) + [w(.5) - w(.25)]\begin{cases} -e+\Delta \\ \lambda(-e+\Delta) \end{cases} + [1-w(.5)](-\Delta)$$

$$= \begin{cases} \{2w(.25) - w(.5)\}e + \{2w(.5) - 1\}\Delta \\ \{(1+\lambda)w(.25) - w(.5)\}e + \{(\lambda+1)w(.5) - 1\}\Delta \end{cases}$$

$$= \begin{cases} \{2w(.25) - .5\}e \\ (1+\lambda)w(.25) - .5\}e + \{.5(\lambda+1) - 1\}\Delta \end{cases}$$

$$P(L_-) = w(.5)\Delta + \{w(.75) - w(.5)\}\begin{cases} e-\Delta \\ \lambda(e-\Delta) \end{cases} + [1-w(.75)](-\lambda)(e+\Delta)$$

$$= \begin{cases} \{2w(.5) - (1-\lambda)w(.75) - \lambda\}\Delta + \{(\lambda+1)w(.75) - w(.5) - \lambda\}e \\ \{(1+\lambda)w(.5) - \lambda\}\Delta + \lambda\{2w(.75) - w(.5) - 1\}e \end{cases}$$

$$= \begin{cases} (1-\lambda)(1-w(.75))\Delta + \{(\lambda+1)w(.75) - .5 - \lambda\}e \\ .5(1-\lambda)\Delta + \lambda\{2w(.75) - 1.5\}e \end{cases}$$

Thus, for $e < \Delta$ (Prudence questions 3, 7 and 8),

$$\begin{aligned} P(L_+) - P(L_-) &= \{2w(.25) - .5\}e - [(1-\lambda)(1-w(.75))\Delta + \{(\lambda+1)w(.75) - .5 - \lambda\}e] \\ &= \{2w(.25) - (\lambda+1)w(.75) + \lambda\}e - (1-\lambda)(1-w(.75))\Delta \\ &= \{2w(.25) - (\lambda+1)(1-w(.25)) + \lambda\}e - (1-\lambda)w(.25)\Delta \\ &= \{(\lambda+3)w(.25) - 1\}e + (\lambda-1)w(.25)\Delta \\ &> 0. \end{aligned}$$

Likewise, for $e \geq \Delta$ (Prudence questions 1, 2, 4, 6, 9 and 10),

$$\begin{aligned} P(L_+) - P(L_-) &= \{(1+\lambda)w(.25) - .5\}e + \{.5(\lambda+1) - 1\}\Delta - [.5(1-\lambda)\Delta + \lambda\{2w(.75) - 1.5\}e] \\ &= \{(1+\lambda)w(.25) - .5 - \lambda\{2w(.75) - 1.5\}\}e + \{.5(\lambda+1) - 1 - .5(1-\lambda)\}\Delta \\ &= \{(1+\lambda)w(.25) - .5 - 2\lambda\{1-w(.25)\} + 1.5\lambda\}e + (\lambda-1)\Delta \\ &= \{(1+3\lambda)w(.25) - .5(1+\lambda)\}e + (\lambda-1)\Delta \\ &> \{.25(1+3\lambda) - .5(1+\lambda)\}e + (\lambda-1)\Delta \\ &= (\lambda-1)(.25e+\Delta) \\ &> 0. \end{aligned}$$

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	Abdellaout 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)

Appendix B. Details about the summary statistics

Figure B.1 and Figure B.2 show the results on high order risk attitude using Osaka and Seoul samples, respectively. They show a similar pattern regarding prudence. 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).

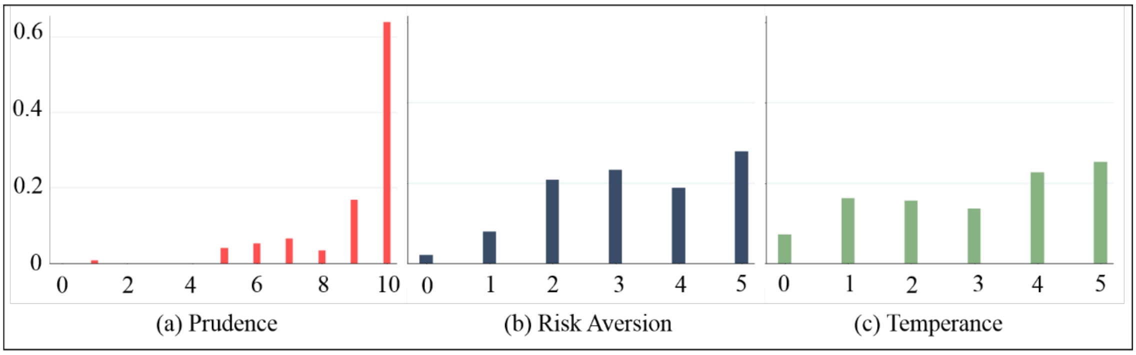

Figure B 1. Summary of Higher order risk attitude using Osaka Sample

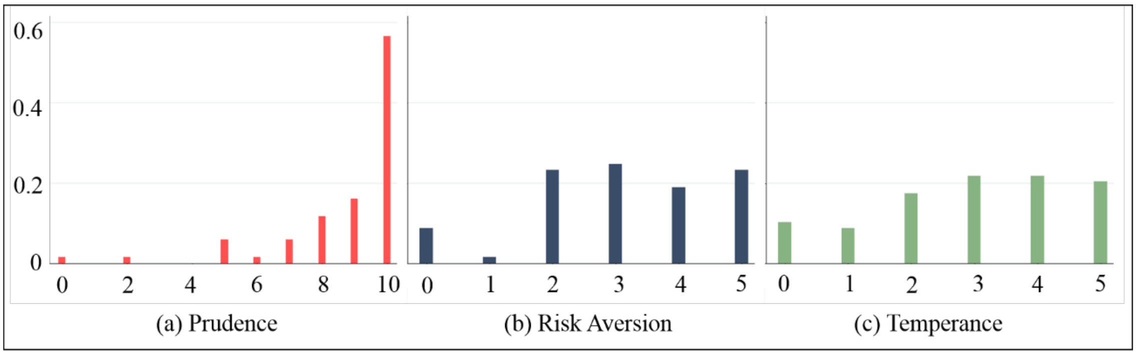

Figure B 2. Summary of Higher order risk attitude using Seoul National University Sample

B.2 Regression using Osaka and Seoul samples respectively.

B.2.1 Current loss case

Table C.1 Regression specification using Osaka and Seoul sample

	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

Appendix C. Robustness check

C.1. Learning effect

In this subsection, we shows the same results using the last 5 periods of the samples. We find the robust pattern as we have shown in Figure 6 and Figure 7.

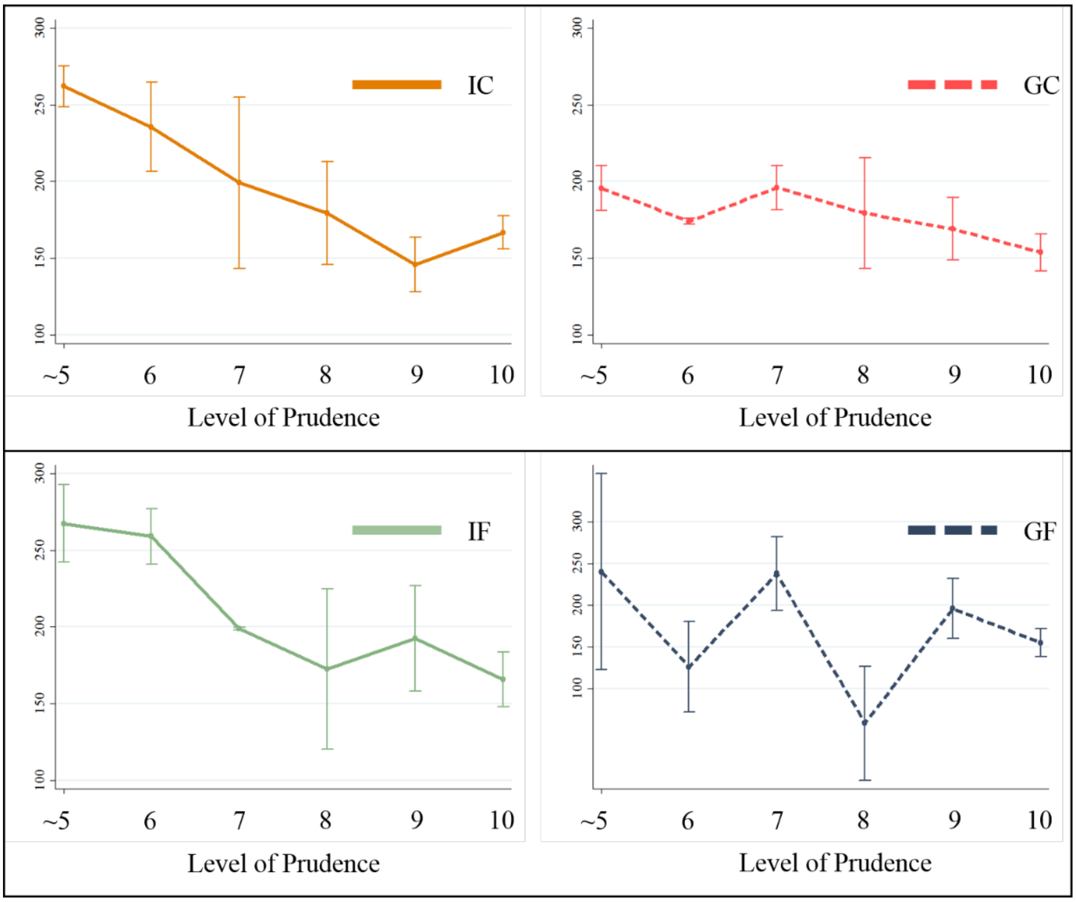

Figure C.1. Robustness check