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The Role of Subsidies in Coordination Games with Interconnected Risk

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ABSTRACT

Can subsidies promote Pareto-optimum coordination? We found that partially subsidizing the cooperative actions for two out of six players in a laboratory coordination game usually produced better coordination and higher total social welfare with both deterministic and stochastic payoffs. Not only were the subsidized players more likely to cooperate (choose the Pareto-optimum action), but the unsubsidized players increased their expectations on how likely others would cooperate, and they cooperated more frequently themselves. After removal of the subsidy, high levels of coordination continued in most groups with stochastic payoffs but declined in deterministic ones. This carry-over disparity between the deterministic and stochastic settings was consistent with the economic theories that agents were more likely to keep the status quo option under uncertainty than without uncertainty. Hence, players with stochastic payoffs were more likely to keep the high coordination level (status quo) brought by the subsidy in the previous subsidy session. A post-game survey also indicated that with stochastic payoffs, players focused on risk reduction. Temporary subsidies promoted lasting coordination because even after subsidy was removed, players still assumed that others players would prefer reduced risks from cooperation. With deterministic payoffs, however, the subsidy might crowd out other rationales for coordination, with many players indicating that the subsidy was the only reason for anyone to cooperate. Hence, the coordination level dropped when the subsidy was removed.

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KEY WORDS group cooperation; subsidy; risk; Pareto-ranked Nash equilibrium

INTRODUCTION

Social actions are often interdependent. In many situations, including interactive games or social networks, people often form expectations on what others will do and reinforce each other's decision on the basis of past experience. Social psychology research on social interactions dates back to social exchange theory, which suggests that social change and stability are a process of negotiated exchanges, and human relationships are guided by cost–benefit analysis and alternative comparison (Kelley & Thibaut, 1978; Thibaut & Kelley, 1959).

The majority of research on social interaction games has focused on social dilemmas in which individual and collective interests usually conflict with each other. In the current study, we investigate a different kind of social interaction than the well-studied social dilemma games, namely coordination games. Unlike social dilemmas, in a coordination problem, people can realize mutual gains but only by making mutually consistent decisions. That is, there are solutions in which individual and collective interests are aligned. A classic coordination game is to the decision on which side of the road to drive.

Many coordination problems have multiple equilibria. For example, the left side or right side of the road can be two equilibria that work equally well as long as all drivers choose the same side. Sometimes, the equilibria are Pareto-ranked with one being better than the others. An example of a Pareto-ranked coordination game is the interdependency among airlines with respect to baggage security (Kunreuther & Heal, 2003). Airline companies have to choose whether to invest in baggage security screening equipment. Such an investment reduces the risk of bombs in bags checked on their own airline, but each company still faces indirect risks of unsafe bags transferred from other airlines that did not invest in the screening equipment. The Pareto-optimal Nash equilibrium (NE) is that all airlines invest in security systems. An inferior NE is that no airline invests, because each believes that the indirect risk from unsafe airlines is so high that the benefits from investing in protection are less than the costs. Kunreuther and Heal (2003) referred to this risk interdependency as the interdependent security game. Other instances of interdependent security include wildfire protection decisions (Shafran, 2008), computer network security updates (Kearns, 2005), and the failure of divisions in financial organizations to control risk (Kunreuther, 2009; Kunreuther & Heal, 2005).

Another real-world coordination example is the garbage disposal decisions faced daily by households in some communities in China. Often 20–30 households share a garbage bin near their apartment building. However, some households leave their garbage outside the bin. This behavior may affect others in at least three ways. First, as garbage left outside accumulates, others must wade through it in order to dump their own garbage inside the bin; this imposes an extra cost. Second, the behavior signals that littering is acceptable in this community, thus reducing the psychological influence of a social norm for public cleanliness. Third, the goal of public cleanliness, even if still valued by some, may seem unattainable so that it is not worth exerting

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effort to try and meet it. The resulting NE is the situation where everyone leaves their garbage outside. Whereas most people prefer the NE in which everyone places their garbage inside the bin, with a cleaner environment at slightly additional cost, the inferior NE of littering outside the bin is so common in China that during the 2008 Beijing Olympic season, one of the public slogans the government circulated was “Learn to be Civilized and Dump your Garbage in the Bin.”

Note the difference between the garbage bin and the airline security examples. Airline security investment is a coordination game in a stochastic setting: Outcomes depend not only on the degree of cooperation (how many airlines invest in protection) but also on low-probability high-impact moves by “nature” (terrorist attacks). The garbage disposal coordination involves deterministic outcomes, which depend only on the degree of coordination, that is, the number of households who leave garbage outside the bin. Other deterministic examples with Pareto-ranked equilibria include hiring private tutors for one’s children for them to achieve better grades than others in their class or using commercial software instead of open source software.

Because of the existence of multiple equilibria in coordination games, solving a coordination problem is often an empirical question that has no theoretical solution. Which equilibrium to reach depends on each individual’s expectation on what actions other individuals will take. For example, if an individual predicts that others will choose the Pareto-optimal action, then a rational individual will choose that action too, because it has the best interest both individually and collectively. Thus the system will reach the Pareto-optimal equilibrium. Communicating with each other is one way to achieve such an equilibrium.

Often we face situations where coordination problems have to be solved without the ability to pass one’s intention to each other. In those circumstances, some equilibria are often reached because they have greater natural salience and/or are more consistent with rules or social norms. For example, Schelling (1960) asked people if they are one of two individuals trying to meet each other in New York without communicating, where they will meet. Any location is a good equilibrium, as long as both individuals choose the same place. With the numerous equilibrium locations in New York, most people choose the Grand Central Station, because it provides a “focal point for each person’s expectation of what the other expects him to expect to be expected to do” (Schelling, 1960, p. 57).

Not all coordination problems have a natural focal point as in the preceding example. Empirically, it has always been a challenge to predict which equilibrium a system will reach or to intervene so that the preferable equilibrium is more likely to be reached. Previous research has tested various ways to encourage coordination, such as developing rules and social norms (Goeree & Holt, 2002), lowering the attractiveness of the inferior action (Brandts & Cooper, 2004), downscaling group size (Van Huyck, Battalio, & Rankin, 2007), and increasing communication and information sharing (Chaudhuri, Schotter, & Sopher, 2009; Van Huyck, Battalio, & Beil, 1993).

One potentially powerful but understudied approach to improve coordination is to take advantage of positive network externalities, that is, the benefits received by an individual from the actions of other in the same network, which is a common feature in coordination games. For this reason, positive decisions by a few individuals are likely to lead others to follow suit. Thus theoretically, a coordination problem can switch from an inferior equilibrium to the optimal one, if a subgroup of individuals is incentivized/subsidized to change their actions, causing others to do the same (Heal & Kunreuther, 2010; Shafran, 2010[1]; Zhuang, Bier, & Gupta, 2007).

The current study uses a subsidy to change a subset of individuals’ actions, which in turn affects other individuals’ expectations and decisions, and eventually leads to a preferable equilibrium. We found that partially subsidizing two out of six players in a laboratory coordination game usually produced greater coordination and higher total payoffs than when subsidies were not provided. This was especially noticeable in a stochastic setting where a subsidy had a significant effect in tipping some groups to the Pareto-optimum equilibrium. After removal of the subsidy, high levels of coordination continued in most groups with stochastic payoffs but declined with deterministic ones. This finding is consistent with the economic theories that the status quo bias was stronger under uncertainty than without uncertainty (Bewley, 1986; Ortoleva, 2010). A post-game survey also suggested that there were differences in the deterministic and stochastic games in terms of how subsidy affected intrinsic motivations for cooperation.

EXPERIMENTAL DESIGN

General setup

An additional complication arises in coordination games characterized by the presence of uncertainty, as illustrated by contrasting the airline security and garbage disposal scenarios. In a stochastic setting, the decisions of the agents depend on both their expectation of others’ actions and their own risk preferences. Previous research has found that people behave differently in a stochastic game than in a deterministic game. For example, Berger and Hershey (1994) found participants less likely to contribute to a public good when returns are stochastic than known with certainty. Bereby-Meyer and Roth (2006) reported that people’s learning to cooperate in a prisoner’s dilemma game is reduced when the payoffs are noisy. Gong, Baron, and Kunreuther (2009) reported that individuals are less cooperative than groups in deterministic prisoner’s dilemma games but more cooperative than groups when the outcomes are stochastic.

Given these observed differences between the stochastic and deterministic settings, we suspect that there also exist significant differences between coordination under uncertainty

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[1] Shafran (2010) also attempted to test the subsidy effect empirically in coordination games. However, the experiment design in Shafran (2010) is such that the two subsidized players are removed from the original seven-player play, and the game becomes a five-player game. In other words, Shafran (2010) removed the function of expectation, which is an essential factor in determining which equilibrium to reach. Hence, instead of testing the actual perception and behavior change of players caused by the introduction of the subsidy, the design in Shafran (2010) tests the differences of two coordination games with different number of players, seven-player game versus five-player game. Their results are consistent with those of previous research that reducing the number of players increases the coordination level (Goeree & Holt, 2002; Van Huyck et al., 2007).

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and no uncertainty. Hence we empirically studied subsidy effects in both types of games. The stochastic game is based on the interdependent security game and social reinforcement model (Heal & Kunreuther, 2010; Kunreuther & Heal, 2003), in which n players each need to make a discrete decision, option A or B. All players face the possibility of a local security breach with probability p of losing L. Option A can eliminate the risk of a local breach at a cost of C. A player also faces possible interdependent security breaches, that is, cross breaches from other players. If any player suffers a loss, all other players have a probability q of being contaminated and losing L. Players can only suffer the loss once, from either the local breach or the cross breach. Each player's initial wealth is Y.

Let $\pi(i, m)$ denote the payoff of a player who chooses strategy i when m out of $n-1$ other players choose strategy A, and $i \in \{A,B\}$. The player's expected payoff for choosing A or B when no other players choose A is given respectively by

$$\pi(A, O) = Y - C - \left\{ q \prod_{t=0}^{n-2} (1-q)^t \right\} L \tag{1}$$

and

$$\pi(B, O) = Y - \left\{ p + (1-p) q \prod_{t=0}^{n-2} (1-q)^t \right\} L \tag{2}$$

On the other hand, if all other players choose A, then

$$\pi(A, n-1) = Y - C \tag{3}$$

and

$$\pi(B, n-1) = Y - pL \tag{4}$$

In a coordination game, $\pi(A,0) < \pi(B,0)$, and $\pi(A,n-1) > (B,n-1)$. That is, a rational and risk-neutral agent will choose A (B) if all other players choose A (B). Thus there are two pure strategy Pareto-ranked NEs, all-A and all-B. All-A is the preferable equilibrium. Depending on the values of the parameters, there is a tipping point s at which $\pi(A,s) \geq \pi(B,s)$ and $\pi(A, s-1) < \pi(B, s-1)$.

The coordination games

Six players played the games presented in Table 1 or 2. The values of the parameters are chosen to satisfy the following conditions: (i) the game is a coordination game with two pure strategy Nash equilibria, one being superior to the other; (ii) there exists a tipping point at which changing one player's decision can tip the entire system from one equilibrium to the other one; (iii) the tipping point is such that it is possible to partially subsidize a subset of the tipping set to test the effectiveness and efficiency of partial subsidy; (iv) the group size is large enough so that no player can infer whether a particular player was subsidized or not in the previous round and yet small enough to recruit sufficient participants; (v) per Institutional Review Board's request, there can be no negative payment in a worst scenario after 20 periods. After taking into consideration the difficulty of gathering multiple players simultaneously in the lab and the cost effectiveness of data collection, we decided that the best small group that satisfies all the above was a six-player group with a tipping point at four.

There were two pure strategy NEs, all choosing A or all choosing B.[2] The tipping point was four, or the tipping subset is for four players to choose A. That is, if four or more players chose A, a player had a higher expected payoff by also choosing A rather than B. Otherwise, the player should choose B. A fictitious currency (Talers) was used with 50 Talers equal to \$1. The parameters in our game were $p = .4$, $q = .2$, $Y = 2000$ Talers (exchangeable for \$40), $C = 32$ Talers, $L = 100$ Talers, $n = 6$, and $s = 4$. Table 1 shows a player's probabilities of suffering a loss when she chose A or B as a function of other players' decisions.

As shown in Figure 1, the expected loss by choosing option B is less than the expected loss (including the cost of choosing A) of option A until at least four players choose A. Theoretically if less than four players choose A, the system tips to the Pareto-inferior equilibrium, all-B. Otherwise, the system converges to the Pareto-superior equilibrium, all-A. Both equilibria were observed in our study. There is a third line in Figure 1 that represents the expected loss from option A for subsidized players. The subsidy was set to 22 Talers. That is, those who are subsidized pay 10 Talers to play option A instead of 32 Talers. For a risk-neutral subsidized player, the expected loss of option A is always less than that of option B.

To create a corresponding deterministic game, we removed the uncertainty of payoffs in the stochastic game and provided players with the expected value of each cell in the stochastic game, as described in Table 2.

Four conditions

A 2 × 2 between-subject design, (subsidy vs. baseline) × (stochastic game vs. deterministic game), allowed us to test the effect of a subsidy in promoting the Pareto-optimum equilibrium in coordination games and to look for an interaction between providing a subsidy and behavior in either the stochastic or deterministic setting.

As in most coordination studies, we ran repeated games to allow for learning and convergence to the equilibria. The same six players played 20 periods of the same game in a session. Each player was given 2000 Talers at the beginning of the session. As shown in Table 1, in each period, a player's probability of suffering a 100-Taler loss, $X\%$, depended on both their own and other players' decisions. The server computer then generated a random number between 0 and 100. If the random number was smaller than or equal to the value of X, the player lost 100 Talers. The losses over the 20 periods were accumulated and deducted from players' initial wealth. Before making their decision between options A and B in each period, players also indicated how many other players they expected to choose A.

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[2] There is also a mixed strategy NE, with all players choosing A 78.23% of the time and choosing B 21.67% of the time.

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Table 1. Probabilities of losing 100 Talers in the stochastic game

		Number of other players who choose option *A*					
		0	1	2	3	4	5
Your choice	Option *A* (cost = 32)	67%	59%	49%	36%	20%	0%
	Option *B* (cost = 0)	80%	75%	69%	61%	52%	40%

Table 2. Possible losses in the deterministic game

		Number of other players who choose option *A*					
		0	1	2	3	4	5
Your choice	Option *A* (cost = 32)	−67	−59	−49	−36	−20	0
	Option *B* (cost = 0)	−80	−75	−69	−61	−52	−40

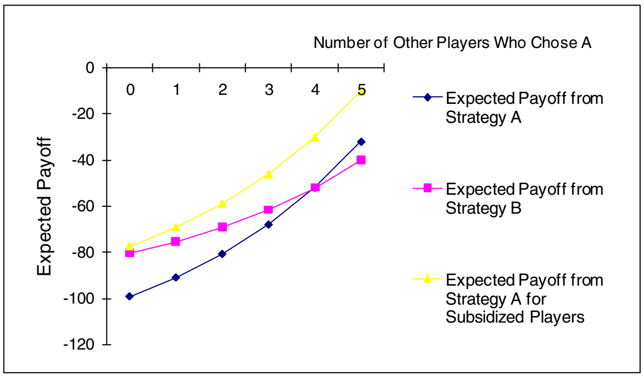

Figure 1. Expected payoffs in the coordination game. Negative numbers indicate losses

After each period *t*, players were given information on their loss, their accumulated losses, wealth level, and the number of players choosing *A* in all past periods, including period *t*.

In the subsidy conditions, in each period, two out of the six players were randomly chosen to receive the subsidy (paying 10 Talers for *A* instead of the full cost of 32 Talers), should they decide to choose *A*. Note that it was a partial subsidy allocated to only two players (which is half of the tipping subset of four players choosing *A*). As will be discussed later in the paper, we believe that the subsidy will change not only the subsidized players' expectation and behavior, but also those of the unsubsidized ones. Hence, it is likely to be more cost effective to apply partial subsidies to a few individuals in the tipping subset than to apply a full subsidy to the entire tipping subset. The subsidy amount and the number of subsidized players in the tipping subset will both have an impact on what others decide to do. The optimal combination depends on multiple factors: the parameters in the game, the nature of the problem, and the decision process of the specific groups. Identifying the optimal combination is beyond the scope of the current study and can be an interesting extension for future research.

As a subsidy involves a positive cost to the policy makers, it would be interesting to test whether the subsidy-generated high coordination level sustains after the subsidy is removed. We tested whether there was a carry-over effect of a subsidy by running a second session in each condition. At the beginning of Session 2, players' wealth levels were restored to 2000 Talers. The same six subjects played the same type of game (stochastic or deterministic) for another 20 rounds with the subsidy removed for those who were given a subsidy in Session 1 and the subsidy added for those who were in the baseline conditions in Session 1. Players were not aware of the existence of Session 2 until they finished Session 1.

Participants and procedure

Two hundred ninety-four people (49 six-person groups) participated in the study; 82% of participants were between 18 and 25 years old, and 62% were female. All were paid $10 for showing up. Twenty percent of the players were randomly chosen to be paid the dollar values of the Talers they earned at the end of the study. The data collection for Group 8 could not be completed because of a mechanical failure. All data analyzed in this paper are from the remaining 48 groups.

The study was conducted in the behavioral labs of two Northeastern universities using Z-tree, a software package for developing economic experiments (Fischbacher, 2007). Each player was provided with a personal computer to make his or her decisions, with the computers of the six group members in the same room but in separate cubicles to provide anonymity. Participants were not allowed to talk to each other. Instructions were read aloud to ensure that the rules and payoff structure of the game were common knowledge, an important consideration in examining how players formed their expectation of other players' decisions.

After reading the instructions and before playing the game, all participants were required to complete a quiz that contained questions regarding the game, the procedure, decision method, and payment information. At the end of the experiment, participants answered questions on demographics, their reasons for choosing *A* or *B*, and the Holt and Laury survey that measured their risk preference (Holt & Laury, 2002).

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HYPOTHESES AND RESULTS

Hypotheses

We believe that subsidy affected the game in two ways. First, it changed the payoff structure of the subsidized players and incentivized them to choose *A*. Second, the behavior change in the subsidized players had an effect on the expectation and behavior of all players. Heal and Kunreuther (2010) showed that, theoretically, changes in the decisions by a tipping set can shift a system from one equilibrium to another. External incentives given to an appropriate set of players can lead to cascading or tipping so the system reaches the socially optimal equilibrium. Hence, we hypothesize the following:

> H1 (General subsidy effect hypothesis): *There is a higher coordination level with a subsidy than without a subsidy.*

As discussed before, expectation plays a vital role in determining which equilibrium to reach. We further hypothesize that subsidy affects the players' decision by changing their expectations on how many of the other players will choose *A*, that is, expectation is a mediator variable between subsidy and coordination level. With two players being partially subsidized, all players adjust their expectations, with the information that the two subsidized players are more likely to choose *A* than without subsidy. However, there is no guarantee that the subsidized players will choose *A* for at least two reasons. First, the trembling hand theory (Selten, 1975) predicts that players may choose unintended strategies through a "slip of hand" or tremble. That is, a subsidized player may accidently chooses *B*, although her intends to choose *A*. Second, individual differences in risk reference indicate that the subsidized players may choose different strategies from each other. Although we expect that the majority of the subsidized players will choose *A*, a subsidized player may opt for *B* if she is risk seeking enough and is unwilling to pay for the subsidized cost (10 Talers) for *A* to reduce risk. On the basis of the expectation adjustment, the players change their strategy and observed behavior. Formally, we will use Sobel's test (Sobel, 1982) to statistically test the following expectation mediation hypothesis.

> H1a: *Expectation is a mediator variable between subsidy and coordination level.*

It is also instructive to ask whether the expectations regarding the cooperation rate differed between subsidized and unsubsidized players. The rational theory predicts that the unsubsidized players would increase their expectation of the coordination rate when realizing that the two subsidized players would probably choose option *A*. The subsidized players would also predict a higher coordination rate for the same reason. Bounded rationality with its acknowledgement of finite attention and limited information processing capacity (e.g., Simon, 1957) predicts that the effect of a subsidy would be more salient to the subsidized players than to the unsubsidized players, because the subsidized players were personally experiencing it. In contrast, the unsubsidized players were told that the others were able to incur a lower cost of investing in *A* than they were; they thus would be expected to see the subsidy as a changed set of game rules (Hertwig, Barron, Weber, & Erev, 2004).

> H1b (Rational theory hypothesis): *Unsubsidized players have higher expectation in the subsidy condition than in the baseline condition.*

> H1c (Bounded rationality hypothesis): *In the subsidy condition, the subsidized players have a higher expectation on the number of other players choosing A than the unsubsidized players.*

Besides the aforementioned general subsidy effects, we also tested the subsidy carry-over effect. Previous research has reported mixed result on the sustainability of the subsidy effect. For example, operant conditioning (Skinner, 1972) research suggests that rewards and punishments influence behavioral patterns and eventually form new habitual behavior. In a recent field study, Charness and Gneezy (2009) paid university students to visit the gym, and attendance rate was improved both during and after the intervention. Similar long-term effect was reported by Levitt, List, and Sadoff (2010a, 2010b) in which financial incentives were provided to students for better performance, and those students continued to outperform the control-group peers after the incentive ended. In our study, subsidy encourages coordination that yields higher payoffs, which functions similarly as a reward for cooperation (choosing *A*). Once the cooperation habit is formed, behavioral inertia/status quo bias predicts that cooperation may continue after the subsidy is removed.

Alternatively, subsidy may mask or crowd out other intrinsic reasons for cooperation, such as pro-social motivations or conditional cooperation based on reciprocity (Frey & Jegen, 2001; Meier, 2007). A subsidy may become the most salient reason for cooperation. In that case, when subsidy is removed, the subsidy-generated cooperation will drop. In the extreme, the crowding-out effects of economic incentives may have a negative impact on cooperation. For example, Meier (2007) found that people were more willing to contribute to charity when a donation-matching mechanism was applied, but the contribution rate declined after the matching mechanism ceased. Furthermore, the post-subsidy reduction was large enough to produce lower average donations relative to the amounts prior to the introduction of the matching mechanism. On the basis of the aforementioned mixed evidence, we have two competing subsidy carry-over predictions:

> H2a: *The higher cooperation rate in Session 1 due to a subsidy sustains after the subsidy is removed.*

> H2b: *The higher cooperation rate in Session 1 due to a subsidy drops after the subsidy is removed.*

Results for session 1

Average cooperation rates (percentage choosing *A*) across periods in the four conditions are reported in Table 3. We will first focus on the data from Session 1. Random effect

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Table 3. Percentage of choosing *A* in the four conditions

Name	DB1-DS2		DS1-DB2		SB1-SS2		SS1-SB2	
# of 6-person groups	13		13		10		12	
	Description	Percentage	Description	Percentage	Description	Percentage	Description	Percentage
Session 1	Deterministic-baseline	.64	Deterministic-subsidy	.76	Stochastic-baseline	.71	Stochastic-subsidy	.79
Session 2	Deterministic-subsidy	.79	Deterministic-baseline-	.67	Stochastic-subsidy	.76	Stochastic-baseline	.79

logit regressions confirmed H1, that is, players were more likely to choose option *A* with a subsidy than without a subsidy ($p < .01$) after controlling for period and individual subject differences. No significant difference was found between the stochastic and deterministic games ($p > .10$). The complete regression results are reported in Table 4.

In the initial analysis, we also included the interaction between subsidy and the game type, and found no significant interaction ($p > .10$). Analysis of variance table that compared the regression models with and without interaction term showed no significant difference ($p > .10$). Hence the interaction term was dropped from further analysis. Note that the coefficient for period is negative and marginally significant ($p = .09$), indicating that the coordination level decreased over time. This is consistent with previous findings in most coordination games (Camerer, 2003).[3] Social welfare, computed as summed payoff minus subsidy cost, was 7% higher in the subsidy conditions than in the baseline conditions, in both the deterministic and stochastic settings ($p < .05$), which indicated that subsidy is both an effective and efficient way to encourage coordination.

Table 5 reports all 48 groups' cooperation rates in the 20 periods of Session 1 grouped into Periods 1–5, 6–15, and 16–20. Again, group averages in each period category confirm H1, namely that subsidy encouraged players to choose option *A*. The subsidy-induced coordination improvement occurred at the beginning periods (Periods 1–5) and was sustained throughout the game. This suggests that the subsidy changed participants' expectations of the number of other players who might choose option *A*, and that the options chosen by others over time confirmed these expectations. Sobel's test (Sobel, 1982) shows that expectation significantly mediated the coordination level ($z = 3.179, p < .01$), confirming H1a.

Compared with the expectations of the players in the baseline conditions, unsubsidized players in the subsidy condition had higher expectations as to how many other players would choose *A* ($p < .01$), confirming the rational theory hypothesis (H1b). The unsubsidized players' expectations, however, were lower than the expectations of the subsidized players ($p = .01$), consistent with the bounded rationality predictions (H1c). The increase in expectations affected the behavior: The unsubsidized players in the subsidy condition were more likely to choose *A* than players in the baseline condition ($p < .01$). Similar results are found when using data from the first period or from the first five periods only (Table 6).

The fact that the players' expectations predict their strategies indicates that the players are belief-based learners (Cheung & Friedman, 1997; Shafran, 2012) who update their beliefs on the basis of their observations of others' behaviors in the past. Interestingly, expectation was not the only factor the players considered when developing their strategies, especially when they faced stochastic payments. The data show that in the stochastic games, the players were more likely to choose *A* in the current period if they did not choose *A* and suffered a loss in the previous period. However, if they chose *A* and still suffered a loss in the previous period, they were less likely to choose *A* again in the current period (both $p < .01$), which is consistent with the behavior of reinforcement learners (Roth & Erev, 1995) who do not differentiate between a bad strategy from a bad outcome.

Figure 2 provides the average cooperation rate in each period. The unit numbers on the *y*-axis correspond to the number of players choosing *A*. For example, the cooperation rate on the *y*-axis is .17 if only one out of six players in that group chose *A*. Consistent with the regression results, Figure 2 shows that the subsidy effects encouraging players to choose *A* were not significantly different in the stochastic and deterministic games. The average cooperation rates of all groups, however, mask important individual group differences and decision dynamics. For example, Figure 3, showing the average cooperation rate of each group in Periods 16–20 of Session 1, reveals important similarities and differences between the stochastic and deterministic games.

First, there is a clear pattern that subsidy did improve the cooperation rates. Recall that the tipping point for choosing *A*, based on the rational theory prediction, is the expectation that four other players will choose *A*. Hence we define an efficient equilibrium as five or more players choosing *A* (i.e., cooperation rate equal to or greater than .83) in the last five periods and an inefficient equilibrium as two or fewer players choosing *A* (i.e., cooperation rate equal to or smaller than .33) in the last five periods. With subsidy, more groups reached the efficient equilibrium and less groups stabilized at the inefficient equilibrium than in the baseline condition. This was true for both the deterministic and stochastic games.

Second, both Nash equilibria, all-*A* and all-*B*, were observed in the study, although a large number of groups never reached the theoretically predicted equilibria. No groups were trapped in the inefficient equilibrium in games with a subsidy, because, as the payoff graph shows in Figure 1, choosing *A* is

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[3] Goeree and Holt (2005) reported that the coordination levels decrease over time in high-cost sessions but increase in low-cost sessions.

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Table 4. Random individual logit model for choosing option *A* in Session 1

Variable	Coefficient	Standard error	*z* value	Pr(>|*z*|)
Dependent variable				
Choosing *A*				
Independent variables				
Constant	1.25	.26	4.72	.00
Stochastic game	.48	.31	1.55	.11
Subsidy	1.08	.31	3.51	.00
Fixed effects				
Period	−.01	.006	−1.68	.09
Rho	5.78	2.40		
Log likelihood	−2385			
Sample size	5760			

always more preferable than *B* for the two subsidized players, unless they are extremely risk seeking. The data show that subsidized players chose option *A* 91% of the time. As mentioned earlier, there are at least two reasons why 9% of the times the subsidized players did not choose *A*. One is because of the trembling hand effect (Selten, 1975). The other reason relates to individual players' risk preferences. If a player is risk seeking enough, she or he may be reluctant to pay the low cost (10 Talers) to choose *A* even with the subsidy. Instead, she or he will opt for the more risky but costless choice of *B*. The data confirm that those who were subsidized but chose *B* are less risk averse than the rest of the players ($p < .05$).

Third, as predicted, subsidy tipped some groups toward the Pareto-superior equilibrium. The tipping effect of the subsidy is clearly illustrated in the stochastic game. As shown in Figure 3, in the stochastic-baseline condition, only two out of 10 groups (20%) had a cooperation rate over .83, only one group converged on the inefficient equilibrium, and the rest of the seven groups were stuck between the two NEs. In the stochastic-subsidy condition, six out of 12 groups (50%) successfully reached the efficient equilibrium.

Fourth, there is a noticeable difference in the patterns of how subsidy affected the deterministic game versus the stochastic game. Eleven of the 13 groups in the deterministic-baseline condition reached the predicted NEs. In particular, seven groups reached the efficient equilibrium, four groups clustered at the inefficient equilibrium, and only two groups settled between the two NEs. In the deterministic-subsidy condition, seven out of 13 groups had two to four players choosing *A*, no group converged at the inefficient equilibrium, and six groups reached the efficient equilibrium.

To summarize, subsidy improved coordination in the stochastic game by tipping half of the groups toward the efficient equilibrium, and by diverting one third of the groups away from the inefficient equilibrium in the deterministic game. However, several questions remain unanswered by the data. For instance, why do players show a dichotomous pattern in the deterministic-baseline condition but cluster in the middle in the stochastic-baseline condition (shown in

Table 5. Average cooperation rates in each group by periods in Session 1

	Stochastic-baseline Group number													
	6	7	9	10	22	23	30	31	32	33				Average
Periods 1–5	1.00	.47	.73	.57	.67	.80	.93	.83	.43	.93				.74
Periods 6–15	1.00	.62	.43	.33	.77	.80	.90	.80	.57	.80				.70
Periods 16–20	1.00	.67	.27	.67	.77	.67	.83	.80	.40	.77				.68
All periods	1.00	.59	.47	.48	.74	.77	.89	.81	.49	.83				.70
	Stochastic-subsidy Group number													
	5	11	12	13	18	19	20	21	35	37	38	39		Average
Periods 1–5	.77	.80	.80	.63	.80	.80	1.00	1.00	.83	.93	.53	.83		.81
Periods 6–15	.77	.80	.58	.83	.73	.80	.98	.98	.87	.98	.50	.67		.79
Periods 16–20	.87	.83	.57	.90	.73	.70	.87	1.00	.77	1.00	.37	.63		.77
All periods	.79	.81	.63	.80	.75	.78	.96	.99	.83	.98	.48	.70		.79
	Deterministic-baseline Group number													
	1	2	15	24	28	29	34	36	45	46	47	48	49	Average
Periods 1–5	.57	.90	.77	.80	.20	.27	.50	.53	.60	.53	1.00	.63	.67	.61
Periods 6–15	.37	1.00	.98	.90	.70	.07	.35	1.00	.28	.43	1.00	.52	.92	.66
Periods 16–20	.37	1.00	1.00	.97	.63	.07	.20	.97	.13	.20	.97	.83	1.00	.64
All periods	.42	.98	.93	.89	.56	.12	.35	.88	.33	.40	.99	.63	.88	.64
	Deterministic-subsidy Group number													
	3	4	14	16	17	25	26	27	40	41	42	43	44	Average
Periods 1–5	.73	.70	1.00	.97	.43	.70	.83	.97	.53	.53	.93	.40	1.00	.74
Periods 6–15	.73	.85	1.00	.82	.75	.55	.98	.98	.57	.50	.95	.45	1.00	.78
Periods 16–20	.60	.80	1.00	.93	.47	.57	1.00	.97	.53	.40	.97	.47	.97	.74
All periods	.70	.80	1.00	.88	.60	.59	.95	.98	.55	.48	.95	.44	.99	.76

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Table 6. Random effect regression to test subsidy effects on expectations

Variable	Coefficient	Standard error	*t* value	Pr(>|*z*|)
Dependent variable				
Expectation on the number of others choosing *A*				
Independent variables				
Constant	3.66	.11	34.49	.00
Players in baseline condition	−.37	.12	−3.00	.00
Subsidized players in subsidy condition	.06	.04	2.16	.01
Stochastic game	.0	.12	.76	.76
Period	.01	.002	6.63	.00
Log likelihood	−8228			
Sample size	5760			

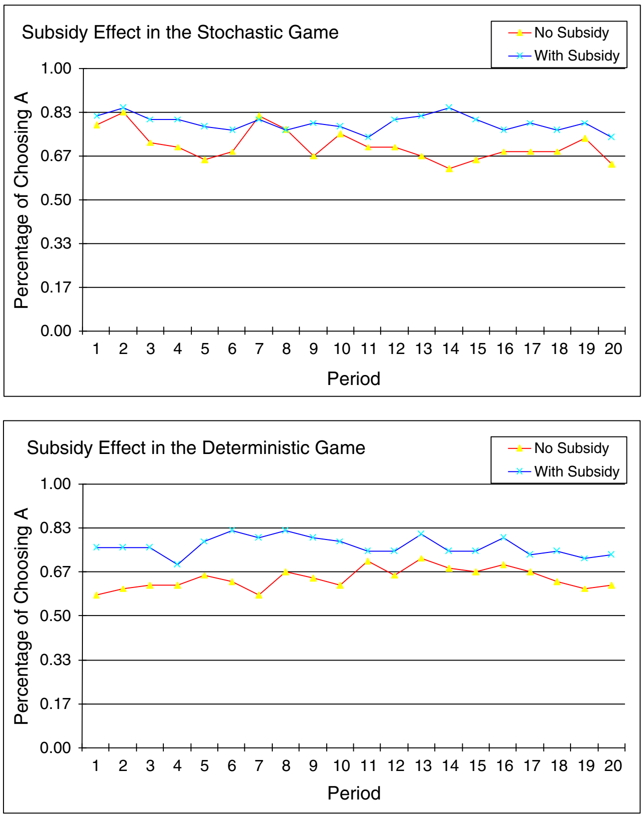

Figure 2. Cooperation rates in Session 1

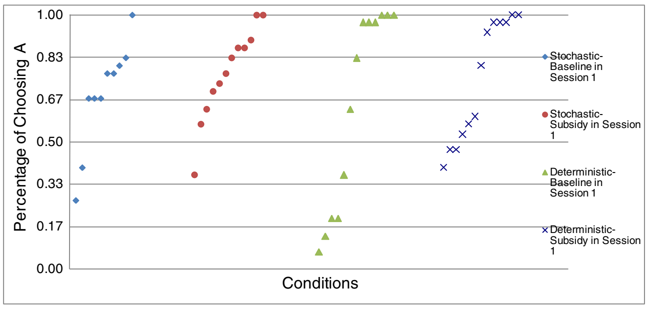

Figure 3. Cooperation rate in groups in Periods 16–20 in Session 1

Figure 3)? Why does subsidy help the divided groups in the stochastic game to reach the efficient equilibrium but not those in the deterministic game? The post-game survey provides some tentative answers to these questions.

An answer to the first question of why most groups in the stochastic-baseline condition chose a mixture of options *A* and *B* appears to be related to the risk control strategy of the players. Players' decisions in the stochastic game depend not only on their expectation of what others will do but also on their own risk preferences. Seventy-eight percent of the players in the stochastic game considered *A* to be a safer option than *B*. Players with a high degree of risk aversion may thus always prefer *A* to *B*, even when they expect others to choose *B*. This would explain why we rarely observed the all-*B* equilibrium in the stochastic-baseline condition. Risk-seeking players may decide not to pay the cost of choosing *A*, even though they expect others to do so, which explains why there were only two groups reaching the all-*A* equilibrium in the stochastic-baseline condition.

How does a subsidy affect the deterministic and stochastic games differently? To answer this question, we first analyze how a subsidy might have encouraged those groups that settled in the middle to reach the efficient equilibrium in the stochastic game. On the one hand, subsidy encourages subsidized players to choose *A*. At an unsubsidized cost of 32 Talers, players who are not very risk averse would be willing to take their chances of a loss and choose *B*; with a subsidized cost level of 10 Talers, they will then want to switch to *A*. On the other hand, the unsubsidized players are also more likely to choose *A* by perceiving that the subsidized players will want to switch from *B* to *A*.

For example, as shown in Table 1, a moderately risk-averse player may expect only one other player to choose *A* and decide that it is not worth 32 Talers to reduce the risk of losing 100 Talers from 75% to 59%. Assume that this player is not subsidized but increases her or his expectation of the number of players choosing *A* from one to three when she or he believes that two subsidized players will choose *A*. She or he is now willing to pay 32 Talers to reduce her or his risk from 61% to 36%. Note that in this example, the new expectation (three players choosing *A*) is still below the tipping point of a risk-neutral agent, four, but a risk-averse player may be tipped toward *A* anyway. This is not likely to be the case in the deterministic game. In other words, although in theory both games have a tipping point of four, the stochastic game may have a lower tipping point depending on the risk preferences of the players in the specific groups.[4]

We speculate that the differences in the actual tipping points are a possible reason why subsidy encouraged some divided groups to reach the efficient equilibrium in the stochastic game but had little effect on those in the deterministic game. The expectation question data indicate that the average expectation of the efficient groups in the stochastic game was significantly lower than that in the deterministic game (4.5 vs. 4.1, $p < .01$). This implies that a lower tipping

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[4] The opposite is possible when an expectation greater than four is not enough to tip a risk-seeking player. But in the current study, most players were risk averse according to the Holt and Laury risk preference scale.

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point is probably required to change players' strategies from *B* to *A* in the stochastic game than in the deterministic game.

Note that in the aforementioned example, an unsubsidized player increases her or his expectation of the number of others choosing *A* from one player to three players by having two subsidized players added. That is, we assume that the unsubsidized player is a naïve decision maker and does not take into account the subsidized players' initial tendency to choose *A* without subsidy or believes that the subsidized players will not choose *A* without subsidy. In the lab or real world, the expectation formation process is probably much more complicated than simply adding the number of the subsidized players (two in this case) to one's prior expectation as to how many players would choose option *A* in the baseline condition. People may add a fraction of two, or adjust it only when their initial expectation is below two.

Table 7. Random individual logit model for choosing option *A*

Variable	Coefficient	Standard error	z value	Pr(>|z|)
Dependent variable				
Choosing *A*				
Independent variables				
Constant	2.72	.33	8.08	.00
Stochastic game	.42	.47	.88	.38
Subsidy removed	−.87	.10	−8.34	.00
Fixed effects				
Period	−.02	.007	−4.28	.00
Interaction				
Stochastic game × subsidy removed	.85	.16	5.36	.00
Rho	7.36	2.72		
Log likelihood	−2203			
Sample size	5988			

Results in session 2

Combined data from Sessions 1 and 2 were used to test H2a and H2b, the *subsidy carry-over effect hypotheses*, with 78 participants (13 groups) in the DS1-DB2 condition, and 72 participants (12 groups) in the SS1-SB2 condition. A random effect logit model tested whether the subsidy effect carried over from the first session to a second session in which the subsidy was removed. The regression results, reported in Table 7, show that there was a significant interaction between game type (stochastic vs. deterministic) and the subsidy carry-over effect ($p < .01$). Participants in the deterministic game were significantly less likely to choose *A* after the subsidy was removed than with a subsidy ($p < .01$), but those in the stochastic game sustained the same level of coordination without subsidy as with the subsidy ($p > .10$).[5] That is, the data support H2a in the stochastic game and H2b in the deterministic game.

The interaction between game type and subsidy carry-over effect can be shown more clearly when we look at cooperation rates in greater detail, as in Figure 4. Figure 4 shows that most groups in the stochastic game maintained the coordination levels they had achieved with the subsidy in Session 1, after the subsidy was removed in Session 2. In the deterministic game, however, after the subsidy was removed, groups manifested a similar dichotomous pattern as observed in the deterministic-baseline condition, as if they had never been exposed to the subsidy. That is, the subsidy effect of Session 1 did not carry-over to an unsubsidized Session 2 for the deterministic game.

Why does the subsidy carry-over effect differ in the deterministic from the stochastic game? There are at least two reasons. First, people might be more likely to adopt the default choice (previous choice) in a stochastic game than in a deterministic game as predicted by some economic theories (Bewley, 1986; Ortoleva, 2010). For example, Bewley (1986) suggested that uncertainty might confuse the decision maker and forced incomplete preferences to her. The inertia assumption then suggested that she or he would switch from the status quo option only when she or he found a better alternative, which was more difficult under uncertainty than without uncertainty, because of the incomplete preference. Ortoleva (2010) further developed the idea by positing the status quo behaviorally using an axiomatic framework, dropping the preference incompleteness and the inertia assumptions. According to Ortoleva (2010), when facing uncertainty, the decision maker had lower confidence in comparing alternatives to the default choice. The status quo became more salient when she faced the choice difficulty, and more "attractive" because of the familiarity associated with the experience with the status quo. Hence the status quo bias became stronger under uncertainty. In the current study, the status quo after the subsidy was removed was the high coordination level brought by the subsidy in the previous session. The subsidy carry-over difference between the stochastic and deterministic settings was consistent with the theoretic predictions in Bewley (1986) and Ortoleva (2010), that decision makers were more likely to keep the status quo (previous decisions) under uncertainty than without uncertainty.

Second, there was a difference in terms of the intrinsic motivation crowding effect of subsidy in the stochastic game than in the deterministic game. Previous research reports that expecting material rewards or economic incentives may reduce intrinsic motivations (Frey & Jegen, 2001; Greene, Sternberg, & Lepper, 1976; Lepper, Greene, & Nisbett, 1973). In the extreme, the crowding effects may carry over after the incentive is removed and result in a negative net effect (Meier, 2007). Our post-game survey showed that in the deterministic game, 43% of players believed that paying a lower cost was the only reason to choose *A*, and that others would choose *A* only when subsidized, which indicates that at least for those players, subsidy masked other cooperation motives. Once the subsidy was removed, those players would no longer have subsidy as a valid reason for choosing *A*, and the subsidy-generated high coordination level would drop back to the pre-subsidy level. Note that the post-subsidy coordination did not fall below the pre-subsidy level,

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[5] The results of a second regression, similar to the one reported in Table 7, to test the subsidy carry-over effect in the stochastic game are reported in Table 9 in Supporting information Appendix B.

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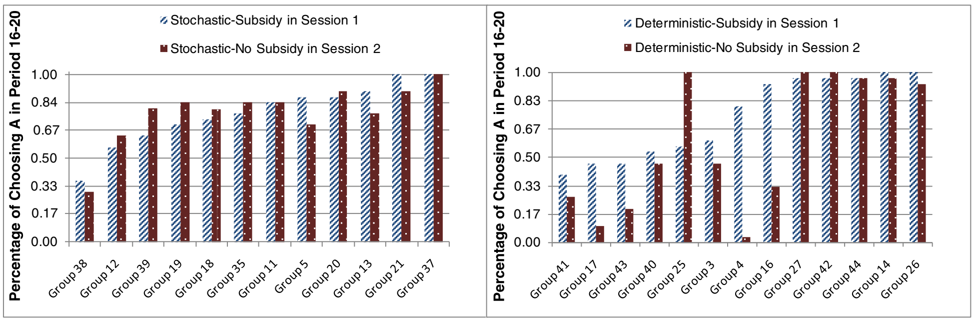

Figure 4. Cooperation rates in Periods 16–20 with subsidy and without subsidy in subsequent session as a function of game type

which implies that although the subsidy did not generate a sustainable coordination pattern, the motivation crowding did not carry over to the post-subsidy period to cause a negative net effect, as reported in the donation subsidy scenario (Meier, 2007).

In the stochastic game, only 22% of players viewed paying a lower cost as the only reason for choosing *A*. Seventy-eight percent of the players simply regarded *A* as a safer option. They assumed that others also preferred reduced risk with or without subsidy. Hence once the subsidy helped the groups reach a coordination level with lower risk, most groups stayed at that level. In summary, subsidy seems to crowd out other possible reasons for cooperation in the deterministic setting, but safety is the principal reason for coordination on *A* in the stochastic setting. As a result, the subsidy effect carries over in the stochastic setting, but not in the deterministic one.

A third possible reason[6] for the carry-over difference in the two games is the partial reinforcement extinction effect (PREE), which is a well-established phenomenon in learning: intermittent reinforcement during acquisition makes subsequent extinction more difficult than if the behavior was acquired through fixed reinforcement. It is true that economists sometimes treat outcomes from deterministic prisoner's dilemma as "fixed" reinforcement, and outcomes from stochastic game as random or partial reinforcement, as the reviewer noted (Bereby-Meyer & Roth, 2006). However, in the original psychology research (Tedeschi, Aranoff, Gahagan, & Hiester, 1968) and subsequent psychology research on partial learning in prisoner's dilemma, the outcomes of deterministic prisoner's dilemmas are treated as fixed reinforcement only if there is no variance in the opponent's strategy response to certain behavior. A normal (deterministic) prisoner's dilemma where there exists strategic uncertainty from the opponent is treated as random reinforcement. To be more specific, if a person chooses to cooperate in a deterministic prisoner's dilemma, it is a fixed reinforcement design only if her or his opponent always responds by cooperating or always responds by defecting.

In our experiment, because of the existence of strategy uncertainty in both deterministic and stochastic games, both games apply partial reinforcement. Nevertheless the stochastic game does have an extra layer of uncertainty in the outcomes, resulting in a lower percentage of reinforcement occurrences than in the deterministic game, although the expected reinforcements (payoffs) are the same in the two games. Does the extra noise in the stochastic game make the learned cooperation harder to extinct? To answer this question, let us take a closer look at the psychological mechanisms driving the PREE. Previous research has shown evidence that the PREE takes an inverted U-shaped function of reinforcement percentage (Grant & Schipper, 1952; for a review, see Lewis, 1960). That is, the PREE is higher in the middle percentage region and lower with either very high or very low reinforcement percentages. Grant and Schipper (1952) suggested two processes underlying the inverted U-shaped extinction, discrimination and learning. The discrimination process indicates that high percentage reinforcements make acquisition series easy to "stand out" from the extinction series, hence less resistance to extinction with the PREE being a decreasing function of the reinforcement percentage. The learning process, however, implies the opposite, namely that the PREE is an increasing function of the reinforcement percentage, because the learned response strength increases in the number of reinforced trials, and the response strength correlates with the resistance to extinction. The two processes combined explain the inverted U-shaped PREE on the reinforcement percentage.

In our study, it is difficult to judge whether the PREE is in the increasing or decreasing section of the inverted U, without further research. Hence, it is unclear whether the lower enforcement percentage resulting from the extra layer of uncertainty in the stochastic game makes the extinction easier or harder than in the deterministic game. Our guess is that because the participants in both games were well aware of the removal of the subsidy, both had no difficulty distinguishing the extinction series (post-subsidy games) from the acquisition series (with-subsidy games). The major difference then lies in the second process, learning, which produces an increasing function of PREE in the reinforcement percentage. If that is true, the PREE is actually stronger in the deterministic game than in the stochastic game, although the difference is not large enough to offset the first two reasons discussed earlier.

CONCLUSIONS

Prior research shows that people often have difficulty reaching the efficient equilibrium in coordination games with multiple

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[6] We thank an anonymous reviewer who brought the importance of the PREE to our attention.

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Pareto-ranked Nash equilibria. The current study investigates the effect of subsidy in a coordination game, both in a deterministic setting and a stochastic setting. We find that partially subsidizing one third of the players not only encourages the subsidized players to cooperate but also changes the unsubsidized players' expectations and behavior, so that some groups are tipped toward the efficient equilibrium. Social welfare is increased with subsidy in both the deterministic and stochastic settings. Furthermore, the subsidy-induced coordination improvement is sustained after the subsidy is removed in the stochastic game, but not in the deterministic game, consistent with the economic theories that the status quo is more likely to be accepted under uncertainty than without uncertainty. A post-game survey also indicated that with stochastic payoffs, players focused on risk reduction. Temporary subsidies promoted lasting coordination because even after subsidy was removed, as players still assumed that other players would prefer reduced risks from cooperation. With deterministic payoffs, however, the subsidy might crowd out other rationales for coordination, with many players indicating that the subsidy was the only reason for anyone to cooperate. Hence, the coordination level dropped when the subsidy was removed.

The experimental results in this paper have important public policy implications. For example, for the garbage disposal case, a partial subsidy can be implemented by providing free garbage pick-up service to some households. According to the subsidy effect found in the study, this will affect the behavior of both households receiving the pick-up service and those who do not receive the service (subsidy) directly but expect that more people will now dispose garbage properly. Once enough people leave the garbage in the garbage bin, the extra costs of disposing the garbage are removed, and the system tips toward the superior NE in which all dispose their garbage in the bin and enjoy a clean environment. Similarly in the airline security case, a subsidy can be provided to some airlines to partially offset the cost of updating the security screening equipment. The subsidy will encourage both the subsidized and unsubsidized airlines to update their equipment so all airlines invest in the screening equipment (the superior NE) and reduce the risk of a bomb placed in an airplane.

Note that differences in the subsidy carry-over effect differences between the deterministic and stochastic games reported in the current study will likely lead households in the garbage disposal example to return to the inferior equilibrium once the free pick-up service ceases. However, in the airline security example, the Pareto-optimal equilibrium is likely to be sustained even when the subsidy is no longer provided.

More generally, if the laboratory results hold in community settings, then a limited budget might best be used to support temporary subsidies in stochastic settings, spread among many groups, because the coordination on Pareto optimum will often persist after the subsidy ends. In deterministic settings, subsidies might have to be maintained indefinitely and might crowd out cooperation on the basis of on other rationales, such as social expectation to cooperate.

There may be other ways to encourage cooperation in deterministic settings. For example, besides using subsidy to encourage cooperative behavior, a portion of the budget can be used for campaigns to educate people about the benefits of reaching a more desirable equilibrium, or use social rewards instead of monetary incentive to change social norms so that the cooperative behavior is more sustainable.

Another implication of the current study is that, instead of playing down the uncertainty aspects in a coordination scenario, as public policy makers often do, one should highlight the uncertainty existing in the problem. This will take advantage of people's natural risk-averse tendencies and result in a higher likelihood of opting for the default choice so that a more efficient risk-reduction cooperation can be reached.

We encourage future work that test the subsidy effect and the subsidy carry-over effect under conditions more similar to a natural environment, such as allowing players to communicate, or introducing a social norm for coordination. Another interesting extension for future research is to identify optimal subsidy policy design for coordination games. In the current study, we allocated partial subsidy to half of the tipping subset. For the same cost, we could apply either a lower subsidy to more players or a higher subsidy to fewer players. As mentioned earlier in the paper, the optimal combination depends on multiple factors: the parameters in the game, the nature of the problem, and the decision process of the specific groups. Future research to identify systematic patterns on how each factor responds to the subsidy design will be helpful in applying subsidy policies in the most cost effective way.

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