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EMPIRICAL ARTICLE

The role of game riskiness on the expectation-cooperation link in social dilemmas and its relations with fear and greed

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Abstract
Game riskiness is an index to describe the variance of outcomes of choosing cooperation relative to that of choosing defection in prisoner's dilemmas (PD). When the variance of cooperation is larger (smaller) than that of defection, the PD is labeled as a more-risky PD (less-risky PD). This article extends the previous work on game riskiness by examining its moderating role on the effect of expectation on cooperation under various PDs. We found across three studies that game riskiness moderated the effect of expectation on cooperation such that the effect of expectation on cooperation was larger in more-risky PDs than in less-risky counterparts. This effect was observed in N-person PD (Study 1), PD presented in both gain and loss domains (Study 2), and PD where expectation was manipulated instead of measured (Study 3). Furthermore, we found that participants cooperated more in PDs presented in the gain domain compared to those presented in the loss domain, and this effect was again moderated by game riskiness. In addition, we illustrated mathematically that game riskiness is related to other established indices of PD, including the index of cooperation, fear index, and greed index. This article identified game riskiness as a robust situational factor that can impact decisions in social dilemmas. It also provided insights into the underlying motivations of cooperation and defection under different expectations and how game riskiness can be utilized in cooperation research.

1. Introduction

A social dilemma depicts a mixed-motive situation that the rational pursuit of self-interest leads to suboptimal collective outcomes. In a social dilemma, the optimal collective outcome can only be achieved through mutual cooperation, but the best individual outcome can only be achieved through unilateral defection. However, if everyone chooses to defect, each will receive a worse outcome than if everyone chooses to cooperate (Dawes, 1980; Van Lange et al., 2013). A common type of social dilemma is a two-person prisoner's dilemma (PD), where the two players decide simultaneously whether to cooperate or defect. Following Rapoport and Chammah's (1965) payoff notations, when both players choose cooperation (C), both receive the Reward outcome (R). When both players choose defection (D), both receive the Punishment outcome (P). When one chooses C and the other chooses D, the player who chooses C receives the Sucker outcome (S), whereas the player who chooses D receives the Temptation outcome (T) (Table 1). A PD game has a unique structure of T > R > P > S.

Table 1. *The four possible outcomes in a prisoner's dilemma.*

		Another person	
		Cooperation	Defection
You	Cooperation	You: Reward (R) Other: Reward (R)	You: Sucker (S) Other: Temptation (T)
	Defection	You: Temptation (T) Other: Sucker (S)	You: Punishment (P) Other: Punishment (P)

There is virtually an infinite number of PD games that can be constructed by varying one or more of the four possible outcomes provided that the four outcomes satisfy the criteria of T > R > P > S. A large body of research has found that PDs with different payoff structures can lead to very different decisions (for a review, see Parks et al., 2013), so instead of determining the payoff values arbitrarily, many researchers rely on different indices of PD to construct games that are suitable for particular research questions. One frequently considered index is the index of cooperation (K), which indicates the degree to which the PD can induce cooperation (Rapoport, 1967). The value of K is given by (R – P)/(T – S) such that PDs with a higher K value should induce more cooperation (Rapoport, 1967). K has been used to represent the degree of conflict in social dilemmas and numerous studies and meta-analyses have considered K as one of the main predictors of cooperation (e.g., Columbus et al., 2020; Haesevoets et al., 2018; Spadaro et al., 2022; Thielmann et al., 2020).

This article focuses on another index of PD, the game riskiness index, that may also be worth researcher's attention. Game riskiness (*r*) is a parameter or an index to describe the 'risk', or more specifically, the *variance*, involved in a PD (Au et al., 2012). The value of game riskiness is determined by the variance of cooperation outcomes (R and S) relative to the variance of defection outcomes (T and P), and its formula is given as follows:

$$\text{Game riskiness } (r) = \frac{\mathrm{R}-\mathrm{S}}{(\mathrm{R}-\mathrm{S})+(\mathrm{T}-\mathrm{P})}.$$

A PD with the variance of cooperation outcomes greater than that of defection outcomes will have an r value greater than 0.5 (labeled as a *more-risky PD*); a PD with the variance of cooperation outcomes smaller than that of defection outcomes will have an *r* value smaller than 0.5 (labeled as a *less-risky PD*); a PD with the variance of cooperation outcomes equals to that of defection outcomes will have an *r* value equal to 0.5 (labeled as a *risk-neutral PD*).

Past studies found that game riskiness can influence cooperation through interacting with expectation of cooperation (hereafter expectation). Expectation, also known as beliefs (e.g., Moisan et al., 2018), is the degree to which one thinks that the one's interaction partner(s) are going to cooperate and has been found to be one of the strongest predictors of cooperation (Pruitt & Kimmel, 1977; Yam et al., 2018; Zettler et al., 2013). Ng and Au (2016) showed that game riskiness moderated the effect of expectation on cooperation such that the positive effect of expectation on cooperation was stronger among more-risky PDs than less-risky PDs. Put it another way, under high expectation, people cooperated more in more-risky PDs; under low expectation, people cooperated more in less-risky PDs.

One major purpose of this article is to extend the previous work on game riskiness by addressing several limitations of past studies. Although Ng and Au (2016) found that game riskiness moderated the effect of expectation on cooperation, the findings were based on standard two-person PDs presented in a gain domain. The generalizability of the findings to other PDs is unknown. Because real-life mixed-motive situations often involve more than two people and can involve both gains and losses, in order to enhance the external validity, this article will test such interaction effect on N-person PDs (NPDs), which are PDs involving more than two decision-makers, and PDs presented in both the gain and loss domains. Using the PDs presented in different domains, we will also examine how framing can impact cooperation in PD, and explore whether the effect of framing on cooperation would also be moderated by game riskiness. Furthermore, expectation was measured instead of being manipulated in Ng and Au (2016). It is possible that a player's decision induces him or her to think that the other player will also act in the same way due to a false consensus effect or a justification of one's own decision (Ross et al., 1977). In order to enhance the internal validity, this article aims to establish the causal direction of expectation and cooperation by explicitly manipulating expectation.

More importantly, past studies did not consider how the game riskiness index is related to other established indices, and whether it can predict cooperation over and above the index of cooperation. Therefore, another major purpose of the present research is to connect the game riskiness index to other established indices in PD, including the index of cooperation (Rapoport, 1967), fear index, and greed index (Harris, 1969, 1972), so as to see how these indices are related to each other and how they affect cooperation.

Addressing these research questions is essential in several ways. First, there are many studies examining how trust, beliefs, and expectation can impact cooperation (e.g., Brañas-Garza et al., 2017; Dorrough & Glöckner, 2016; Evans & Van De Calseyde, 2017). If game riskiness can reliably moderate the effect of expectation on cooperation, researchers who focus on these topics may want to consider game riskiness when constructing PD games for their studies. Second, understanding how game riskiness is related to other indices can provide insights into how the variance of cooperation outcomes and defection outcomes can be translated to different psychological motivations of cooperation and defection in social dilemmas. Third, addressing these research questions can also provide insights into how the game riskiness index can be used in cooperation research. Past studies have made use of different indices of PD to examine how personality traits and hormones can affect behavior. For instance, Hilbig et al. (2018) used PDs with different indexes of cooperation to study the mechanisms of how honesty-humility can drive cooperation. Other researchers also used PDs with different fear and greed indices to study how oxytocin can regulate intergroup conflict (De Dreu et al., 2010; Zheng et al., 2016). Through examining how game riskiness can affect cooperation, we can gain a better understanding of how the index can be applied to study cooperation.

2. Game riskiness

Broadly, risk involves two important components: negativity and variability. Negativity concerns exposure to the chance of loss or a bad consequence (e.g., MacCrimmon & Wehrung, 1986; Weber et al., 2002), while variability concerns the variance of possible outcomes of a given decision (e.g., Arrow, 1965). In the context of PD, some researchers conceptualize risk utilizing the negativity component. For instance, Parks (2004) reasoned that cooperation is a more risky choice in PD. Consider the four possible outcomes in Table 1, where T > R > P > S. The worst S outcome can only be obtained through cooperation. Defection, on the other hand, guarantees the second-lowest P outcome. Therefore, cooperation is always a more risky choice than defection.

Other researchers conceptualize risk in PD utilizing the variability component. Under these conceptualizations, risk is neither good nor bad, but just indicates the degree of fluctuation of outcomes. For example, Glöckner and Hilbig (2012) proposed that the riskiness of cooperation depends on the environment of PD. Cooperation is less risky in cooperation-friendly environment where the value of index of cooperation (K; Rapoport, 1967) is high, but is more risky in a cooperation-unfriendly environment where the value of K is low. They suggested that in a cooperation-friendly environment, both players would expect cooperation. Therefore, over repeated encounters, a stable payoff of R (low variability) would be possible. However, in a cooperation-unfriendly environment, both players would expect defection. Hence, defection can ensure a stable P outcome (low variability), but cooperation may lead to a fluctuation in R and S outcomes (high variability).

Another way to conceptualize the riskiness in PD is game riskiness (Au et al., 2012), which also focuses on the variability component of risk. This conceptualization has several distinctive features. Different from Parks (2004) which stated that cooperation is a more risky choice in all PD, the game

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Table 2a. *An example of more-risky PD (Game A).*

		Another person	
		Cooperation	Defection
You	Cooperation	You: 30 Other: 30	You: 5 Other: 35
	Defection	You: 35 Other: 5	You: 25 Other: 25

Table 2b. *An example of less-risky PD (Game B).*

		Another person	
		Cooperation	Defection
You	Cooperation	You: 15 Other: 15	You: 5 Other: 35
	Defection	You: 35 Other: 5	You: 10 Other: 10

riskiness conceptualization stipulated that a PD can be more risky to cooperate or defect, depending on the variance of cooperation outcomes (R and S), and that of the defection outcomes (T and P). Distinct from the conceptualization of Glöckner and Hilbig (2012) which implicitly requires repeated encounters, the game riskiness model can be applied to one-shot PD. More importantly, PDs with different riskiness of cooperation but the same value of index of cooperation (K) can be constructed. Consider a more-risky Game A (T = 35, R = 30, P = 25, S = 5) with r = 0.71, the value of K is (30–25)/(35–5) = 0.17. A less-risky Game B (T = 35, R = 15, P = 10, S = 5) with r = 0.29 can be constructed with the same K value of (15–10)/(35–5) = 0.17 (Tables 2a and 2b). It is important to note that the r index describes the *relative* variance of cooperation compared with that of defection, rather than representing the *overall* variances of the PD.

3. Game riskiness and expectation

Prior research has shown that game riskiness interacts with expectation to influence cooperation (Ng & Au, 2016). To illustrate this game riskiness and expectation interaction effect, consider Games A and B as examples again. On the one hand, when a player expects the other to cooperate, he or she can get either the T or the R outcome. The difference between T and R is greater for less-risky Game B (35–15 = 20) than for more-risky Game A (35–30 = 5), so a player should have a lower temptation to defect in Game A than in Game B because he or she can only get 5 (versus 20) more by defection. On the other hand, when a player expects the other to defect, he or she can get either the P or the S outcome. The difference between P and S is greater for more-risky Game A (25–5 = 20) than for less-risky Game B (10–5 = 5), so a player should have a higher temptation to defect in Game A than in Game B because he or she can get 20 (versus 5) more by defection. Therefore, under high expectation, people should cooperate more in more-risky PDs; under low expectation, people should cooperate more in less-risky PDs. This prediction was supported by an empirical study using two-person PDs (Ng & Au, 2016).

4. The present research

There are four major aims for the present research. First, we examine whether the interaction effect of game riskiness and expectation on cooperation can be generalized from two-person PD to NPD. Second,

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Table 3. *Payoff matrix of NPD.*

	Number of other players choosing cooperation		
Choice	*0*	*x*	*N – 1*
Cooperation	S'	$S' + \frac{x\,(R'-S')}{N-1}$	R'
Defection	P'	$S' + \frac{x\,(T'-P')}{N-1}$	T'

Note: x refers to the number of players choosing cooperation, N refers to the number of players in the group.

we investigate the generalizability of such interaction effect from PD presented in a gain domain to PD presented in a loss domain. We also explore how framing can impact cooperation in PD, and whether the effect of framing on cooperation would be moderated by game riskiness. Third, we attempt to establish the causal relation of expectation and cooperation by manipulating expectation directly. Finally, we examine the relation between the game riskiness index and other established indices of PD and test whether and how these indices influence cooperation.

4.1. N-person PD

NPD is a social dilemma that involves more than two decision-makers. It is important to examine how the interaction effect of game riskiness and expectation can be generalized to NPD because most of the mixed-motive conflicts in daily life involve more than two people (Barcelo & Capraro, 2015; Szilagyi, 2012).

Table 3 shows the payoff matrix of an NPD. The possible outcomes of an NPD can be represented by four values such that R' represents the universal cooperation outcome in which all players choose cooperation; P' represents the universal defection outcome in which all players choose defection; T' represents the unilateral defection outcome which a player receives when all other players choose cooperation but he or she chooses defection; and S' represents the unilateral cooperation outcome which a player receives when all other players choose defection but he or she chooses cooperation. The typical two-person PD is a special case of NPD when the number of players is two. Appendix A illustrates mathematically that the moderating role of game riskiness on the effect of expectation on cooperation can be applied to NPD of any group size by considering how the expected value of cooperation and defection change when expectation changes. In this article, we verify this prediction empirically using NPDs with three to six people in a group. We hypothesize that game riskiness interacts with expectation to affect cooperation in all NPDs with three to six people in a group (*Hypothesis 1*).

4.2. Framing

So far, research on game riskiness has presented the PD in a gain domain such that individuals gain something by playing PD games, and their goal is to maximize their own gains. This article investigates whether the finding can also be generalized to PD that is presented in a loss domain such that individuals lose something by playing PD games, and their goal is to minimize losses. A PD presented in a gain domain can be transposed to a loss domain while keeping the values of r and K unchanged. Consider Games A and B in Tables 2a and 2b as examples again. Game A (T = 35, R = 30, P = 25, S = 5) can be transposed to loss domain with (T = –5, R = –10, P = –15, S = –35) while keeping r = 0.71 and K = 0.17. Similarly, Game B (T = 35, R = 15, P = 10, S = 5) can be transposed to loss domain with (T = –5, R = –25, P = –30, S = –35) while keeping r = 0.29 and K = 0.17. Given that a PD in a gain domain can be transposed to a loss domain while maintaining the same values of r and K, we hypothesize that the interaction effect of game riskiness and expectation on cooperation will be generalizable to a PD presented in a loss domain (*Hypothesis 2*).

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Testing whether the interaction effect can be extended to PD presented in a loss domain is important because how a PD is presented may affect the cooperation rate of individuals, though the results of past studies have been mixed. Early studies investigating the effect of framing on cooperation have been mainly focused on comparing cooperation between public good dilemmas and resource dilemmas. Some researchers proposed that public good dilemmas are regarded as a loss frame while resource dilemmas are regarded as a gain frame because in public good dilemmas, the reference point is what one already has, and one has to decide how much to contribute (which involves a loss to obtain an uncertain benefit), while in resource dilemmas, the reference point is zero, and one has to decide how much to take (which involves a gain) (Brewer & Kramer, 1986; McCusker & Carnevale, 1995). Within these studies, many reported no effects of framing on cooperation (Aquino et al., 1992; Fleishman, 1988), but some researchers reported that individuals in a loss frame cooperated less than those in a gain frame (Brewer & Kramer, 1986); however, some researchers found that individuals in a loss frame cooperated more (McDaniel & Sistrunk, 1991). A meta-analysis found that framing has no effect on cooperation in studies conducted according to game theory designs (Kühberger, 1998). De Heus et al. (2010) investigated the framing effects of two-person PD and found no effect of framing on cooperation. Nevertheless, a recent study that also utilized the two-person PD showed that participants were less cooperative in the loss domain than in the gain domain, and the effect could be explained by expectation such that participants in the loss domain had lower expectation, which led them to cooperate less (Sun et al., 2021). Therefore, apart from extending the interaction effect of game riskiness and expectation on cooperation to the loss domain, the present study will also test the effect of framing on cooperation in PDs in order to add data to help resolve this controversy. Furthermore, we will explore whether the effect of framing on cooperation would be moderated by game riskiness.

4.3. Causal relation of expectation and cooperation

In previous research, the relationship between expectation and cooperation was mainly examined in a correlational way. For instance, Ng and Au (2016) asked participants to indicate their expectations before they made their actual decisions. It is possible that participants inferred other's expectation based on their own determined decisions. Indeed, according to the false consensus effect, participants' expectation is likely to be affected by and mirror their own decision made (Ross et al., 1977). Furthermore, asking participants to indicate their expectations may direct their attention to the possible decisions of others and subsequently affect their own decisions. Thus, in order to enhance the internal validity of the interaction effect of game riskiness and expectation on cooperation, in one of the present studies, we manipulated expectation using two different approaches in order to examine the expectation-cooperation causal effect. We hypothesize that the interaction effect of game riskiness is still robust when expectation is manipulated (*Hypothesis 3*).

4.4. Game riskiness and other indices

Apart from the game riskiness index, many other indices have been proposed to quantify various aspects of a PD. For instance, as abovementioned, the index of cooperation (K) was proposed to indicate the likelihood of a PD to elicit cooperation (Rapoport, 1967). The fear index (F), given by (P – S)/(T – S), and greed index (G), given by (T – R)/(T – S), was proposed to indicate the degree to which a PD will elicit defection due to motivation of fear and greed, respectively (Harris, 1969, 1972). Specifically, a PD with high fear index will elicit defection because players are fearful of receiving the lowest S outcome. A PD with high greed index will elicit defection because players are tempted to be greedy to get the highest T outcome.[1] Numerous studies have utilized PDs with different fear and greed

[1]Some researchers have operationalized fear and greed in a slightly different way. For instance, Mengel (2018) proposed the RISK index, given by (P – S)/P, and the TEMPT index, given by (T – R)/T, which largely correspond to the fear index and greed index proposed by Harris (1969, 1972), respectively.

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indices to examine different motivations for defection (e.g., De Dreu et al., 2010; Huang et al., 2020; Zhen & Yu, 2023). Other indices were also created based on different models of PD, like the subjective expected relative similarity (Fischer, 2009) and the interdependence theory (Kelley et al., 2003). Stivers et al. (2017) conducted a cluster analysis on the existing PD indices in the literature and found that the indices can be largely classified into four major families, namely the cooperation indices, greed indices, fear indices, and risk indices, as well as two other families which are hybrid of the four families. They also found that the game riskiness index, although similar to some other indices, is nonredundant with the other indices. In this article, we focus on the relations among four indices including the index of cooperation (Rapoport, 1967), greed index, fear index (Harris, 1969), and game riskiness index (Au et al., 2012) which correspond to the four families of indices proposed by Stivers et al. (2017), respectively.

As mentioned in the previous section, PDs with different values of r can be constructed while keeping the value of K the same. The study of Ng and Au (2016) used a set of PDs with similar values of K (either 0.3 or 0.4). Although keeping the value of K constant can avoid K being the confounding variable, it does not allow us to investigate the unique effect of r and K in predicting cooperation. Therefore, in one of the present studies, we orthogonally manipulated r and K so that the independent effect of r and K on cooperation can be assessed. It also allows us to examine whether the $r \times$ expectation interaction effect on cooperation would still hold after accounting for K. We argue that both K and r can predict cooperation, but they influence cooperation in different ways. On the one hand, we hypothesize that K has a positive effect on cooperation (*Hypothesis 4a*), which has been demonstrated in numerous empirical studies (e.g., Haesevoets et al., 2018; Spadaro et al., 2022). On the other hand, we hypothesize that r will predict cooperation through interacting with expectation, and this holds true even after accounting for K (*Hypothesis 4b*).

We also illustrate mathematically that r is related to the fear index and greed index. Specifically, as illustrated in Appendix B, while the value of K is kept constant, when r increases, the value of the fear index increases but the value of greed index decreases. Consider Games A and B in Tables 2a and 2b again. Both PDs have the same K value of 0.17. When r increases from Game B to Game A ($r_b = 0.29$, $r_a = 0.71$), fear index increases ($F_b = (10–5)/(35–5) = 0.17$, $F_a = (25–5)/(35–5) = 0.67$), but greed index decreases ($G_b = (35–15)/(35–5) = 0.67$, $G_a = (35–30)/(35–5) = 0.17$). In addition, the values of F and G are the same for a risk-neutral PD ($r = 0.5$). For a more-risky PD, the value of F is greater than G; for a less-risky PD, the value of G is greater than F.

Understanding the relations between game riskiness and the fear and greed indices can provide insights into how the variance of cooperation outcomes and defection outcomes can be translated to different psychological motivations of cooperation and defection in social dilemmas. The above illustration suggested that while more-risky PDs induce more fear but less greed, less-risky PDs induce less fear but more greed. Moreover, it can provide a theoretical explanation of the game riskiness and expectation interaction effect from a motivational perspective. On the one hand, more-risky PDs are games with a relatively large difference between P and S and a relatively small difference between T and R. These games have relatively high values of F and relatively low values of G. When individuals have low expectation, driven by the high fear of receiving the low S outcome, they will likely choose defection. However, when they have high expectation, they will likely cooperate because they have a low temptation to be greedy. On the other hand, less-risky PDs are games with a small difference between P and S and a large difference between T and R that they have relatively low values of F and relatively high values of G. When individuals have low expectation, they may still be cooperative because the PD should induce low level of fear. However, when they have high expectation, they may still not be very cooperative because the PD should induce high level of greed. These predictions are in line with both the previous empirical findings (Ng & Au, 2016) and the predictions based on the expected value difference between cooperation and defection, as illustrated in Appendix A.

Because of the way r, F, and G are related to each other, when we manipulate r and K orthogonally, it can also generate a set of PDs with different fear and greed indices that allow us to explore the effect of fear and greed on cooperation. Although fear and greed are both motivators of defection theoretically

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(Harris, 1969, 1972), some empirical studies have suggested that greed motivates defection to a greater extent than fear (e.g., Ahn et al., 2001; Rapoport & Eshed-Levy, 1989; Zhen & Yu, 2023). This study can verify whether this is true by testing the extent to which fear and greed indices can predict cooperation.

4.5. Overview of studies

Three studies were conducted to address the four aims of the present research. Study 1 tests *Hypothesis 1* that game riskiness interacts with expectation to affect cooperation in NPDs. Study 2 tests *Hypothesis 2* that such interaction effect is robust in PDs presented in both the gain domain and loss domain. It also tests *Hypotheses 4a* and *4b* that the index of cooperation has a positive effect on cooperation, and that game riskiness interacts with expectation to affect cooperation even after accounting for the index of cooperation. Apart from the main hypotheses pertaining to game riskiness, Study 2 also tests the effect of framing on cooperation, and explores the extent to which fear and greed indices can predict cooperation. Finally, Study 3 tests *Hypothesis 3* that the interaction effect of game riskiness and expectation on cooperation is robust when expectation is manipulated.

5. Study 1 (NPD)

Study 1 investigates whether the interaction effect of game riskiness and expectation on cooperation can be extended to NPD. Because increasing group size may lead to decrease in cooperation due to diminished perceived efficacy (Isaac & Walker, 1988; Kerr, 1989, but see Barcelo & Capraro, 2015; Duffy & Xie, 2016 for an opposing perspective), we limit the group size of NPD to three to six people in this study so as to avoid a floor effect of cooperation. In addition to the key variables, we also included measures of risk preference and social value orientation (SVO) in this and subsequent studies. We report the rationales for including these measures and the additional data analyses concerning these two variables in the Supplementary Materials.

In this and all subsequent studies, we report how we determined our sample size, all data exclusions (if any), and all experimental conditions. The data and materials of the studies described in this article are available in the Open Science Framework (OSF) at https://osf.io/5mhdn/.

5.1. Method

5.1.1. Participants

A total of 146 (42 men, 103 women, 1 unreported) students from a university in Hong Kong were recruited via a university mass mailing system to participate in a decision-making experiment. We targeted a sample size of around 150 participants which was predetermined based on past studies examining the game riskiness and expectation interaction effect (Ng & Au, 2016). To achieve this sample size, we posted 13 experimental sessions with a maximum quota of 18 participants per session, and expected that 12 participants on average would actually show up in each session. The age of participants ranged from 18 to 30, with a mean of 20.23 (SD = 2.19) years old. They were promised a show-up fee of HK$50 (US$6) and a chance to win a variable bonus depending on their decisions in the experiment. The monetary values of the bonus participants received ranged from HK$85 to $560 (US$11 to $72). A total of 13 experimental sessions were conducted with 8–15 participants in each session.

5.1.2. Procedures and materials

The experiment was implemented using paper-and-pencil questionnaires. Participants were informed that one of them would be randomly selected at the end of the experiment by a lucky draw, and that the selected participant would receive a monetary bonus depending on one of his or her decisions in the experiment. The bonus was provided to motivate participants to make decisions seriously. Participants were told that the experiment consisted of two main parts. The first part comprised three measurements of risk preference and two measurements of SVO (details about these measures are presented in Supplementary Materials), which were presented as individual decision-making games. The second part comprised 25 one-shot NPDs, which were presented as group decision-making games.

After participants completed the first part, they were introduced to the NPD. They were told that they would be randomly assigned to a group of three to six people, and they would remain in that same group to play a set of 25 group decision-making games. They would know the group size but they would not know who they were paired up with. Although the group membership did not change across the 25 games, participants were also told that no decision feedback would be given and to treat each game as an independent game. Participants were then presented with some examples of the NPD. They were briefed in detail on how to interpret the payoff matrices and the charts. They were also asked to finish a short quiz to ensure their understanding of the instructions. After that, the experimenter randomly assigned participants into a group of three, four, five, or six depending on the total number of participants in that experimental session. Participants received a sheet of paper stating the group size they were assigned to. After that, they were asked to complete the NPD task and indicate their decisions in a questionnaire.

Participants were randomly assigned to one of the four experimental conditions to play a set of NPDs. These experimental conditions corresponded to the four cases of which N = 3, 4, 5, and 6, respectively. Each set of games consisted of 25 one-shot NPDs, of which 10 were constructed as more-risky PDs with $r = 0.70$; another 10 were constructed as less-risky PDs with $r = 0.30$; and the remaining five were included as filler games with random payoff matrices to increase the variation of the NPDs and were not analyzed. The payoff matrices of the 20 NPDs that were of major interest were generated according to the payoff values presented in Appendix C. The T', R', P', and S' outcomes of the 20 NPDs were the same across the four conditions of group size. Depending on the group size, the other payoff values were generated according to the formulas in Table 3. Appendix D illustrates the NPD payoff matrices of N = 5 as an example. The value of K for the 20 NPDs was all kept at 0.4, which indicates medium cooperativeness.

For each game, participants were asked to choose between two alternatives, namely the cooperation option (labeled as A) and the defection option (labeled as B). Participants were shown the payoff matrix informing the participants about the potential values they could obtain in the game, as a function of their own choices (i.e., option A or B) and the number of other players in their groups who chose option A in that trial (ranging from 0 to N-1). A payoff chart was also presented complementarily to facilitate the participants' understanding of the corresponding payoff matrix. Participants played the 25 NPDs in a fixed presentation order that was randomly predesignated in advance.

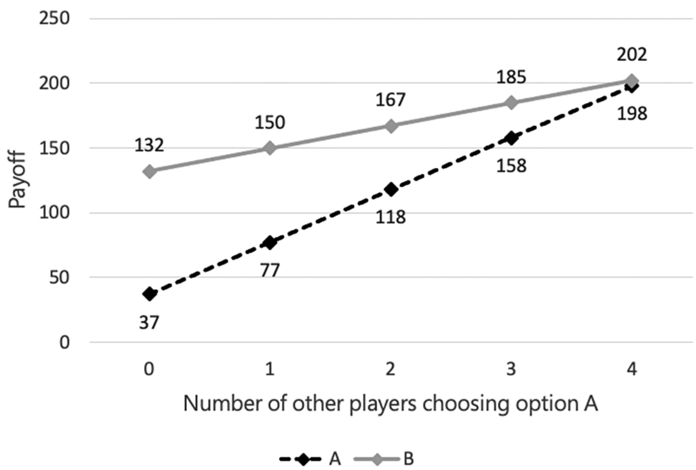
Participants were also asked to estimate and indicate the number of other players in their groups who would choose option A (ranging from 0 to N-1) before they made decisions on each of the 25 games. Expectation of each game was calculated by the proportion of other players the participants estimated to choose option A. For instance, in a group size of four, if the participant indicated that they thought two other players would choose option A, then the expectation would be 2/(4–1) = 66.7%. Figure 1 shows a sample trial of NPD with a group size of five.

After all participants completed the NPD games, they filled in a set of demographic questionnaires, received their payment and bonus, and were debriefed and thanked.

5.2. Results

The average cooperation rate and expectation of participants on the 20 NPDs that were of interest were 18.9% and 35.3%, respectively. The average cooperation rate and expectation on the 10 more-risky NPDs were 24.8% and 38.8%, respectively, and those on the 10 less-risky NPDs were 12.9% and 32.0%, respectively. Expectation and cooperation were highly correlated ($r_s = .73$, $p < .001$). Appendix C shows the average expectation and cooperation rate of each game.

	Number of other players choosing option A				
Your choice	0	1	2	3	4
A	37	77	118	158	198
B	132	150	167	185	202



Please tick an answer (✓) in each of the following questions :

A. According to your estimation, how many players (among the 4 other players) do you think will choose option A?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4

B. Your choice is:

☐ A ☐ B

Figure 1. *A sample trial of the 5-person PD shown to participants (Study 1).*
Note: The payoffs are in HK$ (1HK$ ≈ 0.13US$).

5.2.1. Game riskiness and expectation interaction

Because each participant responded to 20 NPDs, the responses of NPDs were nested within each participant and hence there would be dependencies of responses within each participant. We used generalized estimating equations (GEEs) with an exchangeable structure using SPSS 24.0 to examine the game riskiness and expectation interaction effect on cooperation in order to take into account the dependencies of responses within each participant (Muth et al., 2016; Zeger & Liang, 1986). A binary logistic model was adopted because the dependent variable was a dichotomous variable (cooperation choices were coded as 1 and defection choices were coded as 0). We first tested a model including game riskiness only as the independent variable (more-risky NPDs were coded as 1 and less-risky NPDs were coded as 2). We found a main effect of game riskiness on cooperation ($B = -0.80$, $SE = 0.18$, $\chi^2(1) = 20.00$, $p < .001$, odds ratio (OR) = 0.45). The cooperation choice was chosen more frequently in more-risky NPDs (24.8%) than in less-risky NPDs (12.9%). We then tested a model with game riskiness, expectation (as a continuous variable ranging from 0 to 100), and their interaction term

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as independent variables. Consistent with our prediction, there was a significant game riskiness and expectation interaction effect on cooperation (B = –0.027, SE = 0.005, $\chi^2(1)$ = 33.13, p < .001, OR = 0.97). The effect of expectation on cooperation was stronger in more-risky NPDs (B = 0.052, SE = 0.005, $\chi^2(1)$ = 98.05, p < .001, OR = 1.05) than in less-risky counterparts (B = 0.023, SE = 0.004, $\chi^2(1)$ = 45.49, p < .001, OR = 1.02), though both types of NPD showed a significant positive effect of expectation on cooperation. In other words, an increase in 1% of expectation (out of 100%) enhanced the odds of cooperation by 5% in more-risky NPDs, but only by 2% in less-risky NPDs. Although in terms of odds ratios, the effect size of the interaction effect may appear pretty small (just around 3% difference in terms of odds of cooperation), considering that the odds ratios represent the change in odds for just 1% increase in expectation (out of 100%), the effect size is actually not small. For instance, based on this effect size, when participants in a five-person group indicated that one more group member would cooperate (expectation increased by 25%), the odds of cooperation would increase by 267% in more-risky NPDs, but only by 78% in less-risky NPDs. As an alternative way to interpret the interaction effect, we coded the expectation of each trial into either high (coded as 1) or low (coded as 0) expectation using 50% as the cutoff point. In this way, 39.9% of trials were coded as high expectation and 60.1% were coded as low expectation. For trials of high expectation, cooperation choice was chosen more often in more-risky NPDs than in less-risky NPDs (B = –1.26, SE = 0.19, $\chi^2(1)$ = 41.82, p < .001, OR = 0.28). Conversely, for trials of low expectation, cooperation choice was chosen more often in less-risky NPDs (B = 0.58, SE = 0.19, $\chi^2(1)$ = 8.97, p = .003, OR = 1.79).

In order to examine whether group size exerted an influence on the game riskiness and expectation interaction effect, we also included group size as a between-subject factor in the GEE to test the three-way interaction effect on cooperation. Consistent with our mathematical illustration, the game riskiness × expectation × group size interaction effect on cooperation was not significant ($\chi^2(3)$ = 2.96, p = .398). Group size did not have a significant influence on the game riskiness and expectation interaction effect on cooperation. The game riskiness × expectation interaction effects on cooperation were significant in both the three-person group (B = –0.019, SE = 0.007, $\chi^2(1)$ = 7.95, p = .005, OR = 0.98), the five-person group (B = –0.034, SE = 0.012, $\chi^2(1)$ = 7.92, p = .005, OR = 0.97), and the six-person group (B = –0.036, SE = 0.008, $\chi^2(1)$ = 19.20, p < .001, OR = 0.96), though the effect on the four-person group did not reach the conventional level of statistical significance (B = –0.023, SE = 0.013, $\chi^2(1)$ = 3.46, p = .063, OR = 0.98). These results supported our *Hypothesis 1*.

5.3. Discussion

This study provided evidence that the moderating role of game riskiness on the effect of expectation on cooperation can be generalized to the NPD with a group size of three to six people, which was consistent with our mathematical prediction. Specifically, the effect of expectation on cooperation was stronger for more-risky NPD than for less-risky NPD. Low expectation participants cooperated more in less-risky NPD, while high expectation participants cooperated more in more-risky NPD.

6. Study 2 (framing)

Study 2 examined whether the interaction effect of game riskiness and expectation on cooperation can be generalized from PDs presented in a gain domain to those presented in a loss domain. In this study, r and K were also manipulated orthogonally so that the independent effect of r and K on cooperation can be assessed. It also allowed us to test whether the r × expectation interaction effect on cooperation would still hold after accounting for K. As demonstrated above mathematically, manipulating r and K orthogonally can also generate a set of PDs with different fear and greed indices that allowed us to explore the effect of fear and greed on cooperation. Past studies on game riskiness have been focusing on comparing more-risky PD (r > 0.5) with less-risky PD (r < 0.5) (Au et al., 2012; Ng & Au, 2016). How people make decisions in risk-neutral PD (r = 0.5) is unknown. Therefore, this study added a condition of risk-neutral PD.

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6.1. Method

6.1.1. Participants

A total of 184 (50 men, 132 women, 2 unreported) students from a university in Hong Kong were recruited via a university mass mailing system to participate in a decision-making experiment. We targeted a sample size of 180 participants which was larger than that in Study 1 because one additional factor (i.e., framing) was included in the experimental design. We determined the sample size from experience instead of power analysis because, to the best of our knowledge, there is no suitable formulation to determine the sample size pertaining to GEE analyses involving a continuous independent variable. To achieve this sample size, we posted a total of 23 experimental sessions with a maximum quota of 12 participants per session and expected that eight participants on average would actually show up. The age of participants ranged from 17 to 29, with a mean of 19.93 (SD = 2.14) years old. They received a reimbursement ranging from HK$67 to $158 (US$8 to $20), depending on their decisions in the experiment. A total of 23 experimental sessions were conducted with 6 to 12 participants in each session. An even number of participants were recruited in each session so that their decisions in PD could be paired with another participant.

6.1.2. Procedures and materials

Participants were told that they would have an initial endowment of HK$110 (US$14) and they would play a series of decision-making games during the experiment. They were informed that one of the games would be randomly drawn at the end of the experiment, and that they would gain or lose a certain amount of their reimbursement depending on their decisions on the selected game, at a rate of HK$1 for every $10 gained or lost in that game.[2] They could gain a maximum of HK$48 (US$6) and lose a maximum of HK$43 (US$5) through the decision-making games. Therefore, participants were guaranteed a minimum payment of HK$67 (US$9), which was a typical remuneration for experiments of this length of time, even if they lost the maximum amount. They were then instructed to complete the individual decision-making games and questionnaires, which included the risk preference measures, the SVO measure, and other measures that were not related to this research project (a full list of those measures can be found in Supplementary Materials). All the decision-making games and questionnaires were administrated through the Qualtrics online survey platform.

After participants finished the individual decision-making games and questionnaires, they were introduced to the PD games, which were presented as two-person decision-making games. Participants were briefed in detail on how to interpret the payoff matrices and how to indicate their expectations of the other player's choices. They were also asked to finish a short quiz to make sure that they knew how to play the games. Participants were then told that they would be randomly and anonymously paired with other players to play a total of 60 games, and that the pairings might vary across each game. Participants received no feedback on the other player's decisions.

Participants played a total of 60 one-shot PD games, 12 of which were included as filler games with asymmetric payoff values to increase the variation of the PDs and were not analyzed. Among the 48 games that are of primary interest for the study, one-third of them were constructed as more-risky PDs with $r = 0.70$; another one-third were constructed as less-risky PDs with $r = 0.30$; and the remaining one-third were constructed as risk-neutral PDs with $r = 0.50$. For each group of games with the same values of r, half of them were presented in a gain domain with all payoff values being positive; and the other half were presented in a loss domain with all payoff values being negative. Consequently, the 48 games were categorized into six subsets (i.e., three levels of $r \times$ two levels of framing), with eight games in each subset. The values of K ranged from 0.09 to 0.39 and were matched across the

[2] In both the advertisement posted on the mass mailing system and the informed consent, participants were told that they would receive a variable study payment ranging from HK$67 to HK$158, depending on their decisions made during the experiment. We only mentioned that they may "lose" their study payment during the experiment as a cover story.

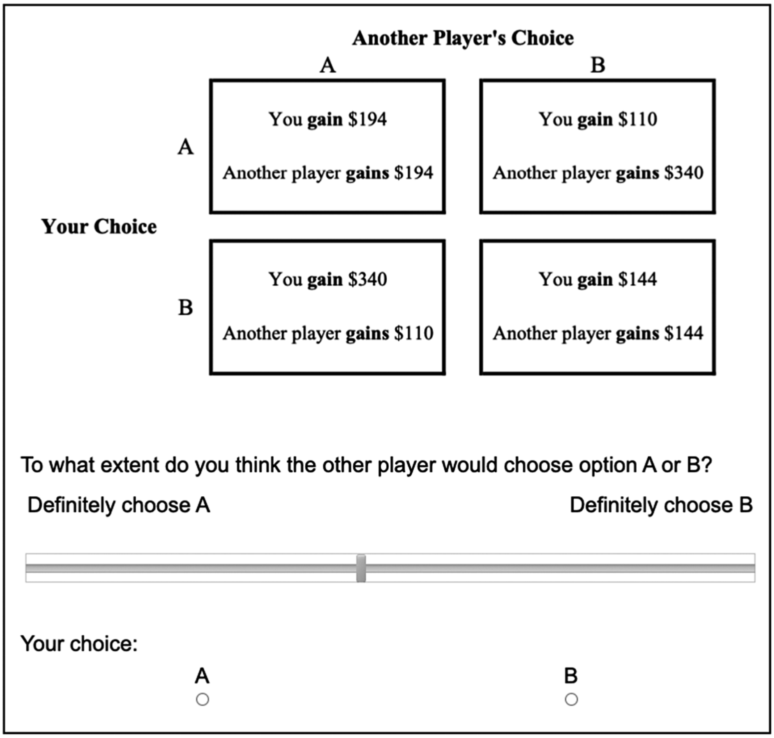

Figure 2. *A sample trial of PD shown to participants in Study 2.*

Note: The payoffs are in HK$ (1HK$ ≈ 0.13US$).

six subsets of games.[3] The values of fear index and greed index ranged from 0.03 to 0.67. Appendix E presents a list of the 48 PD games. The cooperation and defection options were labeled as A and B, respectively, for half of the games, and vice versa for the other half of the games. The 60 PDs were randomly divided into three blocks with 20 games in each block, and six between-subject conditions were created to counterbalance the presentation order of the three blocks. The presentation order of the 20 games within each block was also randomized with one page showing one game. After completing each block, participants could choose to take a short break before moving on to the next block.

Before making decisions on each of the 60 games, participants were asked to indicate the extent to which they expected the other player would choose option A or B by selecting a point on a slider. The slider is comprised of 101 points (ranging from 0 to 100), and the actual numerical values to which the points correspond were not shown to participants. Selecting a point on the leftmost position indicates that the participants thought the other player would definitely choose A; while that on the rightmost position indicates that they thought the other player would definitely choose B. Figure 2 shows an example of the PD presented to participants.

After all participants completed the PD games, they filled in a set of demographic questionnaires, received their corresponding payment, and were debriefed and thanked.

6.2. Results

Data from one participant were excluded from the analyses because the computer crashed during the experiment. The average cooperation rate and expectation of participants on the 48 PDs that were of

[3]The values of K were limited to the range between 0.09 and 0.39 because the r value sets an upper bound of the K value such that $r > K/(K + 1)$ (see Appendix D of Au et al., 2012 for details).

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interest were 33.9% and 50.3%, respectively. For PDs in a gain domain, the average cooperation rate of more-risky PDs, risk-neutral PDs, and less-risky PDs were 37.4%, 35.6%, and 33.3%, respectively. For PDs in a loss domain, the average cooperation rate of more-risky PDs, risk-neutral PDs, and less-risky PDs were 34.3%, 30.1%, and 32.5%, respectively. Similar to Study 1, expectation and cooperation were highly correlated ($r_s = .636$, $p < .001$). Appendix E shows the average expectation and cooperation rate of each game.

6.2.1. Game riskiness, expectation, and framing interaction

Similar to Study 1, we used GEE to examine the main effects and interaction effects of game riskiness, expectation, and framing on cooperation. We first tested the main effects of game riskiness, expectation, and framing on cooperation separately. Game riskiness was included as a categorical variable with three levels ($r = 0.3$, 0.5, and 0.7, coded as 1, 2, and 3, respectively); framing was included as a categorical variable with two levels (gain domain and loss domain, coded as 1 and 2, respectively); expectation was included as a continuous variable. We found a main effect of game riskiness on cooperation ($\chi^2(2) = 7.11$, $p = .029$). Cooperation choice was chosen more frequently in more-risky PDs compared with risk-neutral PDs (35.8% versus 32.8%, $B = -0.13$, $SE = 0.05$, $\chi^2(1) = 6.74$, $p = .009$, $OR = 0.88$), and compared with less-risky PDs (35.8% versus 32.9%, $B = -0.13$, $SE = 0.06$, $\chi^2(1) = 4.34$, $p = .037$, $OR = 0.88$). However, cooperation rates of risk-neutral PDs and less-risky PDs were not significantly different (32.8% versus 32.9%, $B = -0.003$, $SE = 0.05$, $\chi^2(1) = 0.004$, $p = .951$, $OR = 1.00$). We also found that expectation positively predicted cooperation ($B = 0.035$, $SE = 0.003$, $\chi^2(1) = 128.94$, $p < .001$, $OR = 1.04$). In addition, there was a significant effect of framing on cooperation ($B = -0.14$, $SE = 0.05$, $\chi^2(1) = 9.00$, $p = .003$, $OR = 0.87$). Participants cooperated more in PDs presented in the gain domain (35.4% on average) than in the loss domain (32.3% on average).

We then examined the two-way interaction effects of the three variables on cooperation. Consistent with our hypothesis, there was a significant game riskiness and expectation interaction effect on cooperation ($\chi^2(2) = 68.03$, $p < .001$). The effect of expectation on cooperation was significantly different between more-risky PDs and less-risky PDs ($B = 0.017$, $SE = 0.002$, $\chi^2(1) = 63.34$, $p < .001$, $OR = 1.02$). The effect was also significantly different between more-risky PDs and risk-neutral PDs ($B = 0.007$, $SE = 0.002$, $\chi^2(1) = 15.44$, $p < .001$, $OR = 1.01$). The effect was also significantly different between risk-neutral PDs and less-risky PDs ($B = 0.010$, $SE = 0.002$, $\chi^2(1) = 35.71$, $p < .001$, $OR = 1.01$). Simple effect analyses revealed that the effect of expectation on cooperation was the strongest in more-risky PDs ($B = 0.046$, $SE = 0.004$, $\chi^2(1) = 129.01$, $p < .001$, $OR = 1.05$), followed by risk-neutral PDs ($B = 0.038$, $SE = 0.004$, $\chi^2(1) = 100.39$, $p < .001$, $OR = 1.04$), and was the weakest in less-risky PDs ($B = 0.025$, $SE = 0.003$, $\chi^2(1) = 69.38$, $p < .001$, $OR = 1.03$). In other words, an increase in one point of expectation (out of 101 points) enhanced the odds of cooperation by 5% in more-risky PDs, 4% in risk-neutral PDs, and 3% in less-risky PDs. Figure 3 illustrates the interaction effect graphically. In order to test whether the interaction effect was robust across PDs in the gain domain as well as those in the loss domain, we ran the GEE analyses utilizing trials in the loss domain only and found that the effect was still significant ($\chi^2(2) = 49.39$, $p < .001$). The interaction effect was also significant when utilizing trials in the gain domain only ($\chi^2(2) = 39.92$, $p < .001$). These results supported our *Hypothesis 2* that the game riskiness and expectation interaction effect on cooperation can be generalized to PD presented in a loss domain.

Furthermore, the game riskiness × framing effect on cooperation was significant ($\chi^2(2) = 8.42$, $p = .015$). Simple effect analyses revealed that for more-risky PDs and risk-neutral PDs, participants cooperated more in the gain domain than in the loss domain ($B = -0.134$, $SE = 0.061$, $\chi^2(1) = 4.82$, $p = .028$, $OR = 0.87$ for more-risky PDs; $B = -0.251$, $SE = 0.065$, $\chi^2(1) = 15.15$, $p < .001$, $OR = 0.78$ for risk-neutral PDs). For less-risky PDs, participants cooperated to a similar extent in the gain domain and the loss domain ($B = -0.040$, $SE = 0.069$, $\chi^2(1) = 0.34$, $p = .558$, $OR = 0.96$). These results showed that the effect of framing on cooperation in PD depended on game riskiness.

In addition, there was a significant expectation × framing effect on cooperation ($\chi^2(1) = 8.93$, $p = .003$). Although the positive effect of expectation on cooperation was robust in PDs presented

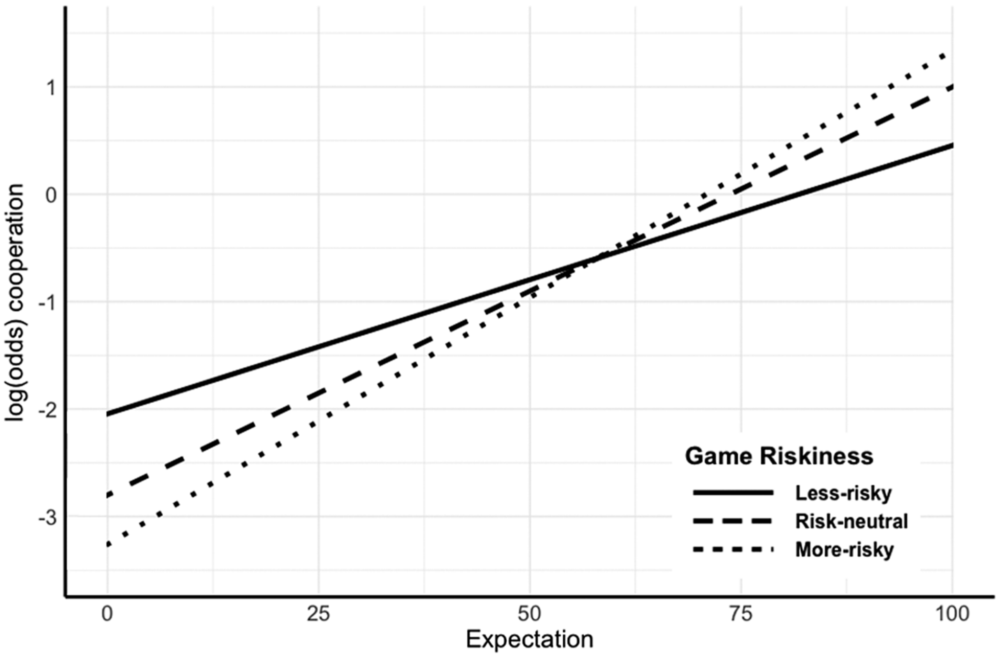

Figure 3. *The game riskiness and expectation interaction effect on cooperation in Study 2.*

Table 4. *Summary of generalized estimating equations results in Study 2.*

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
Variable	χ^2	df	χ^2	df	χ^2	df	χ^2	df	χ^2	df	χ^2	df	χ^2	df
Intercept	42.92**	1	138.97**	1	42.93**	1	144.75**	1	42.90**	1	140.59**	1	145.42**	1
r	7.11*	2					54.43**	2	7.23*	2			53.60**	2
EC			128.94**	1			129.72**	1			129.08**	1	129.90**	1
Faming					9.00**	1			9.00**	1	4.32*	1	3.32	1
r × EC							68.03**	2					66.97**	2
r × Framing									8.42*	2			5.07	2
EC × Framing											8.93**	1	7.89**	1
r × EC × Framing													2.01	2

Note: $^{**}p < .01$; $^{*}p < .05$. The dependent variable is cooperation.
Abbreviations: r, game riskiness; EC, expectation.

in both the gain domain and the loss domain, such effect was stronger in PDs presented in the gain domain ($B = 0.038$, $SE = 0.004$, $\chi^2(1) = 118.89$, $p < .001$, $OR = 1.04$), than in PDs presented in the loss domain ($B = 0.032$, $SE = 0.003$, $\chi^2(1) = 105.90$, $p < .001$, $OR = 1.03$). Finally, we tested the game riskiness × expectation × framing interaction effect on cooperation. The three-way interaction effect was not significant though ($\chi^2(2) = 2.01$, $p = .366$). Table 4 shows the GEE results.

6.2.2. Game riskiness and other indices

In order to examine whether game riskiness can predict cooperation above and beyond the index of cooperation, we included both game riskiness and index of cooperation as predictors in the GEE model. Results showed that index of cooperation positively predicted cooperation ($\chi^2(1) = 67.70$, $p < .001$). Game riskiness also predicted cooperation above and beyond the index of cooperation

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($\chi^2(2) = 7.10$, $p = .029$). This supported our *Hypothesis 4a*. We also ran another GEE model with game riskiness, index of cooperation, expectation, and their three 2-way interaction variables as predictors, and found that the game riskiness × expectation interaction effect remained significant after accounting for index of cooperation ($\chi^2(2) = 67.56$, $p < .001$). This supported our *Hypothesis 4b*. The index of cooperation × expectation interaction effect was not significant ($\chi^2(1) = 0.68$, $p = .409$). The game riskiness × index of cooperation interaction effect was also not significant ($\chi^2(2) = 0.28$, $p = .869$).

We also tested the effect of fear and greed indices on cooperation using separate GEE models. Although greed index negatively predicted cooperation ($B = -0.473$, $SE = 0.124$, $\chi^2(1) = 14.58$, $p < .001$, $OR = 0.62$), fear index did not predict cooperation ($B = 0.036$, $SE = 0.122$, $\chi^2(1) = 0.09$, $p = .767$, $OR = 1.04$).

6.3. Discussion

This study provided evidence that the game riskiness × expectation interaction effect can be generalized from PDs presented in a gain domain to PDs presented in a loss domain. This study also shed light on the strength of the expectation-cooperation linkage in risk-neutral PD. We found that the positive effect of expectation on cooperation in risk-neutral PD was in between the effect in more-risky PD and that in less-risky PD.

We also found that participants cooperated more in PDs in a gain domain than in a loss domain. People in general show a certain degree of loss aversion (Köbberling & Wakker, 2005). It is possible that in the loss domain, participants wanted to avoid a potential great loss (receiving the sucker outcome) by choosing cooperation. Therefore, they were less willing to cooperate in the loss domain. This finding was in line with Sun et al. (2021) which showed that participants were less cooperative in the loss domain. Furthermore, we were able to replicate their finding that such domain effect was not moderated by the index of cooperation ($\chi^2(1) = 0.02$, $p = .878$). Nevertheless, we found a game riskiness and framing interaction effect on cooperation. Participants cooperated more in the gain domain than in the loss domain in more-risky PDs and risk-neutral PDs, but not in less-risky PDs. It is likely that in less-risky PDs, the difference between the P and S outcomes is relatively small, so the effect of loss aversion would be smaller, because the loss of receiving the P outcome and the loss of receiving the S outcome are similar. Hence, this study extended the findings of Sun et al. (2021) by demonstrating a boundary condition of the effect of domain on cooperation.

In addition, we found that the positive effect of expectation on cooperation was stronger in PDs presented in the gain domain compared to those presented in the loss domain. This could be again explained by loss aversion. People may not be willing to cooperate in the loss domain even when they expect that the other player will cooperate because they may be afraid of losing a lot by receiving the S outcome.

We orthogonally manipulated game riskiness and index of cooperation in this study and found that game riskiness can predict cooperation above and beyond the index of cooperation, a well-established index that is shown to predict cooperation. When considering the interaction effect of expectation on cooperation, the game riskiness × expectation interaction effect was robust, but the index of cooperation × expectation interaction effect was not significant. Taken together, these results suggested that while index of cooperation influences cooperation in a rather direct way, game riskiness usually functions as an essential modulator that influences cooperation together with other frequently studied social psychological variables including beliefs and framing. Finally, we found that the greed index negatively predicted cooperation, but the fear index did not. These findings were consistent with previous studies on fear and greed (Ahn et al., 2001; Rapoport & Eshed-Levy, 1989; Zhen & Yu, 2023).

7. Study 3 (manipulation of expectation)

Expectation was measured instead of being manipulated in Studies 1 and 2. One potential problem is that expectation and game riskiness may not be completely orthogonal. We found in Study 1 that participants had a higher expectation in more-risky PDs than in less-risky PDs.[4] Therefore, an experiment is needed to orthogonally manipulate expectation and game riskiness in order to enhance the internal validity of the findings.

One of the easiest ways to generate expectation is to inform participants of their partner's probability of cooperation (e.g., Zettler et al., 2013). However, in a symmetric information PD where both players receive the same information, the awareness that the other player is also informed of the probability of cooperation may create an additional source of influence that can affect the decision of individuals. Consider as an example where Player A and Player B are playing a PD game. Player A was informed of the probability of cooperation of Player B, through the past cooperation history of Player B, for example. At the same time, Player A was aware of the fact that Player B was also informed of the probability of cooperation of Player A, and this can in turn alter the expectation as well as the actual decision of Player A. In order to have a purer manipulation of expectation, we utilize a modified PD game in which only one of the players is able to make the actual decision, while another player's response is determined by a robot to make decisions at a known probability. In this study, two experimental conditions were included. In one condition, participants were told that the robot's cooperation probability was randomly determined. In the second condition, participants were told that the robot's cooperation probability was determined by that actual player's past cooperation history. We included these two experimental conditions in order to see whether the sources of expectation would have an influence on people's decisions and whether the moderating effect of game riskiness is robust across different sources of expectation.

7.1. Method

7.1.1. Participants

A total of 210 (66 men, 144 women) students from a university in Hong Kong were recruited via a university mass mailing system to participate in a decision-making experiment. We planned to recruit 240 participants, which was more than that in Study 2 because this study involved a between-subject variable, sources of expectation. To achieve this sample size, we posted a total of 24 experimental sessions with a maximum quota of 16 participants per session and expected that 10 participants on average would actually show up (though the number of participants recruited was a bit smaller than the targeted sample size). The age of participants ranged from 18 to 30, with a mean of 20.28 (SD = 2.07) years old. Participants were guaranteed a reimbursement of HK$90 (US$11.6) upon completion of the experiment, with an additional chance to win a monetary bonus ranging from HK$60 to $360 (US$7.7 to $46.0). A total of 24 experimental sessions were conducted with 6–12 participants in each session. Similar to Study 2, an even number of participants were recruited in each session so that their decisions in PD could be paired with another participant.

7.1.2. Procedures and materials

Participants were told that the study consisted of three main parts, which included a set of online questionnaires and two sets of decision-making games. Participants were informed that one of them would be randomly selected at the end of the experiment to receive a certain amount of bonus payment depending on his or her decisions made in the decision-making games. They were then instructed to fill in an online questionnaire via an online survey platform which included the risk preference and SVO

[4]We conducted GEE analyses to examine whether participants had different expectations in PDs with different game riskiness. A linear model was adopted because expectation was a continuous variable. In Study 1, we found a main effect of game riskiness on expectation ($B = -0.07$, $SE = 0.02$, $\chi^2(1) = 11.86$, $p = .001$). Participants had a higher expectation in more-risky PDs (38.8%) than in less-risky PDs (32.0%). However, the main effect of expectation on cooperation was not significant in Study 2 ($\chi^2(2) = 3.23$, $p = .199$). Participants had similar expectation in more-risky PDs (51.0%), risk-neutral PDs (49.9%), and less-risky PDs (50.0%).

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measures, and some other measures that were not related to this research project (a full list of those measures can be found in Supplementary Materials). After that, participants were introduced to the PD games in detail which were presented as decision-making games.

Participants played two sets of PD games that were implemented in E-Prime. The first set was comprised of 20 PDs that were presented to the participants in a completely randomized order, including six more-risky PDs (r = 0.7), six risk-neutral PDs (r = 0.5), six less-risky PDs (r = 0.3), and two filler games. In each game, participants were asked to indicate their decisions by pressing keys on the keyboard, with S and K representing the cooperative and defection options, respectively. The main purpose of this first set of PD was to allow us to manipulate the expectation of participants in the second set of PD.

In the second set of PDs, participants were randomly assigned into two experimental conditions, the 'random' condition and the 'past history' condition. Unlike in the first set of PDs where both players could freely choose between the two options, participants were told that in each game, one of the two players would have his or her decision determined by a robot, according to a certain probability whose numerical value would be shown to the other player who can make the decision. They were also told that in some of the trials, they would be the ones who could make the decisions; in other trials, their decisions would be decided by the robot. In the trials where the participant was chosen to be the one who could actually make a decision, participants in the 'random' condition were told that the probability of the robot, which represented the other player, choosing 'S' (cooperation) was determined at random. Participants in the 'past history' condition were told that the probability of the robot choosing 'S' was determined by the decisions that the other player had made in the first set (i.e., the probability for the computer to select S was equal to the percentage of games that the other player had chosen S in the first set). In reality, all of these probabilities were predesignated for the purpose of manipulation of expectation. Figure 4a,b shows the examples of PDs that were presented to the participants in the second set.

Participants were told that they would be paired up to play a total of 42 games, and the pairings changed across games such that they could be playing with a different partner in different games. These 42 PDs were presented in three blocks, each of which consisted of 14 games that shared the same payoff structure. Before the start of each block, they were shown the payoff structure. The first two blocks presented a more-risky PD (T = 340, R = 334, P = 244, S = 110, r = 0.7, K = 0.39) and a less-risky PD (T = 340, R = 206, P = 116, S = 110, r = 0.3, K = 0.39), respectively, and the presentation order was counterbalanced. In these two blocks, participants made their own decisions playing against the robot with a clearly specified probability of choosing 'S' (cooperation) shown on the screen (Figure 4a,b). Within each block, the probabilities shown to the participants in the 14 games were 0%, 0%, 25%, 25%, 30%, 30%, 50%, 50%, 70%, 70%, 75%, 75%, 100%, and 100%, respectively, presented in a randomized order. In other words, there were seven levels of expectation, and each level of expectation was presented twice. The third block presented a risk-neutral PD (T = 340, R = 270, P = 180, S = 110, r = 0.5). In this block, participants were told that their decisions would be determined by the robot and they just needed to press a button on each trial to command their computers to make a decision. The third block was included just to enhance the perceived authenticity of our cover story and it generated no useful data for analyses. Finally, they filled in a set of post-PD game questionnaires, received their corresponding payment, and were debriefed and thanked.

7.2. Results

For the first set of PDs, the average cooperation rate of the 18 PDs was 37.3%. The average cooperation rates of more-risky PDs, risk-neutral PDs, and less-risky PDs were 41.8%, 35.4%, and 34.8%, respectively.

The cooperation rates for the second set of PDs across different game riskiness, expectation, and experimental conditions are presented in Table 5. For the second set of PD, the average cooperation

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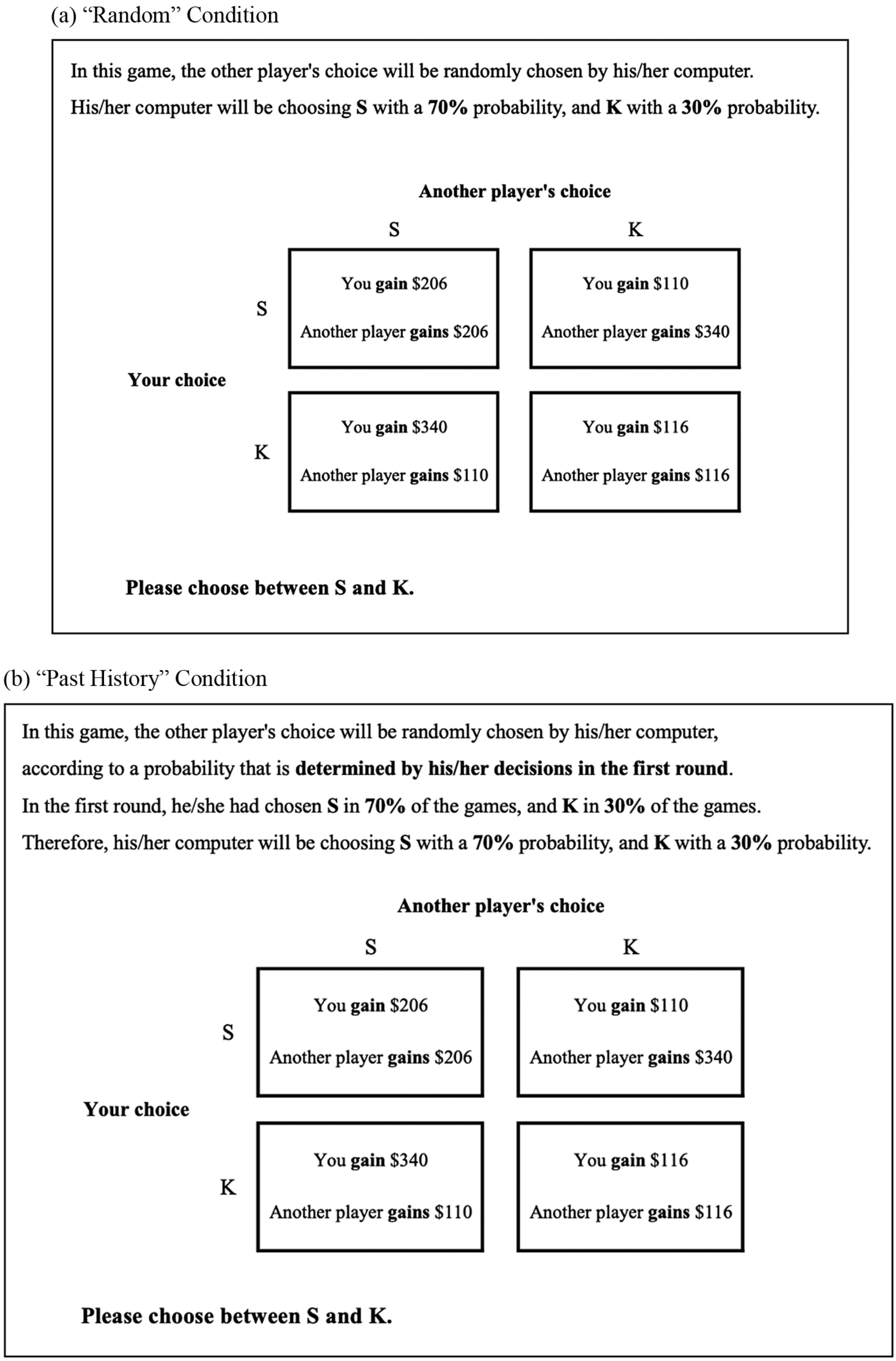

Figure 4. *Sample trials of PD presented to participants in the second round for the (a) ‘random’ and (b) ‘past history’ conditions, respectively (Study 3).*

Note: The payoffs are in HK$ (1HK$ ≈ 0.13US$).

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Table 5. *The cooperation rates for the second round of PD across different game riskiness, expectation, and experimental conditions (Study 3).*

r	P(C)	Coop_R	Coop_PH	Coop_Avg
0.3	0	0.17	0.14	0.15
0.3	0.25	0.20	0.20	0.20
0.3	0.3	0.21	0.20	0.20
0.3	0.5	0.46	0.35	0.40
0.3	0.7	0.46	0.41	0.44
0.3	0.75	0.44	0.41	0.43
0.3	1	0.37	0.39	0.38
0.7	0	0.02	0.03	0.03
0.7	0.25	0.05	0.07	0.06
0.7	0.3	0.05	0.08	0.06
0.7	0.5	0.39	0.32	0.35
0.7	0.7	0.64	0.57	0.61
0.7	0.75	0.65	0.62	0.63
0.7	1	0.74	0.74	0.74

Note: Only seven levels of expectation were shown, since each of these probabilities were presented twice.
Abbreviations: P(C), probability of the other player's computer to select S (Cooperation); Coop_R, cooperation rate for the 'random' condition; Coop_PH, cooperation rate for the 'past history' condition; Coop_Avg, average cooperation rate.

rate of the 28 PDs was 33.5%. The average cooperation rates of more-risky PDs and less-risky PDs were 35.5% and 31.6%, respectively.

7.2.1. Game riskiness and expectation interaction

The game riskiness and expectation interaction effect on cooperation was examined in the second set of PDs, where expectation was manipulated. Similar to Studies 1 and 2, we used GEE to examine the interaction effect. We first included both the data for the 'random' condition and the 'past history' condition in the analyses. We treated the seven levels of expectation (0, 25, 30, 50, 70, 75, and 100) as a continuous variable. Consistent with our prediction, there was a significant game riskiness and expectation interaction effect on cooperation (B = −0.035, SE = 0.003, $\chi^2(1)$ = 121.15, p < .001, OR = 0.97). The effect of expectation on cooperation was significantly higher in more-risky PDs (B = 0.049, SE = 0.003, $\chi^2(1)$ = 266.20, p < .001, OR = 1.05) than in less-risky counterparts (B = 0.015, SE = 0.002, $\chi^2(1)$ = 42.73, p < .001, OR = 1.02). In other words, an increase in 1% of expectation (out of 100%) enhanced the odds of cooperation by 5% in more-risky PDs, but only by 2% in less-risky PDs. We then tested the interaction effect separately for the 'random' condition and the 'past history' condition. We found that the game riskiness × expectation interaction effect on cooperation was robust across the 'random' condition (B = −0.037, SE = 0.004, $\chi^2(1)$ = 71.89, p < .001, OR = 0.96), as well as the 'past history' condition (B = −0.033, SE = 0.005, $\chi^2(1)$ = 47.80, p < .001, OR = 0.97). As illustrated in Figures 5 and 6, in both the 'random' and 'past history' conditions, under low expectation including 0%, 25%, and 30%, participants cooperated more in less-risky PDs than in more-risky PDs. However, under high expectation including 70%, 75%, and 100%, participants cooperated more in more-risky PDs than in the less-risky counterparts. These findings supported our *Hypothesis 3*.

We also examined whether participants cooperated to a different extent in the two experimental conditions. We found that the main effect of condition on cooperation was not significant (B = 0.10, SE = 0.14, $\chi^2(1)$ = 0.52, p = .471, OR = 1.11). Participants cooperated to a similar extent in the 'random' condition (34.7%) and the 'past history' condition (32.4%). Experimental condition did not moderate

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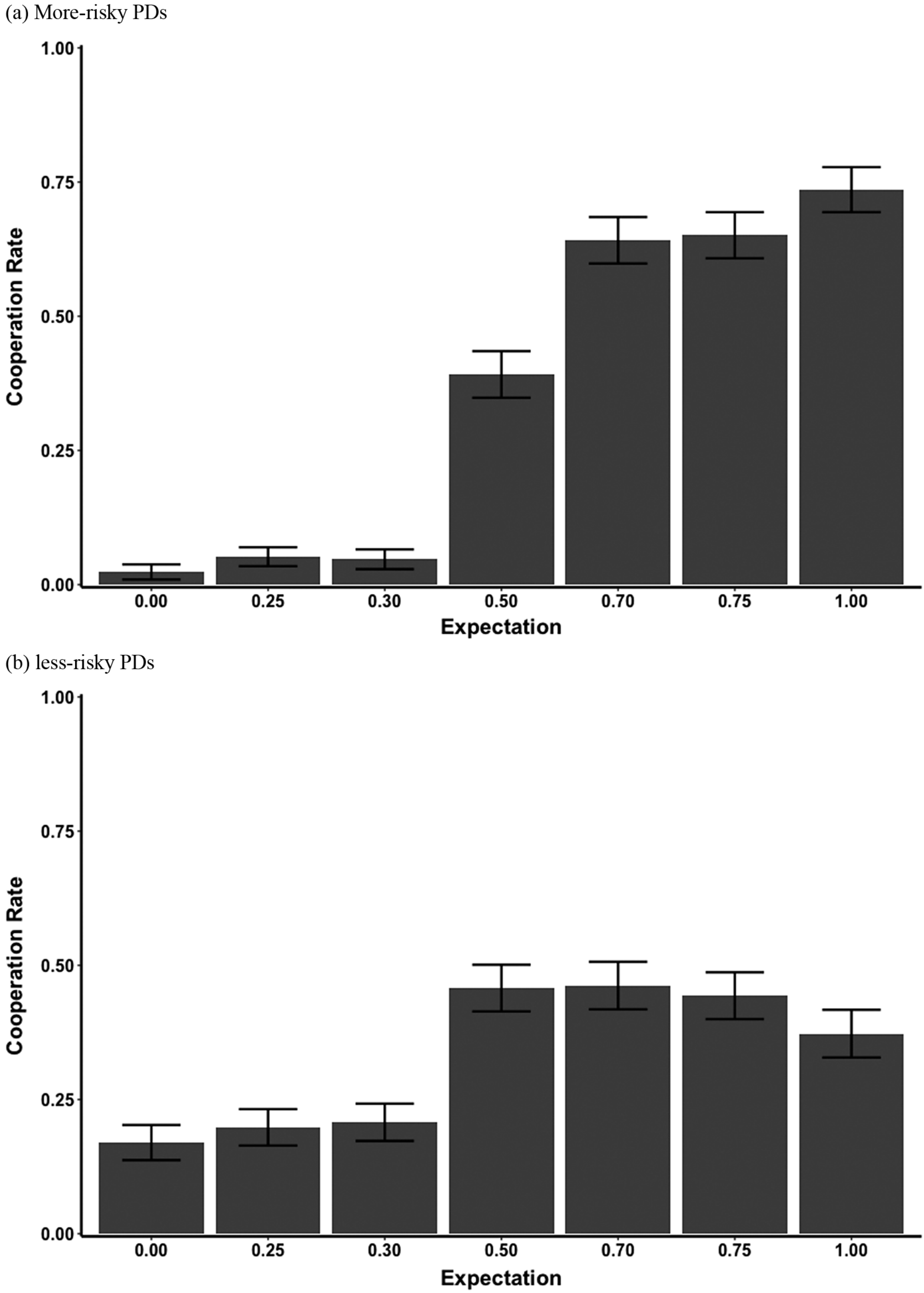

Figure 5. *Graphs of cooperation rate against different levels of expectation in the 'random' condition for (a) more-risky PDs and (b) less-risky PDs (Study 3).*

Note: Error bar represents ±1 standard error.

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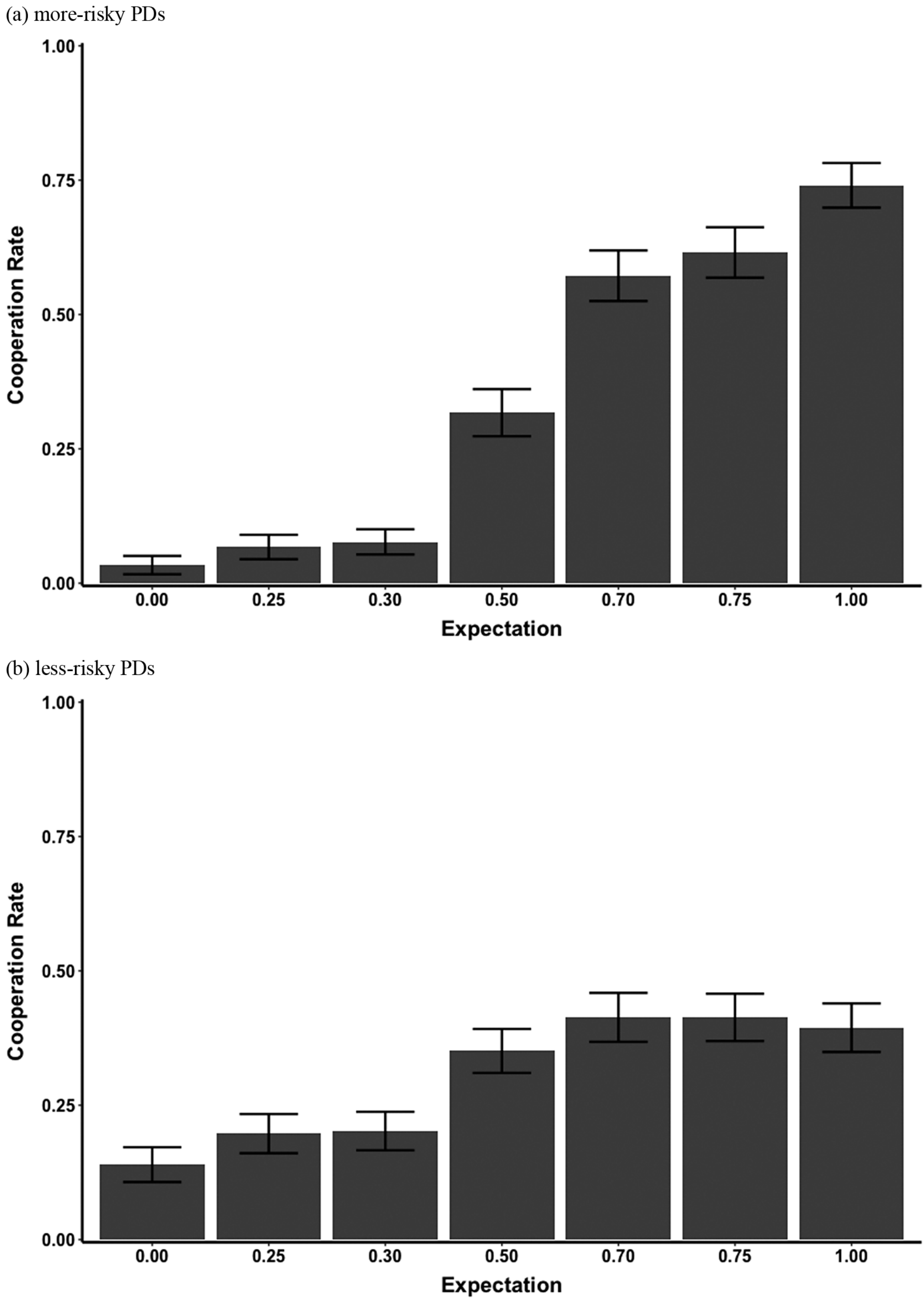

Figure 6. *Graph of cooperation rate against different levels of expectation in the 'past history' condition for (a) more-risky PDs and (b) less-risky PDs (Study 3).*

Note: Error bar represents ±1 standard error.

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the effect of expectation on cooperation ($B = -0.0004$, $SE = 0.004$, $\chi^2(1) = 0.01$, $p = .921$, $OR = 1.00$). We also tested the game riskiness × expectation × condition three-way interaction effect on cooperation, but the effect was not significant ($B = 0.004$, $SE = 0.007$, $\chi^2(1) = 0.38$, $p = .538$, $OR = 1.00$). These results suggested that the source of expectation did not alter the decisions of participants much. The strength of the game riskiness × expectation interaction effect on cooperation was similar across the two conditions.

7.3. Discussion

This study strengthened the internal validity of the game riskiness × expectation interaction effect by manipulating expectation and game riskiness orthogonally. The effects were robust no matter whether the expectation was elicited at random or informed based on the past cooperation history of the other player. The effect also held under two extreme cases of expectation, 0% and 100%. When participants were certain that the other player would choose defection, their cooperation rate was extremely low in more-risky PDs (only 3%). However, they still cooperated 15% of the time in less-risky PDs. The difference between the P and S outcomes is relatively small in less-risky PDs, so even when participants were certain that the other player would choose defection, some of them may still be willing to choose cooperation to increase the other player's outcome at a relatively small cost to themselves. We believe that this non-negligible cooperation rate in less-risky PDs is unlikely due to the reasons that participants did not fully believe the information they received about the other player's behavior or that they did not fully understand the rules of the game because if these were true, participants should have also cooperated to a similar extent in more-risky PDs. When participants were certain that the other player would choose cooperation, participants cooperated 74% of the time in more-risky PDs. Most of the participants did not exploit the other player to choose defection. However, participants cooperated only 38% of the time in less-risky PDs, with a majority of participants exploiting the other player. These results were consistent with the fact that the difference between the T and R outcomes is relatively large in less-risky PDs. Therefore, when participants were certain that the other player would choose cooperation, many chose defection to reap the benefit of the T outcome.

It is reasonable to suggest that the effects of expectation on cooperation would be different across the two experimental conditions. When the probability of the other player's computer choosing cooperation is based on the past history of the other player, this probability somehow carries a message of whether the player is a 'good' or a 'bad' person. People might in turn be more sensitive toward the probability information. For instance, when a person receives a high probability, he or she might think that the other player should be a 'good' person and hence might be more motivated to cooperate. Nonetheless, we failed to find an expectation × condition effect on cooperation in this study. We emphasized the sources of the probability (either elicited at random or based on the past cooperation history of the other player) both before the second set of PD started and during each PD game. We therefore are confident that participants were aware of the sources of probability information. It seems that participants in this study made decisions based mainly on strategic concerns by focusing on the actual probabilities rather than the source of where the probabilities came from. Another possible explanation for this null effect is that participants indeed considered the robot to be somewhat human, as studies found that individuals anthropomorphize machines to a certain extent (Nielsen et al., 2022). In other words, participants in the 'random' condition may have made decisions as if the cooperation probabilities were coming from humans.

One limitation of this study is that deception was used such that the probabilities shown to the participants were actually predesignated instead of determining at random or basing on past decisions of the other player. However, we deem the use of deception necessary because it can provide a stringent test of the causal relationship between expectation, game riskiness, and cooperation. It can also allow us to examine a full spectrum of expectation ranging from 0% to 100%. These goals are almost impossible to achieve without the use of deception.

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8. General discussion

8.1. Summary of findings

First, we found across three studies a robust game riskiness and expectation interaction effect on cooperation across (a) traditional two-person PD and NPD with a group size of three to six, (b) PDs presented in the gain domain and the loss domain, and (c) PDs where expectation was measured and manipulated. In all three studies, we found that the effect of expectation on cooperation was stronger in more-risky PD than in less-risky PD. Under low expectation, participants cooperated more in less-risky PD; however, under high expectation, participants cooperated more in more-risky PD. These findings verified our prediction that the interaction effect can be generalizable to NPD and PD presented in the loss domain. These findings also enhanced the internal validity of the interaction effect by demonstrating the causal link between expectation and cooperation. Second, we found that the effect of framing on cooperation was again moderated by game riskiness such that people cooperated more in the gain domain than in the loss domain only within more-risky PDs and risk-neutral PDs, but not within less-risky PDs. Third, we found that both game riskiness and index of cooperation can predict cooperation. Although the index of cooperation influenced cooperation rather directly, game riskiness impacted cooperation through interacting with expectation. Finally, we found that the greed index negatively predicted cooperation, but the fear index did not.

8.2. Linking game riskiness to other indices

We orthogonally manipulated game riskiness and the index of cooperation and found that when considering the main effects, both the index of cooperation and game riskiness predicted cooperation. However, game riskiness, but not the index of cooperation, interacted with expectation to influence cooperation. These findings suggested that there are two major components that can independently affect cooperation in PDs: (1) the degree of conflict of interest, as indicated by the index of cooperation, and (2) the variance of cooperation and defection outcomes, as indicated by the game riskiness index, and the latter component is contingent upon expectation.

This article also illustrated how game riskiness is related to the fear and greed indices. We showed that when the index of cooperation is kept constant, the game riskiness index is positively associated with the fear index but negatively associated with the greed index. In other words, more-risky PD has a relatively high value of fear index but a low value of greed index, while less-risky counterpart has a relatively low value of fear index but a high value of greed index. In previous experiments that studied fear and greed, manipulating either fear or greed can simultaneously change the degree of conflict of interest of the PDs (e.g., Ahn et al., 2001). The game riskiness index can thus provide a way for researchers of fear and greed to alter fear and greed simultaneously while keeping the index of cooperation unchanged.

Understanding the relations between these indices can also provide us insights into the underlying motivations of cooperation and defection under different expectations. Although two PDs may have a similar tendency to elicit cooperation, the same decisions in the two PDs may be driven by different motivations. A person may choose defection in one PD with a high fear index because he or she is fear of being exploited, but he or she may choose defection in another PD with a high greed index because he or she is tempted to be greedy. Together with our main finding that people under low expectation cooperated more in less-risky PD while people under high expectation cooperated more in more-risky PD, we can infer that while fear (rather than greed) could be the major motivation causing people to defect in more-risky PD under low expectation, greed (rather than fear) could be the major motivation leading individuals to defect in less-risky PD under high expectation.

Interestingly, although the game riskiness index, fear index, and greed index in Study 2 were very highly correlated with each other ($|r| \geq 0.89$), we found that the game riskiness index and greed index predicted cooperation, but the fear index did not. This is in line with Stivers et al. (2017) who suggested that the game riskiness index, fear index, and greed index fell into different categories of indices and hence should drive different behavioral consequences. Our mathematical illustration and empirical findings together suggested that these indices are closely related but distinct from each other.

8.3. Implications on social dilemmas and cooperation research

The results of this article have significant contribution to the theories of social dilemmas. The goal/expectation hypothesis states that people will be likely to cooperate if they have the goal of achieving the optimal collective outcome and they expect that the others will cooperate (Pruitt & Kimmel, 1977). Also, the social projection hypothesis states that 'people cooperate inasmuch as they believe others respond to the situation as they themselves do' (Krueger et al., 2012). Our findings added that the relative riskiness of cooperation versus defection can influence the predictive power of these hypotheses.

Balliet and Van Lange (2013) found in a meta-analysis that the effect of trust on cooperation was moderated by the degree of conflict, which is operationalized using the index of cooperation. That is, they found that the positive effect of expectation on cooperation was stronger when the index of cooperation is lower, and concluded that trust is particularly important in determining behavior under situations of high conflict of interests. We did not find a significant expectation × index of cooperation interaction effect on cooperation, but instead found a robust expectation × game riskiness interaction effect on cooperation. This discrepancy may be because we orthogonally manipulated the index of cooperation and game riskiness, while the two indices may be confounded with each other in Balliet and Van Lange (2013). Future meta-analyses can be conducted to examine whether game riskiness or index of cooperation (or both) can moderate the trust-cooperation link when statistically controlled for each other. Still, our findings can contribute to the existing literature that aside from conflict of interests, the variance of cooperation and defection outcomes can also alter the trust-cooperation linkage.

The findings of this article also suggested that apart from the index of cooperation, researchers should also consider game riskiness when constructing PD games if the research topic is related to trust, beliefs, and expectations. It is particularly important if the effect sizes of the relations between trust and cooperation are the main interest. For instance, researchers studying interpersonal trust may want to select PDs with mediocre game riskiness or statistically control for game riskiness so as to avoid game riskiness being a confound of the effects of interest. It may also be useful to consider game riskiness even if the topic is beyond trust and expectation. For instance, when researchers study cooperation in very competitive contexts where interpersonal trust is low, selecting less-risky PDs as experimental stimuli may be preferred in order to avoid the floor effect, because we showed that under low expectation, individuals cooperated more in less-risky PDs.

Different indices of PD have been used to reveal the underlying mechanisms of how personality traits and hormones can influence cooperation. For example, Hilbig et al. (2018) utilized PDs with different indexes of cooperation to reveal that temptation was a potential motivator of defection among those low in honesty-humility. De Dreu et al. (2010) manipulated the fear and greed indices of PD and demonstrated that oxytocin promoted defensive rather than offensive aggression toward out-groups. It is possible that game riskiness can also be utilized in similar ways to study mechanisms of cooperation. For instance, there has been inconsistent evidence of how testosterone can influence risk aversion (e.g., Apicella et al., 2015; Stanton et al., 2011), and how it can influence cooperation and aggression (e.g., Van Honk et al., 2012; Yang et al., 2021). By studying how testosterone can influence cooperation across PDs with different game riskiness, it may provide insights into how testosterone can impact interpersonal decisions under risk. Future studies can explore how game riskiness can be adopted to understand human cooperation. Finally, given the robust game riskiness × expectation interaction effect on cooperation, researchers may explore the possibility of enhancing cooperation through changing people's perceived riskiness of cooperation in daily life mixed-motive conflicts in the future.

8.4. Conclusion

Despite sharing the same criteria of T > R > P > S, a PD can elicit very different responses depending on its game riskiness index, index of cooperation, and greed index. The game riskiness index can even

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alter the strongly positive expectation-cooperation link. We strongly encourage researchers who study cooperation to carefully select the payoff matrices of PD based on the variables of interest and to continue exploring how different indices of PD can be utilized to advance our understanding of human cooperation.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/jdm.2024.21.

Data availability statement. The data of the studies described in this article are available in the OSF at https://osf.io/5mhdn/.

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Competing interest. The authors declare none.

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Appendix A. An illustration of the relations between game riskiness, expectation, and the expected value of cooperation and defection in NPD

The expected value of cooperation in an NPD is given by

$$S' + \frac{e\,(R' - S')}{N - 1}$$

and the expected value of defection is given by

$$P' + \frac{e\,(T' - P')}{N - 1}$$

where e is the player's expectation of the number of other players choosing cooperation and N is the total number of players in the group.

In every PD, the expected value of defection is always greater than that of cooperation regardless of the expectation. However, we reason that the smaller the difference between expected value of defection and that of cooperation, the greater the likelihood that one will choose cooperation. It is because when such difference is smaller, one can benefit less from defection, compared to cooperation. The difference between the expected value of defection and that of cooperation (y) is given by

$$\begin{aligned} y &= \left[P' + \frac{e\,(T' - P')}{N - 1}\right] - \left[S' + \frac{e\,(R' - S')}{N - 1}\right] \\ &= \frac{e\,[(T' - P') - (R' - S')]}{N - 1} + P' - S' \end{aligned}$$

In order to examine how y changes when e changes, we differentiate y with respect to e.

$$y' = \frac{(T' - P') - (R' - S')}{N - 1}$$

If the value of y' is positive, it means that when expectation increases, the difference between the expected value of defection and that of cooperation increases. Conversely, if the value of y' is negative, it means that when expectation increases, y decreases.

Similar to the two-person PD, we can construct a game riskiness index r' such that

$$r' = \frac{R' - S'}{(R' - S') + (T' - P')}$$

We can see that in more-risky PD such that r' is greater than 0.5, the value of $R' - S'$ is greater than that of $T' - P'$. Hence, y' would be negative regardless of the value of N. In other words, when expectation increases, the defection choice becomes less attractive relative to the cooperation choice. Conversely, in less-risky PD such that r' is less than 0.5, the value of $R' - S'$ is smaller than that of $T' - P'$. Hence, y' would be positive regardless of the value of N. In other words, when expectation increases, the defection choice becomes more attractive relative to the cooperation choice. Therefore, although expectation is positively related to cooperation, game riskiness should moderate this relation. Specifically, the effect of expectation on cooperation should be stronger for more-risky PD than the less-risky counterparts.

Importantly, from the above mathematical illustration, the prediction can be applied to PDs of any group size theoretically, because the number of players in a group does not alter the sign of y'. Therefore, we predict that the findings obtained from a two-person PD can be generalized to a PD of any group size.

Appendix B. Relation between game riskiness index, fear index, and greed index

By definition,

$$\begin{aligned} r &= \frac{R - S}{(R - S) + (T - P)} \\ K &= \frac{R - P}{T - S} \\ F &= \frac{P - S}{T - S} \\ G &= \frac{T - R}{T - S} \end{aligned}$$

If K is kept constant, then we can write $R - P = c\,(T - S)$, for some constant c. Consequently, r can be expressed as

$$\begin{aligned} r &= \frac{R - S}{(R - S) + (T - P)} \\ &= \frac{(R - P) + (P - S)}{(R - P) + (T - S)} \\ &= \frac{c\,(T - S)}{(1 + c)\,(T - S)} + \frac{P - S}{(1 + c)\,(T - S)} \\ &= \frac{c}{1 + c} + \frac{F}{1 + c} \end{aligned}$$

which shows that r is a monotonically increasing function of F when K is kept constant. In a similar vein, we have

$$\begin{aligned} r &= \frac{R - S}{(R - S) + (T - P)} \\ &= \frac{(T - S) - (T - R)}{(R - P) + (T - S)} \end{aligned}$$

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$$= \frac{T - S}{(1 + c)\,(T - S)} - \frac{T - R}{(1 + c)\,(T - S)}$$
$$= \frac{1}{1 + c} - \frac{G}{1 + c}$$

which shows that r is a monotonically decreasing function of G when K is kept constant.

If $r = 0.5$, then

$$2\,(R - S) = T + R - P - S$$
$$P - S = T - R$$
$$\frac{P - S}{T - S} = \frac{T - R}{T - S}$$
$$F = G$$

Appendix C. List of the 20 sets of PD outcomes that were used to create the NPD payoff matrices in Study 1, and their corresponding expectation and cooperation rate

Game	*T′*	*R′*	*P′*	*S′*	r	K	EC	Coop
1	510	502	342	110	0.70	0.40	0.38	0.23
2	460	451	307	100	0.70	0.40	0.37	0.21
3	132	130	100	57	0.70	0.40	0.43	0.28
4	158	156	116	58	0.70	0.40	0.40	0.27
5	321	315	219	81	0.70	0.40	0.42	0.25
6	202	198	132	37	0.70	0.40	0.42	0.28
7	196	194	154	96	0.70	0.40	0.38	0.26
8	200	197	145	70	0.70	0.40	0.38	0.24
9	162	159	103	22	0.70	0.40	0.32	0.20
10	455	446	302	95	0.70	0.40	0.40	0.27
11	510	278	118	110	0.30	0.40	0.27	0.12
12	460	253	109	100	0.30	0.40	0.29	0.10
13	173	130	100	98	0.30	0.40	0.38	0.19
14	214	156	116	114	0.30	0.40	0.33	0.20
15	321	183	87	81	0.30	0.40	0.28	0.10
16	293	198	132	128	0.30	0.40	0.30	0.10
17	196	138	98	96	0.30	0.40	0.37	0.13
18	272	197	145	142	0.30	0.40	0.35	0.15
19	240	159	103	100	0.30	0.40	0.34	0.10
20	455	248	104	95	0.30	0.40	0.28	0.08

Note: Values were corrected to two decimal places, whenever necessary. *EC* and *Coop* were averaged over the four experimental conditions. All the monetary values presented in this article are in Hong Kong Dollars (1 HK$ ≈ 0.13 US$). *Abbreviation: T′, temptation outcome; R′, reward outcome; P′, punishment outcome; S′, sucker outcome; r, game riskiness index; K, index of cooperation; EC, mean of expectation for each game; Coop, cooperation rate for each game.*

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Appendix D. Payoff matrices of the 5-person PDs for Study 1

		Number of other players choosing cooperation				
Game	Choice	0	1	2	3	4
1	Cooperation	110	208	306	404	502
	Defection	342	384	426	468	510
2	Cooperation	100	188	276	363	451
	Defection	307	345	384	422	460
3	Cooperation	57	75	94	112	130
	Defection	100	108	116	124	132
4	Cooperation	58	83	107	132	156
	Defection	116	127	137	148	158
5	Cooperation	81	140	198	257	315
	Defection	219	245	270	296	321
6	Cooperation	37	77	118	158	198
	Defection	132	150	167	185	202
7	Cooperation	96	121	145	170	194
	Defection	154	165	175	186	196
8	Cooperation	70	102	134	165	197
	Defection	145	159	173	186	200
9	Cooperation	22	56	91	125	159
	Defection	103	118	133	147	162
10	Cooperation	95	183	271	358	446
	Defection	302	340	379	417	455
11	Cooperation	110	152	194	236	278
	Defection	118	216	314	412	510
12	Cooperation	100	138	177	215	253
	Defection	109	197	285	372	460
13	Cooperation	98	106	114	122	130
	Defection	100	118	137	155	173
14	Cooperation	114	125	135	146	156
	Defection	116	141	165	190	214
15	Cooperation	81	107	132	158	183
	Defection	87	146	204	263	321
16	Cooperation	128	146	163	181	198
	Defection	132	172	213	253	293
17	Cooperation	96	107	117	128	138
	Defection	98	123	147	172	196
18	Cooperation	142	156	170	183	197
	Defection	145	177	209	240	272
19	Cooperation	100	115	130	144	159
	Defection	103	137	172	206	240
20	Cooperation	95	133	172	210	248
	Defection	104	192	280	367	455

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Appendix E. Payoff values of the 48 PD games and their corresponding expectation and cooperation rate in Study 2

Game	T	R	P	S	r	K	F	G	EC	Coop
1	340	206	116	110	0.30	0.39	0.03	0.58	0.54	0.39
2	340	203	123	110	0.30	0.35	0.06	0.60	0.52	0.35
3	340	200	130	110	0.30	0.30	0.09	0.61	0.53	0.39
4	340	197	137	110	0.30	0.26	0.12	0.62	0.51	0.38
5	340	194	144	110	0.30	0.22	0.15	0.63	0.54	0.36
6	340	191	151	110	0.30	0.17	0.18	0.65	0.49	0.26
7	340	188	158	110	0.30	0.13	0.21	0.66	0.46	0.26
8	340	185	165	110	0.30	0.09	0.24	0.67	0.50	0.27
9	340	270	180	110	0.50	0.39	0.30	0.30	0.53	0.42
10	340	265	185	110	0.50	0.35	0.33	0.33	0.52	0.38
11	340	260	190	110	0.50	0.30	0.35	0.35	0.55	0.43
12	340	255	195	110	0.50	0.26	0.37	0.37	0.51	0.32
13	340	250	200	110	0.50	0.22	0.39	0.39	0.52	0.36
14	340	245	205	110	0.50	0.17	0.41	0.41	0.50	0.31
15	340	240	210	110	0.50	0.13	0.43	0.43	0.50	0.34
16	340	235	215	110	0.50	0.09	0.46	0.46	0.45	0.30
17	340	334	244	110	0.70	0.39	0.58	0.03	0.61	0.50
18	340	327	247	110	0.70	0.35	0.60	0.06	0.51	0.38
19	340	320	250	110	0.70	0.30	0.61	0.09	0.58	0.44
20	340	313	253	110	0.70	0.26	0.62	0.12	0.49	0.32
21	340	306	256	110	0.70	0.22	0.63	0.15	0.55	0.40
22	340	299	259	110	0.70	0.17	0.65	0.18	0.49	0.30
23	340	292	262	110	0.70	0.13	0.66	0.21	0.50	0.36
24	340	285	265	110	0.70	0.09	0.67	0.24	0.46	0.30
25	−110	−244	−334	−340	0.30	0.39	0.03	0.58	0.49	0.37
26	−110	−247	−327	−340	0.30	0.35	0.06	0.60	0.52	0.39
27	−110	−250	−320	−340	0.30	0.30	0.09	0.61	0.53	0.39
28	−110	−253	−313	−340	0.30	0.26	0.12	0.62	0.48	0.26
29	−110	−256	−306	−340	0.30	0.22	0.15	0.63	0.50	0.33
30	−110	−259	−299	−340	0.30	0.17	0.18	0.65	0.48	0.30
31	−110	−262	−292	−340	0.30	0.13	0.21	0.66	0.46	0.26
32	−110	−265	−285	−340	0.30	0.09	0.24	0.67	0.46	0.30
33	−110	−180	−270	−340	0.50	0.39	0.30	0.30	0.51	0.34
34	−110	−185	−265	−340	0.50	0.35	0.33	0.33	0.50	0.33
35	−110	−190	−260	−340	0.50	0.30	0.35	0.35	0.53	0.38
36	−110	−195	−255	−340	0.50	0.26	0.37	0.37	0.46	0.30
37	−110	−200	−250	−340	0.50	0.22	0.39	0.39	0.49	0.31
38	−110	−205	−245	−340	0.50	0.17	0.41	0.41	0.47	0.26
39	−110	−210	−240	−340	0.50	0.13	0.43	0.43	0.49	0.25
40	−110	−215	−235	−340	0.50	0.09	0.46	0.46	0.46	0.24
41	−110	−116	−206	−340	0.70	0.39	0.58	0.03	0.54	0.45
42	−110	−123	−203	−340	0.70	0.35	0.60	0.06	0.49	0.33

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Game	T	R	P	S	r	K	F	G	EC	Coop
43	−110	−130	−200	−340	0.70	0.30	0.61	0.09	0.55	0.44
44	−110	−137	−197	−340	0.70	0.26	0.62	0.12	0.46	0.30
45	−110	−144	−194	−340	0.70	0.22	0.63	0.15	0.53	0.38
46	−110	−151	−191	−340	0.70	0.17	0.65	0.18	0.46	0.25
47	−110	−158	−188	−340	0.70	0.13	0.66	0.21	0.50	0.33
48	−110	−165	−185	−340	0.70	0.09	0.67	0.24	0.45	0.26

Note: Values were corrected to two decimal places, whenever necessary.
Abbreviations: T, temptation outcome; R, reward outcome; P, punishment outcome; S, sucker outcome; *r*, game riskiness index; K, index of cooperation; F, fear index; G, greed index; EC, mean of expectation for each game; Coop, cooperation rate for each game.

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